To our students past and present.
Preface

Continuing developments in imaging modalities and the increasing availability of more sophisticated equipment have prompted the production of yet another edition of this work. Many images have been replaced and new ones added. The text has been extensively revised and expanded. The purpose of the exercise remains unchanged—to provide a simple and practical exposition of the basic principles of image interpretation and to present it in such a way that it can be easily understood and assimilated. We hope this revised version will be acceptable and provide a useful addition to the armamentarium of both the student and the small animal veterinary practitioner.

J. Kevin Kealy
H. McAllister
J. Graham
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Competent radiologic practice presupposes the availability of good-quality radiographs. Familiarity with the basic principles underlying the production of radiographs is a prerequisite for the radiologist. Accurate positioning of the animal under investigation, correct exposure factors, the use of grids and other ancillary aids, and good processing technique all influence the quality of a radiograph. The use of a technique chart is essential for consistent results. Consistency is important, particularly when studies have to be repeated over time to assess the progress of a particular case. If the radiographs in such studies are not comparable, errors of interpretation are likely to occur. Radiographs may be of poor quality because of improper positioning, improper exposure technique, or poor darkroom technique. It is hazardous to attempt to interpret such radiographs.

Radiographic technique is discussed in this book only insofar as is necessary for a proper understanding of points of interpretation. The necessary detailed information on technique can be found in any of the several works devoted to this topic.

A radiograph is a composite shadow of structures and objects in the path of an x-ray beam recorded on film. Because a radiograph is, in essence, a shadowgraph, the geometric rules applicable to the formation of shadows are also valid for radiographs. Thus, the nearer the object under examination is to the film, the sharper will be its outline. Distance of an object from the film causes magnification of the resulting shadow and some distortion and blurring. The nearer the object is to the source of radiation, the greater will be the degree of magnification. The area being studied, therefore, should be placed as near to the film as possible and at a standard acceptable distance from the source of radiation, usually 100 cm (36 to 40 inches). Because the radiograph (being a shadowgraph) outlines an object in only two planes, at least two views, made at right angles to one another (orthogonal views), are required to demonstrate the object in a three-dimensional representation. Shadows are cast not only of the outline of the body, but also of structures within it (Figure 1-1).

The radiograph is not a simple shadowgraph: some of the x-rays pass directly through the body being examined. These are the useful rays because they affect the film and produce the image. Some of the incident radiation is absorbed within the body, and some is scattered. Scattered radiation reaching the film is undesirable because it causes fogging and blurring, or “unsharpness.” Fogging gives a radiograph a cloudy or hazy appearance. Structure margins are indistinct. Grids are used to reduce scatter. As rule they should be used when the part under examination exceeds 10 cm in thickness.

Fast film/screen combinations reduce exposure times and minimize movement blur. A radiograph shows not only the outline of an organ within the body but also other body structures superimposed on it and on one another.

Not all structures allow x-rays to pass through them in the same way. Dense substances, such as bone, inhibit the passage of radiation, whereas substances that are less dense, such as gases, allow the rays to pass through them virtually unchanged. In between there are substances, such as the soft tissues, that permit more radiation to reach the film than is permitted by bone but not as much as is permitted by gases. It is this differential absorption of x-rays that enables one structure to be distinguished from another. Fluoroscopy is imaging of structures in real time using x-rays and an image intensifier. There is an increased hazard with this technique. It should not replace conventional radiography.

**Density and Opacity**

A radiograph is an image made up of shadows of different opacities. Subject density is the weight per given volume of a body tissue or other object. Bone is more dense than muscle, and muscle is more dense than fat. The denser an object is, the more it inhibits the passage of radiation. Radiographic opacity is a measure of the capacity of a tissue or structure to block x-rays. Where x-rays readily reach the film, the film appears black after processing. If the x-rays are prevented from reaching part of the film, the unaffected area will appear white on the processed film. Between these two extremes, various combinations of light, dark, and gray areas are produced. Radiographic opacity therefore depends on subject density; the greater the subject density, the less radiation reaches the film.
Increased opacity denotes a whiter shadow on the radiograph than would normally be expected. The term thus refers to increased subject density as reflected on the radiograph. Decreased opacity denotes a darker shadow on the radiograph than would normally be anticipated. The decreased subject density allows more radiation to reach the film, causing a greater degree of blackening.

All objects inhibit, to some extent, the passage of radiation. Structures that absorb little of the incident radiation are said to be radiolucent. X-rays readily pass through them, and they appear dark on a radiograph. Structures that inhibit the passage of most of the incident radiation are said to be radiopaque.

Increased radiolucency represents decreased subject density; increased radiopacity represents increased subject density. A radiolucent defect is an abnormal area of decreased radiographic opacity and hence of subject density within a structure.

Five radiographic opacities can be recognized:
- Metal
- Bone or mineral
- Fluid or soft tissue
- Gas (air)
- Fat

Metallic substances are very dense, and they inhibit the passage of virtually all incident radiation. Areas of film covered by such material appear white (radiopaque) on a radiograph.

Bone is not as dense as a metallic substance. It allows little radiation to pass through it compared with other body tissues. Areas of film that have

Figure 1-1 The necessity for two views. A, Four objects have been radiographed in an end-on position. From this view alone, insufficient information is available to enable a comprehensive description to be given of any item. B, A second view, made at right angles to the first one, shows the items, from left to right, to be a key, a coin, a teacher’s pointer, and a mechanical pencil.
been covered by bone appear almost white on a radiograph.

Fluid inhibits the passage of more of the incident radiation than gas but not as much as bone does. A fluid opacity lies between the whiteness of a bone opacity and the blackness of a gas opacity. Fluid opacities appear gray on a radiograph. Because soft tissues consist, for the most part, of fluid, soft tissue opacity and fluid opacity appear similar. All fluid opacities appear the same. It is not possible, consequently, to distinguish radiographically among blood, chyle, transudates, and exudates.

Fat opacity falls between fluid and gas opacities. Fat may help to outline structures that would not otherwise be seen; for example, perirenal fat may outline the kidneys by providing a contrasting opacity to the kidney tissues.

Gases, including air, allow x-rays to pass freely through them. Areas of film covered by gas-containing organs, such as the lungs, appear dark (radiolucent) on a radiograph.

Bone, fluid, fat, and gas occur normally within the body and are said to have biologic densities. Metallic densities are introduced into the body as contrast media (explained later in this chapter), surgical implants, or foreign bodies (Figure 1-2, A to C).
Figure 1-2, cont'd C, A right lateral recumbent abdominal radiograph of a dog with an abdominal swelling showing the five radiographic opacities. The bladder (white square) contains fluid. The spleen (white oval) is soft tissue opacity. Fluid and soft tissue are similar in radiographic opacity. The bony skeleton has a mineral opacity (arrow M) and the right marker (R) is metallic; gas is present in the stomach (arrow A) and the intestines. The caudal abdomen is occupied by a large mass that is a fat opacity (arrow F). Recognition of radiographic opacities in this instance allows the differentiation of a fluid mass from a fat mass. This was a large intraabdominal lipoma.

D, This right lateral recumbent abdominal radiograph of a clinically normal dog shows both the right kidney (arrowheads) and the left kidney (arrows). The left kidney appears larger and is therefore further away from the film/detector and is closer to the x-ray tube. The left kidney appears larger than the right because of magnification. Comparison of the renal silhouettes should only be made on a ventro-dorsal projection, when both kidneys are at an equal distance from the tabletop. Spondylosis is also evident but is an incidental finding.
CONTRAST

Contrast means difference. The subject densities of various tissues result in different radiographic opacities, known as radiographic contrast. A structure can be distinguished on a radiograph only if it contrasts with its surroundings; that is, a structure is seen when it has a different radiographic opacity from what surrounds it. Structures lying in contact with one another cannot be distinguished as separate entities if they have the same radiographic opacity. If a structure is surrounded by a radiopaque material, it will appear relatively radiolucent; if it is surrounded by a radiolucent material, it will appear relatively radiopaque.

Radiographic contrast manifests itself as varying degrees of blackening of the film. Apart from varying subject densities, contrast also depends on the inherent contrast capability of the film; scattered radiation reduces contrast. A low kilovoltage/high milliampere technique produces a radiograph showing a high degree of contrast. A high kilovoltage/low milliampere technique produces a radiograph of low contrast but with a wide range. The former technique is most suitable for areas of low contrast, such as the abdomen.

FACTORS AFFECTING IMAGE QUALITY

Many factors can affect the quality of a radiographic image:

• **Motion**: movement of the subject or the film will cause blurring.
• **Film properties**: fast film results in a less sharp image. This is related to the size of the silver halide crystals in the film emulsion.
• **Film/screen combinations**: faster film/screen combinations give a less sharp image than slower combinations.
• **Object/film distance**: the nearer an object is to the film, the sharper its outline will be.
• **Grids**: grids improve film quality when thicker parts are under examination.
• **Processing**: processing faults affect image quality; underdevelopment results in a pale image and overdevelopment results in a dark, flat image.
• **Artifacts**: adventitious marks on a film, such as scratches, dirt marks, or marks from dirty or damaged cassettes; may interfere with interpretation.
• **Distortion**: distortion of an image can be caused by improper positioning of the patient or the radiation source. Standard positioning is a prerequisite of good film quality.

**Border Effacement (Silhouette Sign)**

Border effacement is when two objects of the same radiopacity are in contact and their individual margins cannot be distinguished from one another. Conversely, an object of a different radiopacity, such as air or fat, interposed between them will provide contrast, and individual margins can then be identified. This latter effect has sometimes been called a negative silhouette. It is seen commonly in thoracic radiographs.

**RADIOLOGIC CHANGES**

As well as demonstrating the varying opacities of bodies under examination, the x-ray beam also delineates their outlines or shapes. The edges of a bone permit determination of its size and shape, and the varying opacities of the cortex and medulla will be visible. A radiograph, then, is an image consisting of the outlines of structures and their varying opacities. It therefore can be said that as far as abnormalities are concerned, five observations of significance can be made from the study of a radiograph. One can detect changes in:

• **Size**
• **Shape**
• **Number**
• **Position**
• **Opacity**

A pathologic condition in an organ can sometimes be deduced from the fact that it displaces an adjacent organ. Changes in opacity include changes in radiographic detail. For example, changes in trabecular pattern within a bone may be the first radiographic evidence of a disease process.

**STANDARD VIEWS**

For changes in outline, position, and opacity to be appreciated, it is essential that the radiologist be familiar with the radiologic appearance of normal structures—that is, radiologic anatomy. If one is unfamiliar with the normal appearance, one cannot appreciate aberrations from it. Because almost any structure can be rotated through 360 degrees, it would be virtually impossible to become familiar with all the possible projections that could be produced from any given organ. Consequently, standard views of each part of the body are used. These usually consist of two views made at right angles to one another so that a three-dimensional impression is gained of the structure under study.

Agreed terms are used to describe the standard projections. The terminology used in this book is that suggested by the Nomenclature Committee of the American College of Veterinary Radiology. The committee recommended that veterinary anatomic directional terms should be those listed in the Nomina Anatomica Veterinaria. Radiographic projections are described by the direction in which the central ray of the primary beam penetrates the body part of interest—from the point of entrance to the point of exit. The subject area of interest should be as close to the film or detector as possible. Structures within the body that are further away from the film are magnified (Figure 1-2, D).

**Definitions**

The meanings to be ascribed to the different directional terms are as discussed in the following sections (Figure 1-3).

**Dorsal**—Dorsal means the upper aspect of the head, neck, trunk, tail, and cranial (anterior) aspects of the limbs from the antebrachio carpal (radiocarpal) and tarsocrural (tibiotarsal) articulations distally (downward). Dorsal also means toward the back or vertebrae.
**Ventral**—Ventral means the lower aspect of the head, neck, trunk, and tail. Ventral also means toward the lower aspect of the animal.

**Cranial**—Cranial is a directional term that describes parts of the neck, trunk, and tail positioned toward the head from any given point. Cranial also describes those aspects of the limbs above the antebrachiocarpal and tarsocrural joints that face toward the head.

**Rostral**—Rostral describes parts of the head positioned toward the nares from any given point on the head.

**Caudal**—Caudal is a directional term that describes parts of the head, neck, and trunk positioned toward the tail from any given point. Caudal also describes those aspects of the limbs above the antebrachiocarpal and tarsocrural articulations that face toward the tail.

**Palmar**—The term palmar is used instead of caudal when describing the forelimb from the antebrachiocarpal articulation distally.

**Plantar**—The term plantar is used instead of caudal when describing the hindlimb from the tarsocrural articulation distally.

**Proximal**—Proximal describes nearness to the point of origin of a structure.

**Distal**—Distal describes remoteness (farther away) from the point of origin of a structure.

**Superior and Inferior**—The terms superior and inferior are used to describe the upper and lower dental arcades.

**Recumbent**—Recumbent means the animal is lying down when the radiograph is made. Most radiographs of the dog and cat are made with the animal in the recumbent position, and this position should be presumed unless the contrary is stated. The term decubitus is used when a horizontal beam is used.

**BEAM DIRECTION**

The direction of the x-ray beam is described from its point of entry into the body to its point of exit. For example, a right-left lateral recumbent view means that the animal is lying on its left side, and the x-ray beam enters the body through the right side and exits through the left side. This is generally termed a left lateral recumbent (LLR) view. A ventrodorsal (VD) view means that the x-ray beam enters the body ventrally and exits dorsally to reach the film. A dorsoventral (DV) view indicates the opposite. Mediolateral means the x-ray beam enters a limb from the medial side and exits on the lateral side. Most so-called lateral radiographs of the limbs are taken in a mediolateral direction. In a lateromedial view, the x-ray beam enters a limb from the lateral side and exits on the medial side.

**Fluid level** refers to an interface between fluid and gas. A fluid level is usually seen on a standing lateral radiograph using a horizontal beam when there is a mixture of fluid and gas within a viscus. The fluid line is always horizontal. A standing lateral view is a lateral view made with the animal in the standing position and with the x-ray beam directed horizontally. A fluid level may also be seen on a decubitus view using a horizontal beam. The term decubitus is used when a horizontal beam is used with the animal in a recumbent position. It is always necessary to use a horizontal beam to demonstrate a fluid level.

Appropriate safety measures should be adopted irrespective of beam direction, and special care is needed when horizontal beams are in use.

**TECHNIQUE**

Standard views are views taken at right angles to one another and usually are made in the routine examination of a part of the body. The most common are the dorsoventral, ventrodorsal, lateral, mediolateral, craniocaudal, dorsopalmar, and dorsoplantar. An oblique view is made at an angle somewhere between the standard views. In the case of oblique views, in addition to stating the anatomic points of entry and exit of the x-ray beam, the angle of obliquity may be given. This information enables studies to be repeated with accuracy. Thus L50D-RVO is read as left 50 degrees dorsal-right.
Contrast media are frequently used as diagnostic aids. A contrast medium is a substance introduced into the body to outline a structure or structures not normally seen or poorly seen on plain radiographs.

Radiographic contrast agents may be either positive or negative. Negative contrast agents are gases; the most commonly used gases are air, carbon dioxide, and nitrous oxide. These agents are used in imaging the urinary bladder and proximal or distal gastrointestinal tract. Negative contrast studies of the pericardial and peritoneal spaces have been described but have now been superseded by ultrasound. Positive radiographic contrast agents may be particulate suspensions or water soluble. Barium sulfate is the contrast agent used in suspensions, and a paste is used to evaluate the gastrointestinal tract. It is not suitable for use in body cavities or joints because it will provoke an intense granulomatous reaction. Water-soluble positive contrast agents are divided into two classes, nonionic and ionic, based on whether the molecules dissociate when in solution. Ionic contrast agents are hyperosmolar compared with plasma, whereas the nonionic agents have an osmolarity closer to that of plasma. These agents can be injected intravenously or introduced into almost any body cavity to improve contrast and detect a lesion. Only the nonionic agents may be injected into the subarachnoid space to outline the spinal cord in myelography.

A filling defect is a space-occupying mass within a hollow organ (see Chapter 2, p.154). Contrast medium fails to fill the organ fully at the site of the mass (defect). A plain radiograph is one made without any contrast agent.

Viewing the Radiograph
Radiographs should be viewed under optimal conditions. A room with subdued lighting is best. The radiograph is placed on a viewing box, or illuminator, which has fluorescent lighting. This device provides an even light intensity over the entire film. Any other method of viewing is unsatisfactory. For anatomic reasons, the entire radiograph does not transmit an even intensity of light. Thin parts of the body will appear darker on the radiograph than will thicker parts. It is useful to have a bright light available to give added illumination to the darker parts. The standard viewing box is designed to illuminate the largest radiographs in common use. When smaller films are viewed, light coming from the viewing screen around the film may cause troublesome glare. Masks are available to adapt illuminators to different sizes of film. Masks can be homemade from dark cardboard or other suitable material. Viewers with varying masking devices are also available. Direct light falling on the illuminator makes viewing difficult. The use of a magnifying glass is sometimes helpful in detecting fine radiographic detail, particularly in the study of bone structure. Increasing the distance between the viewer and the radiograph is often helpful in recognizing diffuse borders or subtle changes.

VD and DV radiographs are, by convention, placed on the illuminator with the left side of the animal’s body to the radiologist’s right; this positioning is used throughout this text. Lateral views should be displayed with the animal’s head facing toward the viewer’s left. Always placing radiographs on the illuminator in the same way facilitates ready recognition of anatomic structures.

Systematic Approach
The radiologist should adopt a systematic approach to the viewing of radiographs. This approach will ensure that all the radiograph—not just the area in which a lesion is believed to exist—is examined on each occasion. Significant changes may be demonstrated away from the area of immediate interest, and these may well be overlooked if the radiograph is not systematically examined. It is especially important that the viewer acquire a habit of making sure that all structures that should be present are indeed there.

It is good radiographic practice to have the areas of interest located at the center of the film. At this location there is the least distortion of the image, and structures on either side can be seen. Because the center of the radiograph tends to attract the eye initially, it is probably good practice to examine the periphery of the radiograph first and systematically progress to the center. Each structure encountered should be noted for position and normality or abnormality. The center of the radiograph is examined last. If an obvious lesion at the center of a radiograph is examined first, there is a tendency to give only a cursory examination to the rest of the film, particularly if the lesion seen is consistent with a tentative diagnosis. Any method of viewing that ensures a full examination of the entire radiograph is acceptable.

Some radiologists prefer to examine radiographs “cold,” that is, without any knowledge of the clinical

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Abbreviations
Common radiographic abbreviations include those listed in Box 1-1.
picture. After a preliminary examination, the radiograph is then evaluated in the light of the clinical and other findings. Preconceived notions about a case may militate against an objective assessment of a radiograph.

Beginners tend to commit two kinds of errors. Either they miss something that should have been seen, or they “overread” the radiograph. Indeed, these errors are not always confined to beginners. Overreading a radiograph means drawing conclusions from it that are not warranted on the basis of objective evidence. This is most likely to happen if one has been involved in the clinical assessment of the case and already reached a tentative diagnosis. A definite tendency exists for one to see what one expects or wants to see.

Good film reading involves several stages. The first step is to identify all the structures on the radiograph, noting features that appear to be abnormal. The second step consists of elaborating a list of possible explanations for the abnormalities seen. The third step is to correlate the radiographic findings with the clinical signs and with the results provided by other ancillary diagnostic tests. The final step is to produce a list of possible diagnoses, arranged in order of probability, taking all the factors into consideration—that is, a list of differential diagnoses.

The best radiologic practice combines knowledge of normal radiographic anatomy with an understanding of physiologic, pathologic, and pathophysiologic processes; consideration of the clinical picture and the results of other diagnostic procedures; and an element of experience. It must be appreciated that the body responds to disease processes in a limited number of ways. Different diseases may produce similar radiologic changes. The same disease does not always manifest itself in the same way. One disease process may be superimposed on another. The use of radiologic signs, provided that the processes that lie beneath them are understood, greatly facilitates radiographic interpretation.

The more radiologic signs that are seen to support a diagnosis, the more probable that diagnosis becomes. Instant diagnoses, based on the recognition of one or two specific signs or on the basis that one has seen a condition before, are discouraged. The ability to read radiographs thoroughly and accurately comes only with practice and attention to detail. The formulation of a list of differential diagnoses, placed in order of probability, is the function of the radiologist, who must be prepared to reconcile his or her observations with the other evidence available.

Computed radiography (CR) and digital radiography produce radiographic images without the use of intensifying screens and film. In the case of CR, a photo-stimulable phosphor plate contained within a cassette is used in an identical manner as a conventional film screen cassette, placed either in a Potter-Bucky tray or on the table top. The photo-stimulable phosphor plate records the x-ray exposure as a pattern of trapped excited electrons. The plate is read by a laser that causes the trapped electrons to emit light as they return to a lower energy level. The emitted light is converted to an electrical signal, which in turn is converted to digital data that are sent to a computer for display.

Digital radiography (DR) involves translating x-ray energy into an electric signal that is in turn converted to digital data (numbers). The process may be direct, indirect, or hybrid. In direct DR, the x-ray energy is converted directly into an electrical signal. In indirect DR, the x-ray energy is first converted to light by using a phosphorescent plate; the light is then converted to an electrical pulse. The data are recorded on a plate, which is connected to a computer, and the x-ray image is available for viewing almost immediately after exposure. It can then be stored or printed out. Hybrid radiographic processes record the output of the phosphorescent plate with a system similar to that found in a digital camera.

CR and DR systems have a number of advantages compared with film screen systems. The linear response of digital systems to the x-ray exposure means that these systems are relatively forgiving of errors in radiographic technique. However, the quality of DR images depends on software processing to produce a degree of contrast that is familiar to the reader. DR and CR images are stored on a computer hard drive and should be saved as DICOM (Digital Imaging and Communication in Medicine) files. Some form of backup device is recommended, ideally at another location. The images may be quite large files, but they can be easily transmitted to a remote location for review by a radiologist or other specialist. These images may be manipulated in multiple ways, including adjusting brightness and contrast, applying sharpening filters, inverting the image, and magnifying part or all of the image.

Viewing the Digital Image
CR and DR images may be printed on film but are more commonly reviewed on a computer. Ideally, a gray-scale monitor with 2- or 3-megapixel resolution should be used when reviewing images. However, such monitors are quite expensive, and a high-quality color monitor with at least 2-megapixel resolution is an acceptable alternative in most clinics.

COMPUTED TOMOGRAPHY
Computed tomography (CT) is an imaging method that uses the principles of tomography. Tomography is the demonstration of a slice through the body displayed without interference from structures lying above or below the level under examination. CT uses x-rays generated by a high-output x-ray tube. The tube is mounted on a gantry opposite a series of detectors. The tube and the detectors rotate in unison around the subject under examination. A fan-shaped beam of x-rays passes through the body at a predetermined level. The pattern of x-rays that reaches the detectors is recorded—a projection. The entire gantry assembly is then rotated slightly, and the procedure is repeated, generating a new projection. A series of such projections is obtained, completely encompassing the body under examination. A computer uses complex mathematical formulas to create an image from the series of projections. This image represents a slice of the body at the level under examination.

The advantage of CT is its ability to distinguish different types of soft tissue, such as brain white and gray
matter or liver and gallbladder. CT achieves this degree of contrast by being able to measure very fine differences in the ability of tissues to stop x-rays passing through them. CT images are digital, and a computer is used for viewing. The gray scale can be adjusted to highlight specific features such as bone or soft tissue (windowing). In CT imaging, tissues and structures are described in terms of attenuation, which is a measure of the capacity of a tissue to stop x-rays. Attenuation is equivalent to radiopacity in radiography. The appearance of a tissue is defined in relation to some reference tissue or its expected normal appearance. Thus isovattenuating means having the same attenuation and would be displayed as the same shade of gray. If the tissue attenuates or stops the x-rays less than the reference tissue or less than expected, it is described as hypovattenuating and is portrayed as a darker shade of gray. The term hyperattenuating is used to describe tissues with more attenuation than expected. These terms are relative rather than absolute, and the reference tissue or structure is usually stated. Superimposed structures are eliminated. Iodinated contrast agents such as those used for myelography or excretory urography may be used by intravenous injection. Lesions with abnormal circulation may show marked contrast enhancement after such injections. In viewing CT images, brightness and contrast are adjusted to highlight specific structures. CT can resolve far greater contrast than can be displayed on a monitor or appreciated by the human eye. Therefore the gray scale of the image is adjusted to assign useful grays to tissues with varying levels of attenuation, referred to as the window. A lung window will show detail within the lungs, but almost all other structures appear white with little detail. A bone window will display detail of skeletal structures such as cortex and trabeculae, whereas soft tissues appear gray with little detail and lungs appear quite black. A soft tissue window shows good contrast and detail within soft tissue structures such as the liver. Hepatic veins can be distinguished from the gallbladder and other soft tissues, whereas bone appears white and lungs dark.

CT may be used to image almost any body part. Among the more common applications are diseases of the nasal cavity, sinuses, and ears. It may also be used to evaluate the spine, brain, joints, lungs, mediastinum, pleural cavity, and abdominal masses (see Figure 2-1, I to L; Figure 3-6, M to O; and Figures 5-9, D to F, and 5-10, O).

**Magnetic Resonance Imaging**

Unlike CT, no ionizing radiation is used in magnetic resonance imaging (MRI). MRI uses hydrogen atoms to generate an image. Hydrogen is universally distributed in the body, principally in water molecules. Hydrogen atoms are essentially spinning protons and have an electrical charge. Each atom acts as a tiny bar magnet. Under normal circumstances, these tiny magnets are arranged randomly. MRI uses relatively strong magnetic fields, ranging from 0.05 to 3.0 tesla in clinical use. In a strong magnetic field, a small majority of the protons will be forced to point in the direction of the field while spinning at a specific rate. A radio signal pulse at the same frequency as the spin of the protons will knock them out of their equilibrium state. As the protons return to their original state, they release energy in the form of a radio signal, effectively an echo of the original pulse used to disturb the protons. This signal is collected by a scanner, processed, and displayed. Smaller gradient magnetic fields are used to localize signals from specific blocks of tissue.

Whereas CT offers good soft tissue detail, the contrast seen with MRI is superb. Different sequences of radiopulses can be used to emphasize different tissue characteristics. Manipulation of the parameters such as the timing and duration of the radiopulse and the interval before an echo is recorded is used to highlight tissue features. MRI has superb contrast resolution in soft tissues and is very sensitive to changes such as edema and hemorrhage. Signal intensity is used to describe the appearance of tissues in MRI, just as attenuation is in CT imaging. It is a relative measure of the radio signal generated by tissues in response to the stimulating radio energy pulse. If something is termed isointense, it has the same appearance as some reference tissue—for example, a mass might be isointense to the gray matter of the brain. Hypointense means less signal and appears darker, whereas hyperintense means more signal and a brighter appearance. As in CT, these terms are relative and must be defined in relation to the expected normal appearance, reference tissue, or appearance before the use of contrast. Bones, ligaments, and tendons appear quite dark on all image sequences because they have very little water content and therefore very little hydrogen to generate a signal. Nonetheless, MRI can provide useful data about these structures.

Like CT, MRI uses contrast agents that enhance lesion visibility. However, in the case of MRI, the agents are based on gadolinium, which alters the local magnetic field and changes signal intensity. Lesions that accumulate gadolinium appear bright (hyperintense) with some sequences. MRI is capable of distinguishing or resolving objects of approximately 1 mm in size, which is termed spatial resolution. This is similar to CT but compares poorly to radiographic systems, which can resolve objects of 0.1 mm in size. MRI has excellent contrast, showing different soft tissues as distinct shades of gray, which creates the impression of much finer detail.

Unlike CT, which is limited to images in the plane of the gantry, images can be obtained in any plane, so slices can be varied infinitely to highlight lesions. MRI applications include imaging disease of the central nervous system, nasal cavity and sinuses, joints, and the abdomen (see Figure 5-32, D and E).

The physics of MRI is very complex, and the reader is referred to more specialized works on this subject.

**Nuclear Medicine (Scintigraphy)**

Scintigraphy is a branch of nuclear medicine. It is an imaging technique in which radionuclides (radioactive elements emitting gamma rays) are administered to a subject. The radionuclides are attached to chemicals to form radiopharmaceuticals that accumulate in the tissue of interest. Most radiopharmaceuticals are analogues...
of physiologic substances or biologic organic molecules. Their presence, and their concentration, can be detected by gamma-ray detection equipment—usually a gamma ray camera. The gamma rays are converted by the camera into signals from which a computer produces a digital format that is used to construct an image of the area under examination. Nuclear medicine images are described in terms of uptake of the radiopharmaceutical. The degree of uptake is subjectively assessed in some techniques, while in others quantitative analysis is performed. In this way normal and abnormal tissues can be identified by the selective accumulation of the radioactive substances within them (see Figure 2-10, P through W, and Figure 4-30, Z1).

ULTRASOUND

Ultrasound denotes high-frequency sound waves inaudible to the human ear. Audible sound frequency is of the order of 50 to 20,000 kilohertz (1 kHz = 1000 cycles per second). In diagnostic ultrasound, a pulse of ultrasound waves is directed into the body. It traverses the tissues until it reaches a reflecting surface from which it is reflected back to the transmitter, which also acts as a receiver. The returning signal is called an echo. The returning echoes reach a computer that processes the signals and displays them on a screen as a two-dimensional (2-D) representation. Diagnostic ultrasound frequencies range from 2 to 15 megahertz (1 MHz = 1 million cycles per second). Use of this noninvasive, flexible, and relatively safe technique is becoming widespread in practice. Consequently, invasive radiographic procedures such as cardiac angiography and other contrast studies, such as those of the urinary tract, have been to some extent superseded.

Interpretation of ultrasonograms requires an understanding of the principles of ultrasound and its interaction with tissue. In addition, one must be familiar with the ultrasound machine and the transducer, as well as their capabilities and the artifacts that can be generated. Otherwise, problems with misinterpretation or overinterpretation will arise. The ultrasonographer must develop a standard imaging protocol and an appreciation of three-dimensional anatomy. The ultrasonogram is essentially an image of a thin slice of tissue. The orientation of the transducer and the plane of section within the body cavity or organ of interest are standardized, as is the nomenclature for various organ studies.

Radiographic and ultrasonographic examinations are complementary. Thoracic radiographs may indicate simply cardiac enlargement, whereas echocardiography (ultrasound of the heart) permits assessment of the various cardiac components and an accurate evaluation and quantification of the cardiac disease problem. The presence of fluid on radiographs often renders organs invisible, whereas fluid may enhance the ultrasonographic appearance of structures.

Ultrasound Production

Ultrasound waves are generated by the piezoelectric effect in a suitable medium, such as a specially manufactured crystal made of lead zirconate. When an electrical impulse is applied to the crystal, the piezoelectric effect results in the crystal becoming deformed. It then vibrates, and ultrasound waves are generated. The crystal acts both as an emitter (1% of the time), sending ultrasound waves into the body, and as a receiver (99% of the time), receiving returning echoes. When it receives ultrasound echoes, it produces electrical impulses proportionate to the strength of the returning echoes. These impulses are displayed as various shades of gray on the monitor. The stronger the returning echo, the brighter the point is on the screen image. The time between emission and the return of the reflected echoes depends on the distance traveled. The ultrasound machine calculates the position of the source of reflection of the returning echoes and displays it at a specific site on the monitor. The image is constantly updated, which permits a dynamic display. A centimeter scale enables the operator to appreciate the relative depth of structures on the image.

The instrument in which the crystal is mounted is called a transducer or probe. Its body contact surface is called a footprint. Diagnostic ultrasound machines may have crystals mounted in a transducer in a variety of ways, either as a single crystal or as multiple crystals in various formats. Transducer crystals are usually made to vibrate at a predetermined frequency (dedicated). Some transducers have several different crystals mounted in them (multipurpose) or permit variation of the electrical impulse to the crystal (multifrequency).

An oscillating crystal may be made to sweep over an area by mechanical or electronic means to produce a fan-shaped beam (sector) of ultrasound waves. Electronic firing of a sequence or array of aligned stationary crystals produces a longitudinal or square-shaped beam (linear array). These designs permit a beam of sound to be produced and swept across the surface of the transducer and from there into the tissues. More sophisticated transducers vary the method of electronic format or transducer shape. For the various advantages and disadvantages of these transducer types and details of ultrasound physics in general, the reader is referred to more specialized texts.

Interaction of Ultrasound With Tissue

The emitted ultrasound beam is produced in small bursts. The velocity of sound in tissues varies, being slow in gas (air), fast in soft tissue, and fastest in bone. The calculated speed of ultrasound through body soft tissues is approximately 1540 m/sec.

The density of various body tissues has a profound effect on ultrasound transmission. If a tissue is homogeneous, no sound is reflected. It is the interaction of ultrasound waves with different tissue structures and interfaces that allows some echoes to be reflected back to the transducer. The rest of the ultrasound beam may pass through the tissue and be variably reflected. Where there are interfaces of varying tissue densities, there is a difference in ultrasound transmission resulting in attenuation (weakening) of the beam.
As the ultrasound beam and returning echoes travel through tissue, there is some attenuation. The attenuation depends on the transducer frequency and on the tissue. Lower frequency (2.0 to 3.5 MHz) sound waves travel further into tissue, but the image resolution or definition they produce is relatively poor. Conversely, higher frequency (7.5 to 10 MHz) sound waves become attenuated in tissue more quickly, but resolution of the resulting image is much better. So there is a trade-off between tissue depth and image resolution and quality (Figure 1-4, A and B). Therefore careful selection of transducer frequency is required, depending on the structure under examination. For example, a 7.5-MHz transducer may be excellent for renal sonography of a cat but may not be adequate to evaluate the heart of a Great Dane.

For all but human fetal applications, the perceived wisdom is to run the transducer at full power and reduce the gain control of the ultrasound machine if the image becomes too bright. The power of the ultrasound beam should therefore be set to maximum or as high as possible to obtain a good image by ensuring strong returning echoes. If it is too low, the image quality is reduced because the returning echoes are too weak. Ultrasound pulses and echoes are very weak, and high-power settings are not usually a problem. However, if the image becomes too bright, the gain should be reduced.

The gain control of the machine amplifies the returning echoes so that the signal is strong enough to produce an image. If the gain is set too high, it generates random or spurious echoes and the image is too bright. If the gain is set too low, the image becomes too dark (Figure 1-4, C and D).

The strength of the ultrasound beam decreases as it travels deeper into the tissues. Therefore the signal from deeper structures is weaker. This will result in an image that gets darker as depth increases. Ultrasound

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Figure 1-4 A and B show two sonograms of the liver and stomach of a small dog. A, Using a 5-MHz transducer, the stomach in the near field is visible but the detail is poor. B, Using an 8-MHz transducer, the layers of the stomach are more clearly seen because of the improved resolution and image quality. C and D show the effect of gain on the ultrasound image. C, This image of the cranial abdomen shows the liver but the gain setting is too high. The image is too bright, which will mask details of the tissues. D, This is the same area of the cranial abdomen as in C, but using the correct gain settings. This has improved the tissue detail and image contrast.

Continued
machines have a control setting that should be adjusted to compensate for this effect: the time gain compensation (TGC). TGC allows control of the gain at different depths and should be manipulated so that the image is homogeneous in appearance. The TGC control normally consists of multiple parallel slider controls or knobs (Figure 1-4, E and F).

The characteristic of sound transmission in a tissue type is termed its acoustic impedance. It is defined by the following equation:

Acoustic impedance \( (Z) = \text{Velocity (v)} \times \text{Tissue density (P)} \)

Because the sound velocity in most soft tissues is relatively constant, the differences in tissue density of the various body tissues are an estimate of their acoustic impedance. The differences in the acoustic impedance of tissues vary the intensity of returning echoes. Because most soft tissues have minimal differences in acoustic impedance, most of the sound beam is transmitted through them, and only some is reflected. This transmission and partial reflection of echoes is what contributes to the final image. Compared with soft tissue, the sound velocity decreases in gas-filled structures; therefore gas has a lower acoustic impedance. Bone has a high acoustic impedance and transmits sound at a higher velocity than soft tissue. Consequently, in areas where gas, soft tissues, or bone are located in the ultrasound beam pathway, the marked differences between the acoustic impedance in these areas result in almost total reflection of the beam. Total reflection means no ultrasound transmission beyond the interface; this phenomenon is termed acoustic shadowing. As an example, gas in the colon masks structures beyond it (Figure 1-4, G to I).

The transmission of sound through a structure of low attenuation, such as one filled with fluid, results in stronger returning echoes from beyond the structure. This phenomenon is termed acoustic enhancement. An example is the gallbladder/liver interface (Figure 1-5).

Transducers have an optimal imaging zone along the beam length. This area is termed the focal zone, and it varies with the crystal frequency. Some machines have an electronic focusing device that moves the focal zone closer to or farther from the transducer surface. It is important when imaging tissues to try to optimize the focal zone of the transducer over the area of interest. This endeavor may also be managed by varying the imaging orientation or planes. Structures that lie close to the skin and transducer surface often lie outside the optimal focal zone of the transducer. The use of a fluid offset, or standoff, is often advantageous under such circumstances. A standoff is an echolucent material that may be part of the transducer or may be a detachable component. It is placed on the skin, and it moves the ultrasound source away from the skin, thus bringing skin surface structures into the focal zone of the transducer. If it is detachable, it must be closely applied to the transducer. Coupling gel is applied between the transducer and the standoff and between the standoff and the skin.
Chapter 1  ■  The Radiograph

The returning echoes can be displayed in a variety of ways on the ultrasound machine. The echoes are displayed as voltage spikes on a linear trace. The intensity of each echo is indicated by a variation in the amplitude of the spike plotted against a depth scale. This is termed the A-mode (amplitude), and its use is restricted to specialized ophthalmology examinations (Figure 1-6).

The most common display is the brightness, or B-mode, presentation. Modern machines permit...
variation in the computer updating frequency, or frame rate. Frame rate, or the number of images acquired per second, is determined by multiple factors. Frame rate determines the temporal resolution—that is, the capacity to identify individual events that occur at different times. With a greater depth of view, the time required for a pulse to travel out and an echo to return increases and frame rate is decreased. The more pulses or scan lines used to construct an image, the lower the frame rate. Conversely, a shallow depth of view and fewer scan lines allow a higher frame rate. Finally, the capacity of the machine to analyze and process data limits the frame rate. In current equipment, the last factor accounts for the much higher frame rates that can be achieved now compared with what was possible some years ago.

Faster updating, or frame rates of the images, is necessary for cardiac work when structures are moving quickly. Better-quality images are obtained from relatively static structures such as muscles and tendons by using a lower frame rate. The returning echoes are digitized and converted into various intensities of brightness in two dimensions on a gray-scale format and are displayed on a monitor. Strong echo returns are very bright, and poor echoes are gray or black. The returning image is continuously updated by the computer to give a 2-D image that is a dynamic, or real-time, image. The continuous computer update allows motion to be appreciated. A scale on the monitor indicates the depth of the tissue under examination (Figure 1-7).

Another form of display is the M-mode, or motion mode. Returning B-mode echoes from a specific area are plotted against time to form a tracing. This tracing sweeps across the monitor and allows the motion of the structures to be studied in the form of a line tracing or map. This mode permits more accurate measurements than 2-D B-mode studies. M-mode is particularly useful for cardiac evaluation (Figure 1-8).

As with radiographic studies, at least two ultrasonographic imaging planes of the structure of interest are required—usually in the sagittal (longitudinal) and transverse planes. The dorsal plane is the term used when the transducer imaging plane is along the long axis of the animal’s body, with the transducer placed on the lateral aspect of the animal. However, depending on the area being examined, the terminology and plane of orientation will vary. This subject is discussed in more detail in the relevant sections.

A permanent record of the sonogram may be obtained by using a thermal imager producing prints, or the sonograms may be saved in a digital format for a computer. Multiformat cameras are available that produce a hard copy format using x-ray film.

**Doppler**

Doppler ultrasonography is used to identify blood flow and velocity and to calculate pressure gradients across cardiac valves. The Doppler principle is based on the fact that the frequency of sound changes as it approaches or travels away from a moving object. For example, an ambulance siren has a higher pitch traveling toward the listener and a lower pitch as it moves away. When ultrasound waves of a known frequency encounter blood cells moving toward the transducer, the reflected sound waves have an increase in frequency. As they move away, the frequency is reduced. The change in frequency is termed the Doppler shift and depends on the blood flow velocity. It depends on the frequency of sound used, the blood flow velocity, the speed of sound in the tissues, and the angle of incidence of the sound beam. The angle of incidence should be as close to zero as
possible to measure true maximal velocity. To record this change in frequency, the interrogating ultrasound beam (insonation angle) must therefore be parallel to the flow of blood and not at an angle to it (i.e., 0-degree angle of incidence). As the angle of incidence increases above zero, the Doppler shift decreases. If the ultrasound beam is perpendicular to the flow, no Doppler shift is recorded. This means that as the angle of incidence increases toward 90 degrees, the flow velocity is underestimated. The most accurate measurements are made at a 0-degree angle when the ultrasound beam is parallel to flow. Correction factors can be used, but significant erroneous results are likely with larger angles of incidence. Angle corrections are never used in echocardiography.

Two types of Doppler echocardiography are pulsed wave (PW) and continuous wave (CW). In PW Doppler, a short pulse of sound is emitted at a specific frequency, and only echoes returning at a defined time are analyzed. The direction of the sound pulse is shown on the display as a line originating at the transducer. The time of flight of the pulse and echo are directly proportional to distance traveled, so the returning echoes are displayed as a line originating at the transducer and appearing above the center horizontal line of the ultrasound beam (Figure 1-8). The Doppler shift is only recorded for a specific point in the image. This preselected point is referred to as a sample volume or gate and is portrayed as two short parallel lines, a small box or circle on the line showing the direction of the Doppler pulse. The area or site of sample volume can be changed with PW Doppler and a precise location set. The maximal velocity measured is limited with PW Doppler, which limits its use in echocardiography.

CW Doppler uses two crystals, an emitter and receiver that work simultaneously. The machine continuously analyzes returning echoes for Doppler shifts. With CW Doppler, the operator knows only that the Doppler shift occurred somewhere along the line of the ultrasound beam. Anatomic localization of blood flow is quite limited. Much higher velocities can be accurately measured with CW than with PW, but the sampling area is along the length of the beam and not at a specific point or sample volume.

The Doppler display has time on the x-axis, or baseline, and velocity (in centimeters or meters per second) on the y-axis. The machine displays the returning echoes as peaks and troughs around a baseline, termed a spectral display. Blood flow toward the transducer is seen above the baseline, and blood flow away from it is seen below the baseline. Blood cells travel at various velocities. The two types of flow are laminar and nonlaminar. With laminar flow, blood cells in a vessel accelerate and decelerate together and move faster in the center of the vessel and more slowly at the walls. This action is seen as thin lines or peaks on the recording (Figure 1-9). Nonlaminar or turbulent flow causes the blood cells to have various velocities (Doppler shifts); this action causes the thin line to broaden, termed spectral broadening.

Duplex Doppler imaging means that the 2-D and PW imaging formats are displayed on the monitor at the same time. This permits the operator to make small adjustments to depth or position on the 2-D format and observe the Doppler changes on the same screen. A small lag phase occurs when switching between the two formats.

Color flow Doppler (CFD) is a form of PW Doppler. In this modality, the machine performs numerous PW Doppler analyses within a rectangular or rhomboidal area superimposed on the image. Rather than portraying the Doppler shifts as a wave form, the data are shown as color superimposed on the B-mode image. This color Doppler box is also referred to as a sample volume. A conventional color Doppler map uses shades of blue and red. The colors do not represent arterial or venous flow. Red is usually assigned to flow toward the transducer and appears above the center horizontal line of the color map. Flow away from the transducer is assigned shades of blue and appears below...
Ultrasound should not be performed first when conventional radiography is the preferred initial study. Ultrasonography and radiography are complementary techniques. Ultrasonography should be used as a supplement to radiography, not an alternative to it.

Technique

Patient preparation is important. Air trapped between the skin and the transducer surface must be removed. Close clipping of the hair and an ultrasonic acoustic coupling gel are prerequisites for most examinations. Sometimes cleaning of the skin with surgical spirit before application of the coupling gel will also be necessary, particularly on greasy skin. Positioning of the animal usually requires lateral or dorsal recumbency. Large or distressed animals may be examined while they are standing or in sternal recumbency.

For optimal imaging of various organs, the location of the transducer is important. An acoustic window must be found, that is, an area that avoids bone or gas structures being interposed between the transducer and the area of interest. Unless the interface is perpendicular to the beam, reflected echoes will not return directly to the transducer and therefore will not contribute to the image formation. The ultrasound beam in 2-D and M-mode modalities should interrogate tissues at a 90-degree angle to ensure maximal return of the reflected echoes. In Doppler examinations the beam direction should be at 180 degrees or as parallel as possible. Manipulation of the animal into various positions may aid the examination. Echocardiographic examination is usually carried out with the animal in lateral recumbency. The transducer is placed on the dependent side of the thorax and the heart imaged from underneath. This position improves contact of the heart with the rib cage and displaces the air-filled lung. A special cutout platform or table is required to facilitate this imaging plane. The terms near field and far field are used to describe areas nearer to or farther from the transducer.

Ultrasound-Guided Biopsy

Ultrasound-guided biopsy, or fine-needle aspiration of tissue, has become a valuable diagnostic aid. Some machines provide a detachable needle biopsy channel that can be clipped to the transducer. This directs the needle toward the area of interest. A biopsy function key on the machine causes two lines to be displayed on the monitor that indicate the path the needle will take in passing to the biopsy site through the biopsy channel. Many ultrasonographers, with practice (e.g., using phantoms), are able to obtain these biopsies freehand. Freehand biopsies allow greater versatility in sampling. After biopsy examination of the tissue, ultrasonography enables assessment of any potential complications, such as bleeding (Figure 1-10; also see Chapter 6).
Advantages and Disadvantages of Ultrasound

The following are advantages of ultrasound:
1. It is noninvasive.
2. It enables evaluation of dynamic function (e.g., in vascular structures).
3. It usually does not require general anesthesia or sedation.
4. It permits accurate fine-needle aspiration or biopsy of tissues.

The following are disadvantages of ultrasound:
1. The equipment can be expensive.
2. Artifacts may lead to misinterpretation.
3. It allows no real appreciation of skeletal structure except for bony surfaces.
4. It is impossible to attribute changes in echotexture and echogenicity to certain pathophysiologic causes (e.g., focal echotexture changes in the liver may be due to fatty infiltration, nodular hyperplasia, glycogen accumulation, necrosis, or neoplasia).
5. Considerable time is required to master ultrasound.

Artifacts

The term artifact refers to the display of information that does not accurately reflect the true image of the area under examination. The information generated may be erroneous, superfluous, absent, or misplaced. It is important to recognize artifacts to avoid misinterpretation. Manipulation of the transducer to ensure that the incident angle of the ultrasound beam is at right angles to the area of interest will often identify whether the perceived echo on the image is genuine. When the beam is not at right angles, it is termed an off-incidence angle.

Acoustic Shadowing

The artifact of acoustic shadowing is created when the ultrasound beam encounters gas or mineralized areas. The beam is reflected back to the transducer, and no image is generated beyond the mineralized region. The artifact appears as an anechoic shadow beyond the gas or mineralized area. It is useful in identifying calculi and other causes of tissue mineralization (see Figure 1-4, G and H).

Acoustic Enhancement

When the ultrasound beam travels through tissue, it is attenuated. The operator can compensate for this attenuation by increasing the intensity of the returning echoes, particularly echoes returning from farther away. When the beam passes through a fluid-filled structure, the attenuation is reduced. The result is a particularly bright or enhanced region that contrasts markedly with adjacent tissues beyond the fluid-filled areas. This phenomenon is particularly useful in diagnostic ultrasonography because it helps to differentiate fluid-filled and solid structures by virtue of their difference in attenuation of sound (see Figure 1-5).

Reverberation

Reverberation occurs when the ultrasound beam pulse is reflected back from a reflective tissue interface to the transducer. It may be seen when there is a large acoustic impedance difference or small, multiple, irregular reflecting surfaces. It is also associated with high gain settings on the machine. The reflected beam is subsequently bounced between the transducer and the reflecting surfaces. The computer interprets the reflected spurious echoes as being a returning echo from a distance twice that of the original reflecting surface. This to-and-fro sequence may occur several times. The resultant image is one of a series of bright lines at regular intervals that decrease in intensity with increasing depth. Reverberation can occur at the skin/transducer interface, which would be external reverberation. Internal reverberation occurs between the transducer and internal reflectors such as gas and bone.

Reverberations can also occur within cystic structures when the sound echoes are reflected back and forth between the walls of the cyst. It is important to recognize this phenomenon to differentiate the real echoes from the spurious echoes (Figure 1-11, A to E).

Ring-Down Artifact

The ring-down artifact is a particular type of reverberation artifact that is seen as a series of parallel lines associated particularly with metallic objects such as biopsy needles.
Chapter 1  ■  The Radiograph

Figure 1-11  A and B illustrate the principle of reverberation. Reverberation occurs when the ultrasound beam pulse is reflected back to the transducer from a reflective tissue interface such as bone or between two reflective surfaces such as air/gas.  

A. The reflected beam in this diagram illustrates reverberation between two reflecting surfaces (R, arrows). The computer interprets the reflected spurious echoes as being a returning echo from a distance twice that of the original reflecting surface. This to-and-fro sequence may occur several times.  

B. This diagram depicts the resultant image as a series of bright lines at regular intervals that decrease in intensity with increasing depth.  

C. This abdominal sonogram of the caudal abdomen shows a series of parallel reverberation lines (arrows) associated with gas in the small intestine.  (A and B, Courtesy Dr. M. Pinilla.)  

D. External reverberation. The series of bright hyperechoic parallel lines (arrow) have been generated between the skin and the transducer surface. Adequate preparation of the skin will prevent this artifact.  

E. The series of hyperechoic bright diverging echoes (arrow) are caused by reverberation from the gas in the stomach (S). Similar artifacts are seen associated with a mixture of gas and feces in the colon.  

F. This is a midline sagittal sonogram of a dog post laparotomy. The abdominal wall is in the near field, and the peritoneal surface is visible (arrowheads). The hyperechoic stripe (upper arrow) is free abdominal air. It is generating a series of hyperechoic parallel lines extending into the image (long arrows). This comet-tail artifact is due to reverberation.
Comet-Tail Artifact
The comet-tail artifact is another type of reverberation artifact associated with multiple echoes generated from small internal reflectors such as gas bubbles or metal. It is characterized by very bright, closely spaced echoes that seem to merge, giving a bright effect similar in appearance to a comet tail (Figure 1-11, F).

Mirror-Image Artifact
The mirror-image artifact occurs at the junction of tissues with a highly reflective curved interface, such as the diaphragm and pleura. An ultrasound pulse travels through the body, reaches a curved echogenic interface (e.g., the diaphragm), and is reflected along a different path back into the organ it has traversed and generates another reflection within the organ (e.g., the gallbladder). This ultrasound pulse returns along its path back to the transducer. The machine places the returning echoes along the original transmitted path of the ultrasound beam to the curved echogenic structure. The result is a mirror-image display. This artifact happens particularly during hepatic ultrasonography when hepatic tissue and the gallbladder are apparently seen on both sides of the diaphragm and may simulate a diaphragmatic rupture (Figure 1-12).

Edge Shadowing
In edge shadowing, lateral margins of a curved or fluid-filled structure appear to fade or drop out of the image, and anechoic, linear, diverging shadows are cast distally from the lateral margins (Figure 1-13).

Side-Lobe Artifact
The side-lobe artifact occurs when echoes generated from the side of the ultrasound beam are returned to the transducer. The machine interprets these side-returning echoes as if they had been generated from the primary central beam. This interpretation by the machine results in erroneous displays of faint echoes on the image. Side-lobe artifacts occur at highly reflective interfaces and curved surfaces such as the bladder or gallbladder (Figure 1-14, A to C).

Slice-Thickness/Beam-Width Artifact
The slice-thickness artifact occurs when part of the emitted ultrasound beam width falls beyond a fluid-filled or cystic structure. Returning echoes from the
adjacent tissue in the area are seen, apparently within the fluid-filled structure, creating the appearance of a mass or sediment. This artifact may be seen in the gallbladder and is sometimes termed pseudosludge. Moving the animal will move true sediment. Pseudosludge has a curved surface and is always seen perpendicular to the ultrasound beam, whereas true sludge will align with the horizontal plane of the animal (Figure 1-14, D and E).

**Propagation Speed Error**

The ultrasound machine operates on the assumption that ultrasound waves travel at the same speed in all tissues within the body. This artifact occurs when the ultrasound beam passes through two adjacent tissues that transmit ultrasound waves at different speeds. Echoes returning from a structure deep to the tissue that carries ultrasound relatively faster will return to the transducer earlier, and the echo will appear on the screen at a shallower depth. Echoes returning from a structure deep to the tissue that carries ultrasound relatively slower will appear on the screen at a greater depth because the time required for the pulse to travel out and back is relatively greater. This will result in apparent discontinuity in a linear structure such as the diaphragm or a segment of small intestine.

**Figure 1-13** Edge shadowing/refraction. A, Refraction of the ultrasound beam around a curved structure such as the gallbladder (GB). It is common at the edges of round structures. Refraction results in a change in direction of the ultrasound beam. As a result, no echoes will reach areas deeper to the area where refraction occurs, and an echo-free black or anechoic (arrows) area will be displayed. B, Transverse scan of the liver. The circular fluid-filled structure in the near field is the gallbladder. Anechoic shadows (arrows) are seen to originate from the margins of the gallbladder (GB) and diverge and project distally into the tissues. This occurs because of a combination of refraction and reflection of the sound waves around and through a cystic structure. This artifact is very common and can be seen with fluid-filled structures such as the gallbladder or urinary bladder. (A, Courtesy Dr. M. Pinilla.)
Figure 1-14  A and B, Side-lobe artifact. A, The ultrasound machine assumes that the transducer generates a single ultrasound beam and that all the returned echoes came from the path of this beam. In reality, the transducer generates a main beam, A, and some secondary ones at different angles (B). Structures along the path of the secondary beams such as the black shape will be displayed as if they were in the plane of the primary beam (gray shape). B, An example of this artifact occurs during the examination of the urinary bladder (B). The secondary beams may encounter the colon and be reflected back to the transducer. The machine will erroneously display these echoes (arrow) within the bladder. They can be mistaken for urinary calculi. (A, Courtesy Dr. M. Pinilla.) C, Sagittal plane ultrasound image of the bladder of a dog. There are several closely grouped calculi (short arrows) within the lumen. An acoustic shadow is present deep to the calculi. The hazy gray echoes adjacent to the calculi within the lumen (long arrows) are side-lobe artifacts rather than sludge or debris. This can be suspected because the edge of the artifactual echo corresponds to the edge of the uroliths and forms two lines, whereas sludge or debris would settle and form a single border. A side-lobe artifact can be confirmed by repositioning the probe, and once the echogenic interface is removed, the artifact will disappear. D and E, Slice thickness artifact. D, Ventral midline sagittal scan of the liver with a dog in dorsal recumbency. The gallbladder is identified as an anechoic structure. A granular echotexture, which has a curved margin (arrow), is seen in the dorsal aspect of the gallbladder. This apparent sediment is an artifact. E, When the transducer is repositioned, the gallbladder (G) lumen is anechoic, and the previous granular material is no longer apparent. On the standard imaging plane, two small polyps (arrows) are now visible on the mucosa of the gallbladder.
Chapter 1 ■ The Radiograph

Box 1-2. Definitions

Echoic/echogenic—The ability to generate echoes.
Echotexture—The image pattern of the tissue being examined.
Anechoic/echolucent—There are no discernible echoes; the result is a black area on the monitor.
Hypoechic—There are discernible echoes, but they are low grade and give a gray image.
Hyperechoic—There are white echoes; there is a high echointensity.
Homogeneous*—Uniform.
Heterogeneous*—Mixed.
Isoechoic—The tissue echogenicity is the same as in similar adjacent structures.

Ventral midline sonogram of the cranial abdomen. The gallbladder (GB) is anechoic. The diaphragm (arrow) has a hyperechoic margin, and the liver texture (L) is isoechoic. An area of acoustic enhancement (arrowheads) is hyperechoic in relation to the rest of the liver. Three small nodules are seen attached to the wall of the gallbladder. These were an incidental finding.

*Homogeneous and heterogeneous may refer to echogenicity or tissue echotexture.

REFERENCES

**The Abdominal Cavity**

The abdominal cavity is lined by the parietal peritoneum, which is continuous with the visceral peritoneum, which covers the viscera. The peritoneum is covered by a thin layer of fluid. The space between the parietal and the visceral peritoneum is normally a potential space. The mesenteries and the omenta are parts of the peritoneum. The retroperitoneal space is that area dorsal to the peritoneum and ventral to the sublumbar muscles. The kidneys lie in the retroperitoneal space.

Visualization of the abdominal organs depends on the following factors, taken singly or in combination:

1. Differences in opacity between one organ and another.
2. The amount of fat—retroperitoneal, mesenteric, and omental—present within the abdomen. Emaciated or very young animals with little abdominal fat show poor contrast.
3. The contents of the abdominal organs vary in density and consequently in opacity. Such contents may help outline the organs, such as air or gas in the stomach, or feces may outline the colon.

All the intraabdominal organs have a soft tissue or fluid opacity. One organ does not contrast well with another. Intraabdominal and perirenal fat provide some contrast. Apart from developmental anomalies, changes within the abdomen are caused by physiologic or pathologic processes. These processes are reflected as changes in opacity, size, shape, or position of intraabdominal structures. A normal structure may be displaced by an abnormal one or by a normal one that has increased in size as a result of physiologic changes. Functional disturbances can rarely be appreciated on plain radiographs. To demonstrate detail within the abdomen, special contrast procedures and ultrasonography are frequently necessary.

**Radiography**

The standard views used to study the abdomen are the left-right lateral recumbent, the right-left lateral recumbent, and the ventrodorsal. The dorsoventral view is not commonly used because when the patient is in sternal recumbency, the viscera are compressed and often irregularly displaced. A standing lateral view may sometimes be used, especially if an accumulation of peritoneal fluid is suspected. It should be remembered, however, that no fluid line will be seen unless there is a concomitant pneumoperitoneum (gas in the peritoneal cavity). Oblique views are useful in certain circumstances when it is necessary to examine the esophagus, stomach, colon, or bladder in more detail than is possible on standard views.

For lateral projections, the sternum should be supported by radiolucent foam pads to maintain it on the same horizontal level as the spine. The hindlimbs should be drawn caudally sufficiently far to prevent thigh muscles from overlying the caudal abdomen. The x-ray beam should be collimated to include the diaphragm and the pelvic inlet. On ventrodorsal views, on which the inguinal skinfolds may cast marked shadows, the “frog leg” position with the hind legs flexed may be preferred to having the hindlimbs drawn out caudally. Chemical restraint may be required with uncooperative animals where local radiation regulations preclude manual restraint.

Because the degree of contrast between the various abdominal organs is small, it is essential that good-quality radiographs be produced so that the maximum amount of information can be obtained. Adequate patient preparation and good radiographic technique are both important. Exposure factors using a lower kilovoltage increases the contrast within the radiograph.

In elective cases, the patient should be fasted for at least 12 hours before investigation. Water is allowed. The use of a mild cathartic administered the day before the examination is helpful. If the area of interest is the gastrointestinal tract, it is probably best not to give an enema initially because it may cause significant changes in the radiologic picture. An enema may be given after the initial survey studies have been made. Isotonic saline enemas are recommended. The temperature of the enema fluid should be lower than body temperature. This lower temperature helps cause expulsion of much of the gas that would remain in the colon if a warm enema were given.
Evaluation of the Abdominal Radiograph
1. A good abdominal radiograph should show the structures in the cranial and caudal abdomen and the abdominal wall.
2. There should be good range of contrast so that the various abdominal structures can be clearly distinguished from one another.
3. Falciform and retroperitoneal fat should be identifiable.
4. The bodies of the vertebrae should be clearly outlined and the bone density clearly identifiable.
5. The film should be neither overexposed nor underexposed.

To determine the thickness of the abdomen when a technique chart is used, the measurement should be made at the point of greatest depth, usually over the caudal rib cage. The actual exposure should be made during the expiratory pause. A grid should be used for animals when the abdomen has a thickness of 10 cm or more. In deep-chested animals on the ventrodorsal view, visualization of the abdominal organs is often poor because of the wide variation between the area of the caudal rib cage and the area of the pelvic inlet.

Normal Appearance
On survey radiographs of the abdomen, the diaphragm, abdominal wall, stomach, small intestine, large intestine, liver, and bladder can usually be recognized. On the ventrodorsal and left-right lateral recumbent views, the spleen is also usually seen.

Figure 2-1 A and B, Ventrodorsal views of a normal abdomen. C and D, Lateral views of a normal abdomen (B and D: 1, Stomach; 2, liver; 3, spleen; 4, kidneys; 5, bladder; 6, colon; 7, cecum; 8, small intestine).
Figure 2-1, cont'd  
E, Normal puppy abdomen. Contrast is poor in this 3-month-old puppy. F, Normal teat shadows. G and H, Normal male dog abdomen. G, Right lateral and H, ventrodorsal radiographs of a normal abdomen of a male dog. A moderate amount of food is present in the stomach, which indicates the caudal margin of the liver. The cecum is a C-shaped gas-filled segment of bowel seen in the midabdomen on the lateral radiograph and in the right midabdomen on the ventrodorsal radiograph. In G, the left kidney is outlined by fat. The right kidney is not seen because it is obscured by superimposition of the colon. The tail of the spleen appears as a thin, elongated, fusiform soft tissue structure in the ventral midabdomen.

The kidneys may or may not be seen depending on the amount of perirenal fat present. The left kidney is seen in most dogs, whereas only the caudal pole of the right may be visible. The complete outline of both kidneys is usually visible in cats. The os penis is seen in the male dog. The prepuce of the male dog is usually seen because of the air that surrounds it, and the teats are often seen in the female for the same reason. The prostate gland may be seen if there is sufficient intrapelvic fat to outline it. The position and appearance of the normal viscera vary somewhat with the posture of the animal, its conformation, respiratory movements, and the amount of food material present in the alimentary tract (Figure 2-1).

Ultrasonography

Abdominal ultrasound is usually performed as a complementary technique to radiography. The combination of both imaging modalities results in more information as to size, shape, and position of organs. In addition, ultrasound provides accurate information on the outline and architecture of tissues. Ultrasonography can be performed anywhere on the abdominal wall, the only impediment being bone and gas-filled structures, which should be avoided. If a general examination is to be performed, then a systematic approach is required. Unless a high-frequency transducer is used, the abdominal wall will not be clearly discernible.
A series of CT images demonstrating the normal anatomic relations of the abdominal structures. The right side of the abdomen is on the left side of the image. **I.** A transverse CT image of the cranial abdomen of a normal dog is displayed in a soft tissue window. The liver has relatively uniform attenuation, but the gallbladder and contents are hypoattenuating compared with the liver. The hepatic veins are slightly hypoattenuating compared with the liver tissue. Note also the falciform fat (arrow) ventral to the liver and gallbladder (asterisk). A small volume of fluid is present in the caudal thoracic esophagus just ventral to the vertebral body, and an air-fluid interface is seen. This is not an uncommon finding. The patient was scanned in dorsal recumbency. **J.** A transverse CT image of the abdomen of a normal dog at the level of the left renal pelvis. The kidney tissue has uniform attenuation. Fat is seen at the renal hilus (arrows) surrounding the renal pelvis and renal vessels. Part of the spleen is visible ventral and to the left of the left kidney. There is a defect in the left side of the vertebra, a result of previous spinal surgery. **K.** A transverse CT image of the abdomen at the level of the splenic hilus. The cranial pole of the right kidney (asterisk) is seen partially surrounded by the renal fossa of the caudate lobe of the liver (arrows). The head of the spleen is folded medially in the left abdomen. **L.** A transverse CT image of the abdomen of a normal dog at the level of the iliac wings. The colon contains mixed attenuation material and multiple small gas bubbles in the center of the image. It lies dorsal to the urinary bladder and indents the dorsal border of the bladder. The urine within the bladder (UB) is slightly hypoattenuating compared with the urinary bladder wall. Note also the external iliac arteries and veins (arrows) dorsal and lateral to the colon and ventral to the iliopsoas muscles.
Chemical restraint is rarely required except when severe abdominal pain is present. Lateral or dorsal recumbency are options, but dorsal recumbency is the usual position. Left lateral recumbency positioning avoids gas rising into the fundus of the stomach. When using lateral recumbency, the patient must be turned to allow the entire abdomen to be examined. Lateral examination from the dependent side, using a cutout table or platform, is used for some examinations because imaging from the dependent side helps avoid gastrointestinal gas. Large dogs may be examined in the animal in the standing position. The hair is clipped close, and an acoustic coupling gel is applied to the skin. Cleaning the skin with alcohol is advocated to improve image quality. However, the use of alcohol on recently clipped skin may cause discomfort. Abdominal ultrasonography may be required to examine a specific organ or for a general examination. The area of skin preparation will vary depending on the purpose of the study.

For small to medium dogs, a 5- to 10-MHz transducer will be adequate. Large and giant breeds will require a 3.5- to 5-MHz transducer. Examination of structures in the cranial abdomen may require an intercostal approach, and a small transducer footprint will be necessary to avoid the ribs.

The usual planes of section are transverse, a cross-section through the body, and a sagittal section or longitudinal section parallel to the vertebral column. Because many organs are somewhat mobile, orientation planes will relate to the organ under examination. Organs such as the kidney often need a third plane of section termed dorsal. This plane requires the transducer orientated in a cranio-caudal direction but aligned along the right or left wall of the abdomen. The convention is to display the cranial aspect of the animal on the left side of the image.

**Abnormalities**

**Abdominal Masses.** Masses within the abdominal cavity are from enlargements of one or more of the intraabdominal structures. Enlargement of an organ may be attributable to physiologic or pathologic processes. Distention of the stomach after eating, enlargement of the uterus during pregnancy, and enlargement of the spleen during barbiturate anesthesia are examples of physiologic enlargements. Pathologic enlargement may be the result of inflammatory processes; abscess or cyst...
A mass can usually be identified on a plain radiograph. Abdominal masses are sometimes masked by intraabdominal fluid. If there is accompanying fluid, it should be removed and another radiograph made so that the mass may be more accurately identified. Alternatively, ultrasonography may be used. Some estimation of the origin of a mass may be gained from its position and from the manner and degree of displacement of other organs. Organs amenable to displacement are the stomach, the small and large intestines, the spleen, the uterus, the bladder, and to a lesser extent the kidneys. Movable organs will be displaced in a direction away from the mass. Such displacements often permit the examiner to suggest which structure is enlarged. For example, an enlarged liver displaces the stomach caudally and dorsally.
Sublumbar masses can be seen on lateral views. They may be caused by enlarged medial iliac (sublumbar) lymph nodes, enlarged renal silhouettes, ureteral rupture with accumulation of urine, hemorrhage, abscess formation, adenomegaly, infection, or neoplasia of vertebrae or sublumbar structures. They displace the adjacent abdominal organs ventrally. Enlarged lymph nodes may present as intraabdominal masses in other locations (Figure 2-2, A to E).

**Ultrasonography.** Ultrasonography is useful in confirming the clinical or radiologic diagnosis of an abdominal mass. It also permits identification and localization of the organ of origin and assists in evaluation of other organs for concomitant disease. It should be done before abdominocentesis. Ultrasound-guided fine-needle aspiration or biopsy aids in a definitive diagnosis of such masses (Figure 2-2, F and G).

**Intrapertoneal Fluid.** Intrapertoneal fluid may be exudative or transudative in origin, or it may be blood, chyle, urine, or bile. Ascites is defined as an effusion and accumulation of serous fluid in the peritoneal cavity. Common causes of ascites are congestive heart failure, liver abnormalities, renal disease, hypoproteinemia, peritonitis, and abdominal neoplasia. The term ascites is used colloquially to describe the presence of any fluid in the abdominal cavity.

**Radiologic Signs**
1. The abdomen appears more radiopaque than normal. Its overall hazy appearance makes the radiograph appear as if it were underexposed. Clear visualization of the vertebral column indicates the exposure to be adequate.
2. The increased opacity is widely distributed throughout the abdomen, causing loss of the detail normally seen. Serosal surfaces are obscured to some degree depending on the amount of fluid and fat present.
3. Gas within the bowel may be seen through the fluid, but details of the serosal surfaces are lost.
4. There is an increased distance between individual loops of intestine that are separated by the fluid.
5. With large volumes of fluid, the intestines tend to occupy a central position in the abdomen unless displaced by an abdominal mass.
6. The abdomen is distended because of the fluid within it.
7. Standing lateral films show an increased opacity in the ventral abdomen where the fluid accumulates and a more natural appearance dorsally. Loops of intestine that contain gas tend to rise to the dorsal abdomen and “float” on the fluid. A gas-fluid interface (fluid level) will not be seen unless there is free gas within the peritoneal cavity (pneumoperitoneum). Fluid levels may be seen within the intestinal tract.
8. Occasionally the faint outline of an intraabdominal mass is identified through the fluid.
9. Smaller amounts of fluid may give the abdomen a hazy or mottled appearance (Figure 2-3, A and B). Other conditions may give a somewhat similar appearance to that of ascites. Intraabdominal hemorrhage may be caused by trauma or anticoagulant poisoning. Effusion of fluid may be associated with peritonitis with loss of detail within the abdomen, either localized or generalized, but the abdomen is not distended. Metastatic seeding of neoplasms may cause loss of intraabdominal detail and be associated with effusion. Emaciation causes loss of intraabdominal detail because of fat depletion. Young animals lack intraabdominal fat and thus show poor intraabdominal detail. Care should be taken not to mistake a fluid-filled viscus for ascites. A grossly distended bladder can extend very far cranially into the abdomen. Perinephrotic pseudocysts may be quite extensive and simulate ascites. An enlarged viscus will displace adjacent organs (Figure 2-3, C). Small amounts of fluid can be difficult to demonstrate radiographically.
Figure 2-3  A and B, Ascites in a cat. The abdomen is grossly distended, and there is loss of intraabdominal detail. There is rotation of the abdomen on both views. The distention made accurate positioning difficult. C, This neutered male 15-year-old cat has a grossly distended bladder. The cranial and dorsal displacement of the intestines distinguishes it from ascites. D, Intraabdominal fluid (F) surrounds an enlarged liver (L) with rounded, nodular margins (M and arrows). Cr, cranial. E, This German Shepherd presented depressed and with palpable abdominal fluid. The abdominal sonogram was obtained with the dog in the standing position. It shows the free fluid (F) to be highly echogenic because of a high cellular content. The colon (C) lies to the left. Diagnosis: splenic adenocarcinoma. F, This dog was examined in dorsal recumbency. Intraabdominal fluid (F) outlines the kidney (K) lying in the retroperitoneal space. Cr, cranial.
Ultrasonography. The presence of intraabdominal fluid, which is a hindrance in radiologic evaluation of the abdominal cavity, assists ultrasonographic examination. Ultrasonography is more sensitive than radiography in detecting small volumes of free fluid. Transudates tend to be anechoic. Anechoic fluid dissecting between organs permits their margins to be examined because the fluid profiles organ edges. Fluid surrounding the bladder or gallbladder throws their walls into relief so that their internal and external aspects can be identified. Abdominal organs appear more echogenic than usual when surrounded by intraabdominal fluid. The relative echogenicity of the fluid can be compared with the normal anechoic urine or bile. Free blood in the abdomen has a more echogenic specular texture than a transudate or modified transudate. Peritoneal masses are also seen, provided they are profiled by fluid. Gross abdominal distention resulting from fluid can make examination difficult because the animal may resent transducer pressure. Abdominocentesis relieves the pressure and makes the procedure less stressful, but care must be taken not to introduce air into the abdomen (Figure 2-3, D to F).

Peritonitis. Peritonitis is inflammation of the peritoneum. It may result from infection, rupture of an abdominal organ, trauma, or a penetrating wound of the abdominal wall. It may be secondary to pancreatitis or pancreatic neoplasia. Peritonitis causes loss of the sharp outline of the abdominal organs so that the abdomen in the affected area appears hazy or blurred. Serosal surfaces are not clearly seen. An associated outpouring of fluid enhances the effect. Large amounts of fluid produce a homogeneous opacity. Small irregular areas of increased opacity (mottling) are often evident as a result of an irregular distribution of small amounts of fluid. There may be associated adhesions.

Peritonitis may be localized or generalized. If it is localized, only those structures in the affected area will lose their radiographic sharpness. If it is generalized, there is a widespread haziness of the abdomen. Abdominal carcinomatosis or metastatic neoplasia produces a picture similar to peritonitis. A nodular or granular pattern may be seen (Figure 2-4, A to G).
In cats, steatitis may cause peritonitis with loss of detail in areas with accumulations of fat—the falciform ligament, the perirenal areas, and the inguinal and sublumbar regions.

Ultrasonography. The presence of echogenic particles oscillating in the abdominal fluid with or without strands of hyperechoic tags of fibrin is suggestive of peritonitis. The serosal surfaces of the abdominal organs may show an irregular outline. All abdominal organs should be carefully examined for a potential source of regional peritonitis (Figure 2-4, H to J).

Free Gas in the Abdomen. Free gas (air) may be seen in the abdomen for up to 4 weeks after laparotomy. Intraabdominal gas may also be the result of a penetrating wound through the abdominal wall or rupture of a viscus.

Radiologic Signs
1. The gas usually has an irregular distribution and does not conform to the shape of normal gastrointestinal gas.
2. Small bubbles trapped between bowel segments may be seen as arrow-like shapes or as triangles.
3. The position of free gas changes according to changes in posture of the animal. A small amount of gas may easily be missed, especially if it is superimposed on part of the intestinal tract.
4. Free gas may outline the liver and be seen between the diaphragm and the liver. It may outline the stomach and the ventral border of the kidneys.
5. Free gas in the abdomen may be demonstrated on a ventrodorsal view with the animal placed in left lateral recumbency and using a horizontal beam (decubitus position). This is the study of choice, because on decubitus ventrodorsal views made in right lateral recumbency, there may be difficulty in distinguishing free gas from gas within the gastric fundus or colon. Several minutes should be allowed to elapse from when the animal is positioned until the radiograph is made. This interval will allow the gas to reach the highest point within the abdomen. The gas will be seen in the uppermost part of the abdomen under the caudal ribs.
6. Free gas may also be demonstrated on a standing lateral view when it will be seen to collect in the sublumbar area.

7. If gas is present in considerable amounts, the various abdominal organs will be outlined by it, and the film may appear to be overexposed (Figure 2-5).

Ultrasonography. Ultrasound may be more sensitive for detecting small volumes of free gas. The patient should be placed in lateral or dorsal recumbency and a few minutes allowed to elapse before scanning to allow bubbles to rise to the upper abdominal wall. A high-frequency linear probe is recommended. Free gas appears as a hyperechoic structure with comet-tail artifacts immediately adjacent to the inner margin of the abdominal wall. Free gas has a similar sonographic appearance to intestinal gas but is distinguished by the absence of a surrounding bowel wall (Figure 2-5, F).

THE ABDOMINAL WALL

Cranially the abdomen is bounded by the diaphragm. Laterally and ventrally it is bounded by the ribs and the abdominal musculature. Its dorsal boundary is formed by the sublumbar muscles. It is lined by the peritoneum, which forms the caudal limit of the abdomen. With the exception of the peritoneum all these structures can be identified on plain radiographs.

Abnormalities

A disruption in the continuity of the diaphragm or the abdominal musculature results in a rupture. There may be mineralization within the muscles in Cushing’s disease (see Figure 6-1, F). Gas may track along fascial planes in pneumomediastinum or after trauma. Tumors of the abdominal wall are rare and the outline may be obscured by intraabdominal fluid.
Hernias. A distinction may be made between protrusions that have a peritoneal lining and those that have an associated abdominal wall rupture. A hernia is a protrusion of abdominal organs through a natural or physiologic opening so that they come to lie beneath the skin. The peritoneum remains intact. A rupture is a protrusion of abdominal organs through a breach in continuity of the abdominal wall. The terms are often incorrectly used interchangeably.

Radiography is sometimes of value in the diagnosis of a hernia. If a hernia becomes strangulated or incarcerated, dilated loops of bowel are seen proximal to the herniated portion of intestine, and the herniated intestine may be dilated.

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Ultrasonography can be used to identify the contents of an inguinal hernia. Gas shadows within the hernial outline indicate the presence of a portion of intestine. The uterus casts a homogeneous, fluid type of opacity, as does the bladder. Fetal skeletons may be seen if the animal is in late pregnancy. A barium study can be used to determine the position of the intestine. Ultrasonography will determine the contents (Figure 2-6, C, G, K, and L).

Ventral Hernia. There may occasionally be doubt as to the nature of a swelling on the abdominal wall. In the case of a ventral hernia, radiographs may show loops of intestine containing gas outside the abdomen and under the skin. The point of herniation may be seen as a discontinuity in the shadow of the abdominal wall. If necessary, intraperitoneal or subcutaneous injection of water-soluble contrast material will coat the abdominal contents and show their position.

Fat and intestines may be identified on ultrasonography. Close examination of the abdominal wall may identify the site of herniation.

Perineal Hernia. Radiographs can be helpful in determining the contents of a perineal hernia. Contrast cystography (see p. 148) will show whether the bladder is in the hernia. If there is retroflexion of the bladder, introducing contrast medium may be difficult.

Fat, a displaced rectum, or the anechoic urine-filled bladder may be identified in the perineal swelling on ultrasound examination (Figure 2-6, D).

Hiatal Hernia. In this hernia there is a protrusion of the stomach, or part of it, through the esophageal hiatus.
The Abdomen

35
of the diaphragm, displacing the terminal esophagus cranially. The cardiac area of the stomach is most likely to be involved. The term hiatal hernia implies a herniation of part of the stomach through the esophageal hiatus into the thorax. With the sliding type of hernia, the displacement is intermittent and usually affects the gastroesophageal junction, together with the cardia of the stomach. A barium study will show the position with a horizontal beam and the patient in dorsal recumbency. Free gas rises to the cranioventral aspect of the abdomen. Gas outlines the caudal surface of the diaphragm (long arrows) and ventral border of the liver and stomach (arrowheads). A large pocket of gas (asterisk) is visible within the pyloric antrum and body of the stomach. This should not be confused with free peritoneal air. Because the patient is in dorsal recumbency, the heart is displaced slightly from the sternum, which should not be mistaken for a pneumothorax. The horizontal line that crosses the image is the edge of the foam positioning device. F. This is a midline abdominal sonogram of a dog with pneumoperitoneum after a laparotomy. Gas within the small intestine is causing reverberation artifacts (long arrow). Free intraabdominal air (short arrow) is seen lying immediately adjacent to the abdominal wall (arrowhead) and also generating reverberation artifacts.

Diaphragmatic Hernia. Diaphragmatic hernia (rupture) is described in Chapter 3. Celiotomography or peritoneography, that is, introduction of contrast medium into the peritoneal cavity, has been described

Figure 2-5, cont’d D, A lateral abdominal radiograph with a horizontal beam, with the patient in dorsal recumbency. There is gas within the pyloric antrum and body of the stomach (asterisk). Two horizontal lines, representing gas fluid interfaces (arrows), are present within the stomach. No gas is present within the peritoneal cavity. With the patient in this position, free peritoneal gas will rise and accumulate just caudal to the xiphoid and ventral to the liver. E, Free intraperitoneal gas in a dog. This is a lateral radiograph obtained with a horizontal beam and the patient in dorsal recumbency. Free gas rises to the cranioventral aspect of the abdomen. Gas outlines the caudal surface of the diaphragm (long arrows) and ventral border of the liver and stomach (arrowheads). A large pocket of gas (asterisk) is visible within the pyloric antrum and body of the stomach. This should not be confused with free peritoneal air. Because the patient is in dorsal recumbency, the heart is displaced slightly from the sternum, which should not be mistaken for a pneumothorax. The horizontal line that crosses the image is the edge of the foam positioning device. F, This is a midline abdominal sonogram of a dog with pneumoperitoneum after a laparotomy. Gas within the small intestine is causing reverberation artifacts (long arrow). Free intraabdominal air (short arrow) is seen lying immediately adjacent to the abdominal wall (arrowhead) and also generating reverberation artifacts.
as an aid in the diagnosis of these hernias. Abdominal organs may be seen within the pericardium in peritoneal pericardial hernia (see Chapter 3, p. 257; and Figure 2-6, E).

Umbilical and Scrotal Hernias. Umbilical and scrotal hernias are usually diagnosed on a clinical examination. Displaced loops of intestine may be seen on radiographs that include the area of the hernial sac. Ultrasonography will identify the contents of the hernia (see Figure 2-56, N).

Abscess. On radiographs an abscess presents as an intraabdominal mass. It may be homogeneous in nature or contain focal lucencies. There may be local lack of serosal detail because of peritonitis. Regional ileus and bunching of the intestines may be observed. Abscess formation may be caused by perforation of the gastrointestinal tract, pancreatitis, foreign body such as a surgical swab or sponge, or trauma (see Figure 2-4, D to F, and Figure 2-6, I).

Ultrasonography. On ultrasonography, intraabdominal abscesses, or abscesses within hernias, produce hypoechoic, poorly margined masses containing variable quantities of fluid. They usually have a mixed echogenic appearance and are surrounded by a capsule and may be attached to the serosal surface of abdominal organs or to the abdominal wall. Adjacent inflammation may be indicated by hyperechoic fat, pockets of anechoic/hypoechoic fluid, and regional intestinal ileus (see Figure 2-4, H). The presence of echogenic particles oscillating in the abdominal fluid with or without strands of hyperechoic tags of fibrin is suggestive of peritonitis. Serosal surfaces of adjacent organs may show an irregular outline (see Figure 2-4, I and J).

THE RETROPERITONEAL SPACE
The retroperitoneal space is the area that lies between the sublumbar muscles and the peritoneum. It contains the medial iliac (sublumbar) lymph nodes, the kidneys, the prostate gland, the adrenal glands, the aorta, and the caudal vena cava. Part of each ureter lies within it. It normally contains an amount of fat, which provides contrast. The kidneys and the prostate protrude from the retroperitoneal space into the abdomen and thus are partially covered by peritoneum.

Abnormalities
The retroperitoneal space may be the seat of sublumbar masses caused by abscessation; enlarged lymph nodes, kidneys, or adrenal glands; or neoplasia of sublumbar muscles, connective tissue, or vertebrae.
Retroperitoneal fluid may be caused by hemorrhage or leakage of urine from the kidneys or ureters (Figure 2-6, N). Gas or air from a pneumomediastinum is occasionally seen outlining structures in this region.

**Ultrasonography**

Ultrasonographic examination permits examination of the sublumbar region. Lymph nodes, vessels, and kidneys are clearly visible. Masses in the region are readily accessible for fine-needle aspiration or biopsy provided that major blood vessels are avoided (Figure 2-6, O and P).

**Abdominal Blood Vessels.** Every sonographic examination of the abdomen should include an examination of the intraabdominal blood vessels. Congenital anomalies, with or without related organ changes, neoplasia, infiltration, or thrombosis, are among the conditions that may be encountered. In the evaluation of vessels, familiarity with their anatomic features is essential. High-frequency transducers are usually used, though larger animals may require lower frequencies. The animal should be fasted for 8 to 12 hours before examination. The method of choice is imaging through the paralumbar region in the dorsal and transverse planes. Studies are more easily performed with the animal in right and left lateral recumbency as the transducer is placed dorsally in the sublumbar fossa and gastrointestinal gas is avoided.

From the left side, the aorta is seen in the near field, that is, nearest to the transducer. The vena cava is seen on the far side of the aorta (far field). The aorta is identified by its pulsation, which may affect the adjacent vena cava.

As one moves from the cranial to the caudal abdomen, the major branches of the aorta can be identified, namely, the celiac, the cranial mesenteric, paired phrenico-abdominals, paired renal, testicular or ovarian, paired lumbar, caudal mesenteric, paired deep circumflex iliac, and external iliac arteries.

Similarly, the main branches of the vena cava are the common iliac veins, paired deep circumflex iliac,
right testicular or ovarian, paired renal and phrenicoabdominals, and multiple hepatic veins.

The portal vein is located in the midventral abdomen and is the vessel closest to the transducer when imaging from the right side with the animal in left lateral recumbency (Figure 2-7, H and I).

**THE LIVER**

**Anatomy**

The liver lies within the intrathoracic portion of the abdomen. It is made up of six lobes, the left medial, left lateral, right medial, right lateral, quadrate, and
caudate lobes. Cranially the liver is convex in outline and lies, for the most part, in contact with the diaphragm. Caudally it is in contact with the right kidney at the renal fossa, the cranial flexure of the duodenum, and the stomach. The depth of the abdomen is greatest in this area. Its right border is formed by the right medial lobe cranially and the right lateral lobe and the caudate process of the caudate lobe caudally. Its left border is formed by the left medial lobe cranially and the left lateral lobe caudally. The quadrate lobe is centrally placed cranially. To the right and to the left the liver is adjacent to the abdominal wall. The gallbladder is situated in the right cranioventral abdomen.

**Radiography**

Because the liver lies in the deepest part of the abdomen at expiration, sufficient kilovoltage should be used to ensure adequate penetration. An impression of liver size can usually be gained from a study of plain radiographs of the abdomen. The location of the stomach often helps in evaluating liver size and position. A barium swallow may be required.

**Normal Appearance**

The exact outline of the liver is not discernible on plain radiographs of the abdomen. On a lateral radiograph, the liver occupies a triangular area between the diaphragm and the ventral body wall, the falciform ligament, and the stomach. Its caudal border, represented by the left lateral lobe, is sharp in outline and may project a short distance caudal to the ventral portion of the costal arch. Sometimes the liver shadow that contacts the stomach merges with that of the spleen, particularly on radiographs made in right lateral recumbency. This merging of shadows obscures the caudal limit of the liver. The liver lies somewhat more caudally in older dogs and may project beyond the costal arch.

On the ventrodorsal view, the liver appears as a homogeneous soft tissue opacity caudal to the diaphragm. Its outline is not well marked. Its caudal
border on the right side may be determined from the position of the cranial duodenal flexure and the cranial pole of the right kidney in obese animals. Centrally the lesser curvature of the stomach marks its caudal limit. On the left it is covered by the fundus of the stomach. The caudal lobes of the lungs are superimposed on the liver to some extent on both lateral and ventrodorsal views, and pulmonary vessels are frequently seen superimposed on the liver shadow.

The exact position of the liver varies with respiration, being most caudally placed at full inspiration. Its position may also vary with the posture of the animal and with conformation. Right lateral recumbency allows the left hepatic lobes to move caudally, causing

**Figure 2-7**

A, Positions of the normal liver and spleen. B, A ventrodorsal view of the abdomen with the outline of the head of the spleen (arrows). C, Midline sagittal sonogram of the cranial abdomen. The relative echotextures of the liver (L) and spleen (S) can be seen. The spleen is hyperechoic compared with the liver. The structure in the far right field is the fluid-filled stomach. D, Normal sharp edge to the caudal liver margin (arrows). E, Midline sagittal sonogram of the liver (L) of a fat dog showing a large quantity of fat (F) in the ventral abdomen outlining the liver margin (arrows).
Figure 2-7, cont'd F1, Normal portal vessels (arrows) in the liver. The portal vessels have bright hyperechoic walls. F2, This midline sonogram of the liver shows normal portal vessels (short arrow) and hepatic veins (long arrow). G, Hepatic veins (arrowheads) draining into the caudal vena cava (CVC). GB, gallbladder. H, Color flow Doppler sonogram showing the caudal vena cava (long arrow coded blue) traveling toward the diaphragm. The aorta is seen in the far field (short arrow, coded red) (see Color Plate 2-7, H). I, This sagittal plane sonogram shows the terminal aorta bifurcation (long arrow) and caudal vena cava (medium arrow) bifurcation and the external iliac vessels (small arrows). J, Bones in the stomach of this 11-year-old Labrador were an incidental finding and were fully digested 24 hours later.
them to cast a larger shadow than in left lateral recumbency. Oblique views may produce an apparent rounding of the caudoventral edge. The liver appears larger in young dogs than in old ones.

The area of the falciform ligament appears larger on expiration than on inspiration. In the cat a distended gallbladder may protrude, simulating hepatomegaly. In obese cats, fat in the falciform ligament may displace the liver dorsally (Figure 2-7, A and B).

**Ultrasoundography**

The animal is placed in dorsal recumbency for ultrasonography. If the patient is placed in lateral recumbency, both left and right recumbencies are used. For large dogs, the standing position may be used. Hepatic ultrasonography requires the cranial abdomen and occasionally the intercostal region to be clipped and prepared. The transducer is placed on the midline at the xiphoid cartilage, and a longitudinal or sagittal image is obtained by aligning the transducer plane parallel to the long axis of the animal and tilting the transducer in a cranial direction. Angling the transducer plane to the right or left sweeps the beam through the liver. Turning the transducer 90 degrees permits a transverse section. The entire liver is examined by angling the transducer steeply from a craniodorsal direction to a cranioventral one. Gas in the stomach may interfere with the examination. In large dogs with a deep-chested configuration, the liver lies more cranially. Interposition of the lung and stomach may give the impression of reduced liver size in such dogs. Small dogs or dogs with gas in the stomach may require an intercostal approach. This latter approach is also useful when specific areas of the liver are being examined and for fine-needle aspiration or biopsy. Moving the animal to displace the gas may be helpful, particularly if an intercostal approach is uninformative.

The hepatic tissue is loosely granular, with an even echotexture and echogenicity. The portal vessels are identified by their bright hyperechoic walls. Hepatic vessels are seen as anechoic linear and circular areas scattered throughout the liver. The hepatic arteries and bile ducts are not usually identified. The cranial border of the liver is identified as a hyperechoic curving border that represents the interface between the lungs and the diaphragm. Liver margins should be sharp and well defined. The relative echogenicity of the liver to adjacent and presumably normal organs should be compared to establish whether any marked abnormalities are present. The liver is hypoechoic compared with the spleen and equal to, or more echoic than, the kidney cortex. However, more than one organ may be abnormal, so comparative observations should be made with caution. The gallbladder is seen as a large pear-shaped anechoic structure on the right side of the liver. Sometimes granular sediment is present, particularly in fasting animals. Various artifacts may be associated with the gallbladder: acoustic enhancement, side-lobe artifact, and edge shadowing (see Chapter 1, pp. 17 and 19).

The caudal vena cava is identified in the midhepatic region traversing the diaphragm (Figure 2-7, G and H). The stomach is seen lying caudal to the liver. Gastric gas is identified as a hyperechoic region undergoing peristalsis within the stomach. The pylorus may be identified as a vaguely circular structure in the right ventral abdomen. The falciform fat that lies ventral to the liver may interfere with the liver examination. It has a variable echogenicity and a linear woven texture. In obese animals, image quality may be less than ideal. Ultrasonographic criteria for hepatic size are not reliable in inexperienced hands (Figure 2-7, C to G).

**Abnormalities**

**Enlargement (Hepatomegaly).** Enlargement of the liver may be the result of cardiac incompetence (passive congestion), Cushing’s syndrome (hyperadrenocorticism), diabetes mellitus, primary or secondary neoplasia, inflammation, abscess or cyst formation, hyperplasia, infiltrative diseases such as lipidosis or amyloidosis, or engorgement with bile.

**Radiologic Signs**

1. Generalized enlargement is associated with rounding of the caudoventral edge, particularly that of the left lateral lobe on the lateral view.
2. There is a visible increase in size. The caudal liver edge projects farther beyond the costal arch than usual.
3. Displacement of structures related to the liver is seen.
4. The stomach is displaced caudally and dorsally on the lateral view and caudally and more often to the left on the ventrodorsal view. The cranial duodenal flexure, right kidney, stomach, and transverse colon are displaced caudally. The diaphragm may be displaced cranially and may show reduced excursion on fluoroscopy (Figure 2-8, A to F).

Localized masses within the liver, depending on their size and location, can cause a variety of displacements of adjacent organs. In general, masses in the right side of the liver tend to displace the stomach and duodenum to the left and dorsally, and left-sided masses tend to displace the stomach and spleen to the right and dorsally. A mass originating in the right side of the liver can displace the tail of the spleen caudally. A mass originating in the caudate lobe of the liver can displace the right kidney caudally. Hepatic cysts may be mistaken for hepatic neoplasia because they may cause severe, focal hepatic enlargement (Figures 2-9 and 2-10, O). Liver masses can displace the small intestine caudally.

Discrete or diffuse mineral opacities are occasionally seen in the liver. They may be associated with neoplasia, granulomatous diseases, or parasites. Dystrophic calcification may be of no clinical significance (see Figure 6-1, E).

**Ultrasonography.** On ultrasonography the liver will appear enlarged with smooth margins. In patients with generalized hepatomegaly, the ventral aspect of the liver extends further caudally than is normal and makes the sonographic window for evaluation of the liver much larger. The liver may extend caudally as far as the umbilicus, so that if the probe is placed on the skin midway between the xiphoid and the umbilicus,
Figure 2-8  A, Enlargement of the liver. The liver (*arrowheads and arrow*) is seen to extend well beyond the costal arch. B and C, Hepatomegaly. An 11-year-old domestic short-haired cat was suspected to have lymphosarcoma. The gastric silhouette is displaced caudally on both views by an enlarged liver. D, and E, Displacement of the stomach and duodenum by an enlarged liver. The full extent of the displacement is not obvious on the lateral view. This is a good example of the value of two views. A carcinoma of the bile duct was found at autopsy. The kidneys are displaced caudally.

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the field of view is filled with liver. Hepatic enlargement can also be assessed by examining the caudate lobe of the liver and the right kidney. If the liver size is normal, the cranial pole of the right kidney sits in the renal fossa of the caudate lobe, and the depth of the caudate lobe and kidney are approximately the same. With severe generalized hepatic enlargement, the caudate lobe appears to partially surround the right kidney. There may be a diffuse increased echogenicity and consequently poor definition of the portal vessels. Changes in echotexture and echogenicity fall broadly into the categories of diffuse or focal changes, with hyperechoic or hypoechoic features. The liver margins should be examined for changes in contour. Rounded edges are seen with hepatomegaly, and nodules may cause bulges on the margin. The presence of intraabdominal fluid outlines the liver edges, permitting small lesions to be seen. However, attribution of a histopathologic diagnosis to “typical” ultrasonographic features is not possible. Accurate diagnosis or confirmation of suspect changes or equivocal observations requires fine-needle aspirates or biopsies.

Diffuse changes can be the result of poor gain settings. A diffuse increase in echogenicity can occur as a result of generalized fatty infiltration, cirrhosis, lymphosarcoma, or steroid hepatopathy. Comparison with the echogenicity of the falciform fat may be helpful. A generalized reduction in echogenicity is associated with hepatic congestion or neoplasia (lymphoma). Diffuse parenchymal disease may be difficult to appreciate, and the appearance is not specific; fine-needle aspiration or biopsy is necessary for diagnosis.

Focal changes in the liver may be solitary or multiple. The echogenicity may vary from anechoic to hypoechoic to hyperechoic or may be mixed or complex and may have distinct or indistinct margins. Focal lesions contrast with the adjacent hepatic parenchyma. Focal lesions that can have variable echogenicity include benign nodular hyperplasia, hemorrhage, abscess, and neoplasia. Nodular hyperplasia is a benign lesion of decreased or increased echogenicity and is a common incidental finding. Focal changes may be seen with either metastatic or primary neoplastic infiltration, and they cannot be differentiated with certainty from benign lesions (Figure 2-8, I to P). Differential diagnosis should include hepatitis and cirrhosis. The so-called target sign, usually a hypoechoic rim surrounding a hyperechoic center, is produced by variations in tissue texture. It is the most consistent, but not a definitive, sign of neoplasia. The
Metastatic lesions in the liver have variable sonographic presentations, and not all parenchymal changes in the liver are pathologic. Fine-needle aspirates or biopsy is required to make a definitive diagnosis.

I. Intraabdominal fluid (F) surrounds a bulbous protrusion (arrows) of a liver lobe (L). The hepatic margins are rounded. Poor skin contact has caused a reverberation artifact on the right corner of the image. J. A 6-year-old Retriever with ascites. Intraabdominal fluid (f) outlines a neoplastic hypoechoic nodule (arrows) at the tip of the liver lobe (l). S, Spleen; g, gallbladder. K. This is a paracostal view from the right side of the abdomen of a 10-year-old German Shepherd with ascites. A discrete circular mass (arrows) occupies the tip of the liver margin. This was a metastasis from a splenic hemangiosarcoma. The gallbladder (g) lies adjacent to the neoplasm. m, Mass; i, intestine; l, liver; f, fluid. L. A midline sagittal sonogram of the cranial abdomen in this dog shows multiple masses. Some are hypoechoic and hyperechoic (medium arrows). Others have a central hyperechoic region (short arrow) typical of a so-called target sign within the liver. These are multiple metastases. M. Hypoechoic metastatic masses of various sizes (arrows) are seen scattered throughout the liver. N. This lacy, hypoechoic pattern (arrows) is sometimes associated with metastatic disease. In this case it was caused by lymphoma.

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diagnosis of benign versus malignant neoplastic disease, or their differentiation from other focal lesions, requires fine-needle aspirate for cytologic evaluation or tissue core biopsy for histopathologic analysis. Fine-needle aspiration by ultrasonography permits the specific sampling of liver tissue and sequential examination of lesions for evaluation of treatment regimens (Figure 2-8, Q and R).

**Hepatic cysts** are usually anechoic, often congenital, and generally an incidental finding. Some cats with polycystic kidney disease may also have hepatic cysts. These may be single or multiple and are variable in size. The contents are usually anechoic, and the capsule is thin and cannot be distinguished from the liver parenchyma. Single large cysts can result in moderate or severe focal hepatic enlargement. Distal acoustic enhancement is a feature (see Figure 2-10, O).

**Hepatic abscessation** is an uncommon finding, and the lesion will vary in echogenicity depending on its stage of development. If gas is present, hyperechoic flocules may be seen oscillating in the lesion. Posterior distal acoustic enhancement is not usually a feature. The thickened abscess wall is usually ill defined and irregular. Occasionally it has a target appearance.

Distention of the hepatic veins may be seen with hepatic venous congestion such as occurs in right-sided cardiac failure. The distended anechoic vessels are seen extending peripherally into the hepatic tissues (Figure 2-8, G and H). The main vessels are seen to drain into the caudal vena cava in the craniodorsal hilar region. This junction often looks like a rabbit’s ears. Focal hemorrhage in the liver parenchyma, when fresh, is usually echogenic and gradually changes to a hypoechoic area as the lesion regresses.

Abdominal **arteriovenous fistulas** have been described in dogs. There may be associated ascites. The fistulas are seen as large, anechoic, tortuous vessels. Doppler ultrasound is required to differentiate these from portosystemic shunts.
**Reduced Liver Size.** The two main causes of reduced liver size are cirrhosis and portal vascular anomalies, congenital or acquired. A cirrhotic liver is reduced in size because of scar formation. Reduced liver size is often more difficult to appreciate on plain radiographs than is enlarged liver size. Radiologic signs associated with reduced liver size include cranial displacement of the stomach and a reduced distance between the stomach and the diaphragm. On the ventrodorsal view the cranial duodenal flexure, the transverse colon, and the right kidney will be more cranially placed than usual. Dogs with a deep, narrow thorax sometimes appear to have a small liver (Figure 2-9, A and D).

**Ultrasonography.** A cirrhotic liver shows a diffuse increase in the echogenic pattern and irregular margins (Figure 2-9, B and C).

**Portal Vein Anomalies.** Portal systemic shunts may be congenital or acquired. Congenital shunts are the result of persistent fetal connections between vessels such as between the portal vascular system and the caudal vena cava or azygous veins. They may be intrahepatic or extrahepatic. Acquired shunts develop as a result of chronic hepatic disorders that cause portal hypertension. A combination of congenital and acquired shunts is rare. Shunts are associated with a wide variety of clinical signs, including failure to thrive, central nervous system involvement (hepatomegaly), vomiting, diarrhea, and urate urolithiasis. Most affected animals are younger than 1 year, although older dogs are sometimes affected. Intrahepatic shunts are more common in large dog breeds, and extrahepatic shunts are more common in small dog breeds and cats. A reduced liver size is seen particularly in small breeds with extrahepatic portosystemic shunts. Renomegaly and crystalluria are often seen. A definitive diagnosis can be made by a contrast study (mesenteric portography). Any of the intravenous contrast agents is suitable. Iohexol or iopamidol could be used. Contrast medium, containing at least 300 mg iodine/mL, at a dose rate of 1 mL/kg body weight, is injected into a jejunal vein. If this is not possible, the injection may be made into a splenic vein or into the splenic pulp close to the hilus (operative splenoportography).

Two or three lateral radiographs are made after completion of the injection. Lateral and ventrodorsal studies are required to identify which part of the liver is affected. Therefore two separate injections are necessary.

The contrast medium should be distributed via the portal vein and the intrahepatic portal vein branches. After traversing the liver, contrast medium enters the hepatic veins and passes into the caudal vena cava. Splenic injections will fail to demonstrate shunts caudal to the spleen. Congenital shunts cause the blood to bypass the liver and enter the systemic circulation through the caudal vena cava or the azygous vein. Intrahepatic shunts are usually seen cranial to the thirteenth thoracic vertebra and extrahepatic shunts caudal to this point. Acquired shunts tend to be multiple and may develop as a result of increased resistance to portal vein flow across the liver (Figure 2-10, A and B1).

**Ultrasonography.** Ultrasound examination of portosystemic shunts is often difficult because of an associated small liver size and gastric gas. The portal vessels in the hepatic parenchyma are poorly defined, and the hepatic tissue may be marginally hyperechoic. Extrahepatic shunts are difficult to identify ultrasonographically (Figure 2-10, B2). If the shunt is intrahepatic, it may be identified between the portal vein and the caudal vena cava. Doppler ultrasonography is useful to establish directional flow. Various positional and transducer planes may be required. General anesthesia with positive pressure ventilation displaces the liver caudally and distends the veins, making the examination easier. However, such animals are particularly poor anesthetic risks (Figure 2-10, C).

**Scintigraphy.** Portal scintigraphy is a reliable method of demonstrating portosystemic shunts. This procedure is usually performed in specialist institutions or referral practices with suitable facilities. It is ideal for identifying portosystemic shunts but not the vessels involved. Technetium-99m pertechnetate (99mTc) in solution is introduced into the colon. Approximately 15% is absorbed into the mesenteric venous system and from there is transported to the portal vein and the liver. In cases of portosystemic shunt, the material bypasses the liver and reaches the heart first. The severity of the shunt can be quantified mathematically. To identify individual vessels, ultrasonography or intravenous contrast studies are required.

**Transsplenic Nuclear Portogram.** Transsplenic nuclear portogram is the currently preferred technique in the diagnosis of portosystemic vascular anomalies that are not diagnosed on ultrasound. The technique is more consistent than rectal portal scintigraphy. The radiopharmaceutical used is a hepatobiliary imaging agent such as mebrofenin or disofenin labeled with 99mTc. These agents are almost completely cleared from the bloodstream on the first pass through the liver. The patient is positioned in lateral recumbency on a table above the gamma camera. Chemical restraint is usually required to avoid inadvertent intraperitoneal injection. With ultrasound guidance, a needle is placed in the splenic parenchyma; after the computer program that acquires the images is started, the radiopharmaceutical is injected. Dynamic images at 1 frame/sec are acquired for 2 to 3 minutes. In normal patients, there is rapid transit of the radiopharmaceutical to the liver and uniform uptake within the liver. Minimal radiopharmaceutical is seen in the heart, lungs, and systemic circulation. In patients with a macroscopic portosystemic shunt, the radiopharmaceutical is detected in the heart and lungs at the same time as or slightly before the liver. Hepatic uptake appears delayed, and there is persistence of the radiopharmaceutical in the vascular system (blood pool) (Figure 2-10, P to W).

**Intrahepatic Gas.** Gas is rarely seen within the liver. It may appear associated with gastric dilation and volvulus. It may be a consequence of air embolism and, when seen, it resembles air bronchograms (see Chapter 3, p. 225).
Figure 2-9  A, A radiograph of this 13-year-old Jack Russell Terrier shows the liver to be well within the costal arch. The gastric axis is displaced cranially. Diagnosis: microhepatica (microhepatia). B, This 5-year-old Retriever has a small nodular liver (l and arrows) surrounded by fluid (f). Diagnosis: cirrhosis. C, Sagittal midline sonogram. A large quantity of fluid (F) is seen in the abdomen separating the small cirrhotic liver (L) from the diaphragm (D). The hypoechoic gallbladder (G) is visible between the liver lobes. Cr, Cranial. D, Microhepatica (microhepatia) in a dog. The distal part of the gastric body and pyloric antrum are displaced cranially. The gastric axis is oriented more cranially than normal. Falciform fat is visible between the liver and the stomach, outlining the caudal border of the liver. The distance between the diaphragm and the stomach is reduced. These findings indicate that the liver is smaller than normal. There were no signs of hepatic disease or hepatic insufficiency in this patient. E, This dog had hyperadrenocorticism. The liver (long arrows) and spleen (short arrows) are separated by fat (arrowheads). The liver is enlarged and is hyperechoic as it is the same echogenicity as the spleen. The liver is isoechoic with the spleen.
Focal gas may be associated with abscessation or emphysematous cholecystitis (Figure 2-10, Z).

THE GALLBLADDER
The gallbladder is a saccular structure that collects bile from the liver and discharges it into the duodenum. Approximately 5% of cats have bilobed or duplicated gallbladders. Cholecystitis is an inflammation of the gallbladder that is rare in dogs and cats. Cholelithiasis (gallstones) may or may not be present. They may be present and not visible (radiolucent) (Figure 2-10, D1, J, and K).

Ultrasonography
The gallbladder size on ultrasonography varies depending on whether the animal has recently eaten. In cats the gallbladder may occasionally be seen as a bilobed structure (Figure 2-10, D2). Thickening of the wall of the gallbladder is difficult to appreciate. Normal wall thickness is of the order of 1 to 2 mm. Cholecystitis or neoplasia may cause thickening of the wall. An echolucent halo around the gallbladder is a sign of cholecystitis with peripheral edema. The presence of free intraabdominal fluid can mimic this sign.

Cholangiohepatitis. Cholangiohepatitis is an inflammatory condition of the biliary tract that sometimes extends to the liver. It is most commonly seen in cats and may be acute or chronic. Ultrasonography is useful in assessing the condition of the liver and biliary tree. The gallbladder is usually distended with variable enlargement of the bile ducts in the hepatic tissue. Mucosal hyperplasia is sometimes seen as an incidental finding in older dogs (Figure 2-10, F and G).

Choleliths. Choleliths produce a granular or focal hyperechoic area, which may or may not cast an acoustic shadow depending on whether the gallstones are mineralized. They can be an incidental finding. Gallbladder enlargement is sometimes seen associated with obstruction of the common hepatic bile duct. This condition may be caused by bile duct neoplasm, cholelithiasis, or pancreatic disease. The gallbladder assumes a tortuous comma shape and may or may not show sludge in the lumen. Subsequently distention of the intrahepatic ducts becomes visible in the area of the hilus (porta hepatis). The ducts have anechoic walls. Artifacts caused by reverberation, or slice thickness, can cause aberrant echoes. Changing the transducer angle will differentiate an artifact from a lesion (Figure 2-10, E, H to N).

Mucoceles. Gallbladder mucoceles are accumulations of inspissated bile within the gallbladder. The sonographic appearance of mucoceles is variable. They may appear as formed echogenic debris, with no apparent internal structure, or have an appearance that has been described as stellate or kiwi fruit–like with radiating linear bands. The gallbladder wall is thickened and hypoechoic. Mucoceles should be distinguished from echogenic gallbladder debris, which is a common finding and almost always of no clinical significance. The appearance of the gallbladder mucocele will not change when the patient is repositioned. Debris is gravity dependent and will change position and shape. Gallbladder mucoceles are often an incidental finding in patients evaluated for other clinical problems. In these patients conservative medical management may result in resolution of the mucocele. Serial ultrasound examinations at 4- to 6-week intervals are helpful in assessing resolution. Mucoceles can cause local peritonitis and rupture of the gallbladder. There is sonographic evidence of

Figure 2-10 A. The five types of congenital portal vein anomalies found in dogs. In addition, the normal fetal (f) and adult (a) portal systems are illustrated. In the fetus, the umbilical vein (u) perfuses the liver, but most of its volume is diverted through the ductus venosus (d) to the fetal heart. Soon after birth, the umbilical vein and ductus venosus atrophy. Portal vein blood (p) then perfuses hepatic sinusoids completely, being collected by the hepatic veins. The abnormal portal systemic shunts are (1) patent ductus venosus (d) with or without a hypoplastic portal system; (2) portal vein atresia, associated with the development of multiple portoportal or portosystemic anastomoses; (3) major solitary portoportal, or portoportal caval anastomosis; (4) isolated, major portal azygous shunt; and (5) portal azygous shunt with discontinuation of the prerenal segment of the caudal vena cava. (A, From Suter PF: Portal vein anomalies in the dog: their angiographic diagnosis. J Am Vet Radiol Soc 16:89, 1975.)

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local peritonitis, such as a small volume of fluid in the right cranial abdominal quadrant and increased echogenicity of the fat adjacent to the gallbladder. These patients are surgical emergencies (Figure 2-10, Y).

**Emphysema.** Emphysema of the gallbladder has been described in the dog in association with diabetes mellitus, but it can occur with no apparent predisposing cause. There may be hepatomegaly. Gallbladder gas appears as irregularly marginated radiolucent areas within the right ventral part of the liver cranial to the pylorus (Figure 2-10, Z1 to Z4).

**THE SPLEEN**

**Anatomy**
The spleen is situated in the left cranial abdomen, approximately parallel to the greater curvature of the stomach. Its head is attached to the stomach by the gastrosplenic ligament and lies adjacent to the gastric fundus, the cranial pole of the left kidney, and the left body wall. The rest of the organ, the body and tail, is freely movable. The spleen is triangular in cross-section. It is related to the greater curvature of the stomach and the left kidney proximally; at its middle it is related to the colon, and distally it is related to the small intestine.

**Radiography**
The spleen is usually seen on plain radiographs of the abdomen made in right lateral recumbency. It is well visualized after intravascular injection of contrast medium.

**Normal Appearance**
On a ventrodorsal view of the abdomen, the spleen appears as a triangular soft tissue opacity on the left side, caudal and lateral to the stomach and cranialateral to the left kidney. In right lateral recumbency, it is seen...
as a rounded, oval, or triangular structure in the ventral abdomen, just caudal to the liver, from which it occasionally cannot be clearly distinguished. The dorsal extremity of the spleen is occasionally seen on a lateral view as soft tissue opacity caudal to the stomach. In left lateral recumbency the spleen may or may not be seen; because of its mobility, it may be obscured by the small intestine. The spleen is greatly increased in size after phenothiazine tranquilization or barbiturate anesthesia. German Shepherds often have large spleens. The spleen is not usually seen on lateral views of the abdomen in the cat but may be seen in the left flank region on the ventrodorsal view. Splenic size in the dog is variable, and because specific criteria for splenomegaly have not been defined, the clinical significance of splenic enlargement is difficult to evaluate. The spleen is much smaller in the cat, varies little in size, and lies completely on the left side of the abdomen (see Figure 2-7, A and B).

Ultrasonography

On ultrasonography the spleen has a dense, homogeneous, granular, speckled echotexture and is more echogenic than the liver and kidney. It occasionally may be necessary to image through the left twelfth intercostal space to show the head of the spleen. From a midline sagittal position, the transducer is angled to the left side of the abdomen. The spleen lies just caudal to the liver and lateral to the stomach. It should be seen in the near field as a horizontal band with the hyperechoic gastric gas beyond it. It has a hyperechoic capsular margin. The length of the spleen can be examined by sliding the transducer along the left abdominal wall; the small intestine lies medial to it. The body often extends across the abdominal cavity and extends caudally to the bladder. The margins should be sharp and well defined. Anechoic splenic veins are scattered sparsely through the splenic tissue (Figure 2-11, A).

Abnormalities

Enlargement (Splenomegaly). Enlargement of the spleen may be attributable to a variety of causes: neoplasia, portal hypertension, hyperplasia in animals with anemia or infection, myeloproliferative disease, toxemia, hematoma, abscessation, barbiturate anesthesia, phenothiazine tranquillization, and torsion. The direction of displacement of adjacent organs depends on the degree of enlargement of the spleen and whether the entire organ is involved. Gross enlargement of the spleen or masses involving its proximal portion displace the stomach cranially and the small intestine caudally, dorsally, and to the right.

Figure 2-10, cont'd C1, Intrahepatic portosystemic shunt in a dog. This is an oblique ultrasound image of the right side of the liver. A large-diameter tortuous vessel (shunt) connects the caudal vena cava (CVC) to the portal vein (PV). C2, Intrahepatic portosystemic shunt in a dog. This is an oblique image of the right liver of a dog. There is a large-caliber, slightly tortuous vessel (asterisk) connecting the portal vein (PV, small arrow) to the caudal vena cava (CVC, large arrow). C3, Color flow Doppler shows turbulent flow, evidenced by a mosaic pattern, within the shunt vessel (arrow). PV, Portal vein; CVC, caudal vena cava. (See Color Plate 2-10, C3.)

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or left. Large splenic masses displace the colon and cecum dorsally. Enlargement of the body or tail of the spleen is the most common cause of a ventral midabdominal mass. Masses in the head of the spleen are less common. A splenic mass or splenic enlargement and the presence of hemoperitoneum are indications for splenic ultrasonography. Mineralization of the spleen is occasionally seen (Figure 2-11, B, C1 to F).

Hematoma

Ultrasonography. Hemorrhagic areas may be identified associated with splenic neoplastic disease, trauma, or clotting disorders or as a spontaneous event. Areas of hemorrhage may appear anechoic. The hematoma appearance is highly variable and depends on its stage of development, and it may be the result of multiple serial hemorrhages. Initially it is hyperechoic; subsequently, when regressing in size, it becomes hypoechoic. As the clot retracts, fluid is seen as anechoic areas surrounding echogenic material (Figure 2-11, J). Acoustic shadowing may be seen associated with metastatic or dystrophic calcification (Figure 2-11, C).

Benign Splenic Lesions. Nodules and masses are frequently encountered when scanning the spleen. There are many benign causes, including hematoma, dystrophic mineralization, lymphoid hyperplasia, extramedullary hematopoiesis, hemosiderin plaques, and myelolipomas. These lesions are most commonly mixed echoic or hyperechoic (Figure 2-11, C1 and M).

Neoplasia. Several forms of neoplasia may affect the spleen, including leukemia, lymphosarcoma, hemangioma, hemangiosarcoma, fibrosarcoma, and leiomyosarcoma. Feline mastocytosis results in gross enlargement of the spleen. Lymphoid hyperplasia is seen commonly in old dogs and can produce radiographically visible nodules and masses (Figure 2-11, C1). Lymphoid hyperplasia is thought to precede benign splenic hematomas. Discrete areas of enlargement within the spleen may result from primary or metastatic neoplasia (see Figure 2-2, A to C, and Figure 2-11, D to F). Splenic enlargement in cats is usually caused by neoplastic disease.

Ultrasonography. The splenic tail in apparently normal dogs may be found just cranial to the bladder. Swollen, rounded margins are abnormal. Causes may include anesthesia, neoplasia, torsion, and chronic hemolytic anemia. Portal venous congestion as a result of hepatic disease may cause splenomegaly, but differentiation from neoplastic disease is difficult. Obstruction caused by a portal vein abnormality may cause splenomegaly. Fine-needle aspirates of the spleen are sometimes nonconfirmatory of a specific cause.
Focal neoplastic disease may be seen as mixed or hypoechoic areas with or without septa. Intraabdominal fluid such as blood may be present, particularly with hemangiosarcoma. Differentiation between hematomas or neoplasms such as hemangioma or hemangiosarcoma is not possible. The splenic margin may be disrupted by the lesion if it is subcapsular in location. Large masses distort the splenic shape. Diffuse infiltrative disease may be subtle and therefore not appreciated ultrasonographically. Lymphosarcoma may cause no visible changes, a generalized decrease in echogenicity, focal hypoechoic areas with poor border definition, or nodules or masses. Comparison of the echogenicity with the adjacent liver and kidney may be helpful. It is important to check other organs for metastatic disease if splenic neoplasia is suspected (see Figures 2-2, F, and 2-11, G to I and K).

Figure 2-10, cont'd E, The discrete hyperechoic structure (arrow) casting a marked acoustic shadow within the liver (L) is a cholelith. It was an incidental finding. F, This 13-year-old dog presented with a history of severe anorexia and jaundice for 2 weeks. The gallbladder (arrowhead) is distended with echogenic material that swirled and settled with the movement of the animal. Diagnosis: ascending cholangiohepatitis. G, This 12-year-old Terrier had cranial abdominal pain and vomiting. A midline sagittal sonogram was performed. A discrete hypoechoic mass (arrow) is identified in a fixed location attached to the wall of the gallbladder (g). It was present on several views and therefore is not an artifact. It probably represents cystic hyperplasia and is of no clinical significance. The animal had pancreatitis. H and I, Sonograms of the liver (l). H, The gallbladder (g) is enlarged. Several anechoic pools of fluid represent the markedly distended bile ducts (d) in cross-section. I, Further distally, a bile duct is seen in longitudinal section to be at least 3 cm in diameter (arrows). The common bile duct (CBD) courses caudally and is lost under the acoustic shadow of the duodenum (DUO). Diagnosis: bile duct obstruction (cranial is to the right in H).
Figure 2-10, cont’d J to L, Ductal mineralized choleliths in a dog. J and K, Lateral and ventrodorsal radiographs show multiple small, irregularly shaped, mineral opacity choleliths within the liver. These are arranged in a branching linear pattern, predominantly located in the right half of the liver. The stomach is moderately dilated with gas because the patient had aerophagia and tachypnea as a result of abdominal pain. Serosal detail in the abdomen is reduced because of fluid within the peritoneal cavity. The fluid accumulation was caused by peritonitis secondary to gallbladder rupture, which was unrelated to the ductal choleliths. L, Multiple small hyperechoic structures are arranged in a branching linear fashion within the liver. There is partial acoustic shadowing seen as the dark streaks deep to the choleliths because they are relatively small. The appearance and location are characteristic of choleliths within intrahepatic ducts. M, Cholelith in a cat. This is a sagittal ultrasound image of the cranial abdomen of a cat, just to the right of the midline. A curved hyperechoic structure (asterisk) is present in the gallbladder (GB), causing a complete acoustic shadow distally. Cranial to the cholelith, a small volume of normal anechoic bile is present in the lumen of the gallbladder. N, Right paracostal sonogram of the liver of a Poodle that was vomiting and had cranial abdominal pain. The gallbladder (g) is enlarged, and a section of the common bile duct (c) is seen lying distally. It is enlarged. The arrow indicates gas in the stomach, which precluded following the bile duct further distally. Diagnosis: bile duct obstruction caused by pancreatitis. O, A 13-year-old Labrador shows an anechoic, partially septated cavity (c) in the liver just caudal to the diaphragm. The gallbladder (g), seen in the near field, is compressed by the mass. Diagnosis: hepatic cyst.
Torsion. When torsion occurs, the spleen has a C shape and appears as a mass in the ventral abdomen, to either the right or left side of the midline. Associated gastric and duodenal distention may or may not be present. The torsion provokes an outpouring of peritoneal fluid, which progressively masks the shadow of the enlarged spleen. It may be associated with torsion of the stomach.

Ultrasonography. The spleen is enlarged with a diffuse, hypoechoic, lacelike, loosely woven appearance. Echogenic thrombi may be present within the splenic veins, and there is absence of venous flow on color Doppler studies (Figure 2-11, L).

Splenic Vein Thrombosis. Splenic vein thrombosis may be recognized on ultrasound in patients with severe abdominal or systemic inflammatory disease. This results in a hypercoagulable state. Normal splenic venous blood flow can be seen on B-mode images as faint flickering within the venous lumen. Color flow Doppler evaluation of the spleen shows relatively uniform low-speed flow in normal splenic veins. It also shows arterial flow, which is not visible on B-mode images. Splenic vein thrombi are usually echogenic and may be seen on B-mode images. Color flow Doppler evaluation of thrombi usually reveals some flow at the periphery of the vessels around the thrombi rather than complete occlusion. Arterial flow is still present.

Acute splenic infarcts are occasional findings in patients with severe systemic illness showing a hypercoagulable state or coagulopathies such as disseminated intravascular coagulation (DIC). The infarct appears hypoechoic compared with normal splenic tissue and results in mild to moderate bulging of the splenic capsule. With color flow Doppler evaluation, no evidence of venous or arterial flow is seen in the affected portion of the spleen. Acute splenic infarcts may resolve within 2 to 3 days. The infarcts are usually not clinically significant but reflect the presence of severe systemic illness.

Figure 2-10, cont’d P to S, Normal transsplenic portal scintigraphy in a dog. Images of the abdomen and thorax are obtained for approximately 1 minute after injection with a radiotracer (radiopharmaceutical). If the portal circulation is normal, the radiotracer is delivered to the liver by the portal vein and passes through the hepatic sinusoids to the caudal vena cava and then to the heart and lungs. If there is a shunt between the portal vein and the systemic venous circulation, the radiotracer bypasses the liver and reaches the heart and lungs first. With ultrasound guidance, a needle was placed in the splenic parenchyma, and a radiopharmaceutical (technetium-99m mebrofenin) was injected. This is a hepatobiliary imaging agent, and there is almost complete clearance of the radiotracer from the circulation on the first pass through the liver as long as liver function is normal. P, On this initial image, the intense focus of radiotracer activity represents the syringe (on the extreme left) and the bolus injected into the spleen. Radiotracer is also seen in the portal vein (PV), coursing dorsally from the site of injection. Q and R, On these two sequential images there is uniform uptake of the radiotracer within the liver. S, The fourth image shows faint tracer accumulation in the heart (arrow) and lungs.

Continued
Figure 2-10, cont’d T to W, Portosystemic shunt in a dog. In ultrasound-guided portal scintigraphy, a needle is placed in the splenic parenchyma and a radiotracer (radiopharmaceutical) injected. T, In this series, the hyperintense focus in the first frame is radiotracer within the syringe (arrow). U, In the next frame, the radiotracer has been injected and partly outlines the portal vein (arrow). V, In this frame, the portal vein is outlined by the radiotracer, which is also seen within the heart (H), but no hepatic uptake is visible. W, On the next frame there is uniform distribution of the radiotracer to the heart and lungs (H and arrows). The radiotracer completely bypasses the liver, indicating a portosystemic shunt. X, This midline cranioventral sagittal sonogram shows the liver (left long arrow) and gallbladder (arrowhead). Within the gallbladder, several structures (medium arrow) project from the mucosal surface. They remained fixed when the animal was moved. These are small polyps. An acoustic enhancement artifact is also evident (short arrows). Y, Gallbladder mucocele in a dog. This is a slightly oblique, sagittal plane image obtained in the right cranial abdomen. The gallbladder (GB) is filled with echogenic bile, which is inspissated and has a characteristic radiating linear pattern, sometimes referred to as stellate or Kiwi fruit-like. A thin band of hyperechoic fat (arrows) is noted adjacent to the gallbladder on the right side of the image. This suggests local peritonitis.
Atrophy. Atrophy of the spleen is sometimes seen in old animals and is difficult to evaluate radiologically.

THE PANCREAS
Anatomy
The pancreas is a gland shaped somewhat like an inverted V. It lies adjacent to the greater curvature of the stomach, duodenum, and ascending and transverse colon. It consists of a body and two lobes.

The right lobe lies in the mesoduodenum along the right flank extending from about the ninth intercostal space to the duodenal loop at approximately the level of the fourth lumbar vertebra. It is closely applied to the descending duodenum. It is related to the ventral surface of the right kidney, the caudate lobe of the liver, the ileum, the cecum, and the ascending colon.

The left lobe is within the greater omentum. It is narrower and shorter than the right lobe. It is related to the caudate process of the liver, the portal vein, the caudal vena cava, and the aorta. Caudally it reaches the cranial pole of the left kidney and the center of the spleen. The body joins the two pancreatic lobes. Cranially it is related to the pylorus. The portal vein crosses it dorsally.
Figure 2-11. **A**, A normal spleen. The spleen (S) has a dense granular echotexture that is hyperechoic. The linear structure lying dorsal to the spleen is a loop of intestine in longitudinal section (I). **B** and **C**, Splenic mineralization in an 11-year-old Bassett Hound that presented with anorexia. **B**, The lateral radiograph shows a large elliptical mineralized mass in the ventral abdomen. **C**, This is a midline sagittal ultrasonogram of the dog’s abdomen. A hyperechoic arc represents the ventral margin of a mineralized mass within the spleen. Acoustic shadowing is evident in the far field. Examination of the dog 1 year later revealed no change. **m**, Mass; **S**, spleen. **C1**, Splenic nodule in a dog. The head of the spleen is visible in the left cranial abdomen, caudal and lateral to the fundus of the stomach and cranial and lateral to the left kidney. A well-defined, circular focal enlargement (arrows) of the spleen is present. A diagnosis of a benign lymphoid hyperplasia was made after ultrasound-guided fine-needle aspiration. **D1**, A large discrete splenic mass in the midabdomen.
Figure 2-11, cont’d  D2, This large splenic mass simulates ascites. The dorsal displacement of the stomach and caudal displacement of the intestines indicate that there is a mass in the midventral abdomen. D3, Irregular enlargement of the spleen from metastatic adenocarcinoma. The enlarged spleen is seen on both sides of the abdomen on the ventrodorsal view. The liver is enlarged because of metastatic lesions. The primary site was not determined. E, An 8-year-old Rottweiler presented with weakness and pallor present for 24 hours. There is a large, roughly circular opacity in the midventral abdomen. Serosal detail is poor in that area. This was a ruptured spleen with associated hemorrhage. The diagnosis was splenic hemangiosarcoma. F, A large mass occupies the ventral midabdomen. Masses arising in this area usually originate from the spleen. This 10-year-old bitch presented with peripheral lymphadenopathy. The mass was a lymphosarcoma. G, This sonogram shows the splenic body with multiple patchy hypoechoic areas within it. This was a lymphosarcoma.

Continued
Figure 2-11, cont’d H, This 13-year-old female dog presented with exercise intolerance and lethargy. A mixed hypoechogenic mass (M) is seen (arrows) within the splenic body (S). It is poorly marginated with focal hypoechoic areas throughout. Diagnosis: splenic fibrosarcoma. I, This 12-year-old German Shepherd presented collapsed and had very pale mucous membranes. A multiloculated septated mass occupies the cranial abdomen. Diagnosis: hemangiosarcoma of the spleen. J, A 14-year-old Jack Russell Terrier was involved in a road traffic accident 2 weeks earlier. Blood-stained abdominal fluid was aspirated at that time. The sonogram shows a predominantly hypoechoic, well-marginated mass (M and arrows) involving the tail of the spleen (S). Diagnosis: organizing hematoma. K, Splenic lymphosarcoma. Sagittal plane sonographic image of the spleen. There are numerous small, poorly defined hypoechoic nodules throughout.

**Radiography**
The normal pancreas is not visible radiographically in the dog. In the cat the pancreas is sometimes seen in obese animals on the ventrodorsal projection medial to the spleen (Figure 2-12, A).

**Ultrasonography**
The pancreas is a difficult organ to find and evaluate, particularly in the normal dog. Gastrointestinal gas may make it difficult to find the pancreas. A 7.5-MHz or higher frequency transducer is recommended. Dorsal or left lateral recumbency is the usual position. Clipping of the cranial abdomen and right paracostal region is necessary. Imaging from the dependent side is often useful. Fasting the animal is important. Instilling fluid into the stomach or allowing the animal to drink to displace gas in the pylorus is occasionally helpful, but it may induce vomiting in clinical cases of pancreatitis and therefore would be contraindicated.

The right lobe of the pancreas is usually localized by the presence of the adjacent descending duodenum, which lies ventrally and laterally, and by identification of the pancreaticoduodenal vein, which runs parallel to the duodenum in the right pancreatic lobe. The right kidney is dorsal to the right lobe of the pancreas. The left lobe lies between the transverse colon and the stomach. With the animal in right lateral recumbency, place the transducer in a sagittal orientation to the right of midline, caudal to the costal arch, and gently depress the skin and locate the right kidney. The pancreas lies very near and ventral to the kidney. Angle the transducer laterally, and the duodenum is identified running caudally and longitudinally from the pylorus. Adjacent bowel gas may necessitate manipulation of the animal to avoid the gas.

In the dog the right limb of the pancreas is relatively larger, whereas in the cat the left limb is larger. In the cat, the left limb extends from the body of the pancreas across midline adjacent to the greater curvature.
of the stomach. The distal part of the left limb extends caudally and almost makes contact with the cranial pole of the left kidney. This part of the left limb may be visible on a ventrodorsal abdominal radiograph of an obese patient as a fingerlike soft tissue opacity structure between the stomach, spleen, and left kidney (Figure 2-12, A).

The left lobe is more difficult to locate because of the presence of gas in the adjacent stomach and transverse colon. Locate the body of the stomach and examine the area caudal to it and ventral to the kidney. With the animal in right lateral recumbency, the left lobe may be seen when imaging from the left paralumbar region. The left lobe is located caudal to the stomach, cranial to the colon, ventral to the portal vein, and adjacent to the caudomedial aspect of the spleen. It is an ill-defined hypoechoic linear entity. Blood vessels course through the substance of the gland.

In the cat, the left lobe of the pancreas is imaged from the left side, just behind the ribs, by using the spleen as an acoustic window. The right pancreatic lobe can be located where it lies between the right kidney, duodenum, and the portal vein.

The normal pancreas has a fine echotexture and is isoechoic to slightly hypoechoic to surrounding fat. The right limb of the pancreas lies along the mesenteric border of the descending duodenum and may be dorsal, dorsomedial, or medial to the descending duodenum, depending on patient position. In cross-section it appears triangular. The pancreaticoduodenal vein appears as a linear anechoic structure in the center of the pancreas, running parallel to the descending duodenum. The head of the pancreas is located between the pylorus and the portal vein. In the dog, the left limb of the pancreas lies caudal to the body of the stomach, medial to the spleen, and cranial to the left kidney. It is usually in close proximity to the common splenic vein. This part of the pancreas is usually less distinct than the right limb. The left limb of the pancreas is larger in the cat and extends caudally from the body of the stomach to almost make contact with the cranial pole of the left kidney. It is best imaged by using a dorsal plane approach, with the probe located just caudal to the last rib. The area between the body of the stomach, spleen, and cranial pole of the left kidney is searched. It is usually slightly less echogenic than surrounding fat, and the capsule may appear as thin, bright, parallel lines. The pancreatic duct may be seen as a linear structure with hyperechoic walls containing anechoic fluid (Figure 2-12, B1 to B4).

Abnormalities

Inflammation (Pancreatitis). Pancreatitis may be acute or chronic. Acute pancreatitis appears to be more common in obese, middle-age bitches. Clinical signs include vomiting, anorexia, pain in the cranial abdomen, and the adoption of a prayer-like posture. The first signs of discomfort often follow the ingestion of a fatty meal. Diarrhea, which may be bloody, is sometimes present.

Radiologic Signs

1. Pancreatitis causes an area of increased soft tissue opacity in the right cranial abdomen resulting from associated peritonitis. Normally, the right cranial abdomen is relatively more radiopaque than the left, and care is necessary in evaluating this area.
2. Swelling of the pancreas causes the duodenum to be displaced toward the right and sometimes dorsally or ventrally, with the pylorus being displaced to the left. This may give the duodenum a C-shaped appearance (Figure 2-12, C1 and C2).
3. The duodenum shows reduced peristalsis with slow passage of ingesta or barium through it. It may be dilated.
Figure 2-12  A, Normal obese cat. The fundus and body of the stomach are present in the left cranial abdomen, beneath the ribs and to the left of the spine. Fat is present in the gastric wall (black arrows), seen as a radiolucent band between the mucosa and muscularis layers. The left limb of the pancreas (white arrows) is visible as a slightly indistinct soft tissue structure adjacent to the cranialateral aspect of the kidney and partially overlapping the spleen. B1 and B2, Normal feline pancreas. B1, This sagittal scan shows the pancreas between the cursors (long arrow). It lies medial to the spleen (top arrow). The pancreatic duct (short arrow) is seen running longitudinally through the gland. B2, On the transverse sonogram, the gland (long arrow) is triangular in shape (between cursors). The colon is visible and casts an acoustic shadow (short arrow). B3 and B4, Normal canine pancreas. B3, This is a transverse image of the descending duodenum and right pancreatic limb of a dog. The duodenum is indicated by the arrowhead. The pancreas is roughly triangular in cross-section (arrows and cursors) and lies along the dorsal border of the duodenum. The pancreaticoduodenal vein is the small bean-shaped hypoechoic structure in the center of the pancreas. B4, This is a sagittal plane image obtained in the right cranial abdominal quadrant of the right pancreas and descending duodenum of a dog. The duodenum is in the near field, extending across the image. The pancreas (arrows) lies dorsal to the duodenum and is similar in echogenicity and echotexture to the adjacent fat. A short section of the capsule is seen as a thin bright line at the tips of the lower right-side arrows, running parallel to the duodenum. The pancreaticoduodenal vein is in the center of the pancreas (arrowhead).
4. The duodenal wall may be thickened, with a static gas pattern.

5. The pyloric antrum may be displaced toward the left.

6. If the left lobe of the pancreas is involved, the transverse colon will be displaced caudally.

7. Granular mottling in the region of the pancreas has been reported, as have corrugation and spasticity of the duodenal wall.

8. Hepatomegaly, resulting from fatty infiltration, is a common finding.

Figure 2-12, cont’d C1, Displacement of the pylorus and air-filled duodenum (arrows) craniolaterally by a pancreatic mass (star) in a 7-year-old Scottish Terrier. C2, The duodenum is displaced laterally and is poorly filled with barium. Serosal detail is lost in the right cranial abdomen. Diagnosis: pancreatitis causing a mass effect. D, A 7-year-old Terrier had occasional vomiting. A sagittal midline sonogram directed toward the left shows a vaguely circular, mainly hypoechoic mass (P) interposed between the liver and the spleen. The mass is surrounded by hyperechoic fat (short arrows). This was a pancreatic abscess involving the left lobe of the pancreas. Cr, Cranial. E, This dog presented with vomiting and abdominal pain. Sonographic examination of the right cranial abdomen showed the duodenum (D) in the near field. Medial to it is a predominantly hypoechoic enlarged pancreas (P) containing focal hypoechoic nodules (large white arrow). The adjacent mesenteric fat is hyperechoic. Diagnosis: necrotizing pancreatitis (same case as Figure 2-4, G).
Figure 2-12, cont'd  

F, This sagittal sonogram shows the duodenum (short arrow) crossing the image in the near field. A hypoechoic area (medium arrow) is seen on the mesenteric border of the duodenum. This is an inflamed pancreas. The adjacent peritoneal fat (long arrow) is hyperechoic, indicating peritonitis. Diagnosis: acute pancreatitis. 

G, This image shows the pancreas (long arrows) deep to the duodenum (short arrow). The pancreaticoduodenal vein (black arrow) is seen running through the gland. The tissue is swollen, and a hypoechoic area is seen within the gland at the bottom of the image. The adjacent fat is hyperechoic, indicating inflammation. Diagnosis: pancreatitis. 

H, This case shows marked enlargement of the pancreas with large hypoechoic areas (long arrows) within the gland tissue. The duodenum (short arrow) is seen in the near field. Diagnosis: pancreatic abscess. 

I, This was a 1-year-old Staffordshire Bull Terrier that had been off form for a month. The cranial abdomen was painful on palpation. The pancreas (arrows) is swollen and irregular and has a patchy echogenicity throughout. A small volume of peritoneal fluid (long arrow) surrounds the gland. The right kidney is also seen (K). Diagnosis: necrotizing pancreatitis, confirmed at surgery. 

J, This is a sagittal sonogram of the right cranial abdomen of a dog. The duodenum (long arrow) is seen in the near field. A small hypoechoic mass (medium arrows) is seen in the substance of the pancreas. This was an insulinoma. The short arrow shows the duodenal papilla.
9. There may be loss of serosal detail of the abdominal viscera well beyond the immediate area of the pancreas as a result of an associated peritonitis and effusion of fluid.

**Ultrasonography.** Changes associated with pancreatitis may be subtle, and a negative finding on ultrasonography does not rule out the presence of disease. However, ultrasound is more sensitive than radiographs. Differentiation of pancreatitis from neoplasia or localized peritonitis is difficult. With inflammation, a mixed echogenic mass, local hypoechoic areas, or nodules are seen. There may also be regional ileus with or without localized gastric or duodenal wall thickening. Fluid may be present in this area. The appearance varies with the stage of the disease. Bilary obstruction may also be present, with distention of the bile duct and gallbladder. The adjacent fat may be hyperechoic, suggesting inflammation. Pancreatic pseudocysts are fluid collections within the pancreatic tissue. They are mainly anechoic, with some cellular echogenicity within them.

Pancreatic abscess, or phlegmon, has characteristics similar to those of other abscesses. Varying amounts of cavitation, fluid, and echogenic particulate material may be seen within the abscess. It can be a sequela to pancreatitis. Patchy hyperechoic and hyperechoic areas with enlargement may be seen with pancreatic necrosis (Figure 2-12, D to I).

Pancreatic disease in the cat is more common than previously thought. Necrotizing pancreatitis as seen in the dog is rare. Chronic pancreatitis is more common, often combined with inflammatory hepatic and small-bowel disease. The disease produces no distinct sonographic changes, and the pancreas may appear normal.

**Neoplasia.** Neoplasia of the pancreas may cause it to increase in size and can produce signs similar to those associated with pancreatitis. The stomach is occasionally invaded by the spreading neoplasm, with destruction of its wall in the affected area. Masses in the pancreas tend to displace the duodenum to the right and ventrally. Abdominal carcinomatosis with intraabdominal fluid formation has been described in association with pancreatic neoplasia.

Endocrine pancreatic tumors are rare. The pancreas may be the seat of a gastrin-secreting tumor, a gastrinoma. It causes hypergastrinemia, hypersecretion of hydrochloric acid, gastric mucosal hyper trophy, and reflux esophagitis. Insulinoma is an insulin-producing tumor. Ulcers may form in the stomach and proximal duodenum. This complex is known as Zollinger-Ellison syndrome. Radiologically, there is increased prominence of the gastric rugal folds, with ulcers in the stomach wall and duodenum. The prognosis is grave.

Insulinomas are usually quite small and difficult to diagnose by imaging tests. The most common sonographic appearance is a small, well-defined, hyperechoic nodule within the pancreas. Metastasis to local lymph nodes and the liver is common. Nodal metastases may cause a mass lesion large enough to be seen on radiographs and are more readily seen with ultrasound than are primary lesions.

**Ultrasonography.** The differential diagnosis of neoplasia from pancreatitis cannot be made accurately by ultrasound alone. Serial examination may be advantageous. Ultrasound-guided fine-needle aspirates are required for a definitive diagnosis. Often a neoplasm is small and consequently easily missed. Pancreatic adenocarcinoma is rare and metastasizes to the peritoneal cavity. Islet cell tumors metastasize to the liver and local lymph nodes (Figure 2-12, J).

**THE ALIMENTARY TRACT**

The alimentary tract is composed of the esophagus, stomach, and intestines.

**THE ESOPHAGUS**

**Anatomy**

The esophagus begins at approximately the level of the middle of the first cervical vertebra and ends at the entrance to the stomach. During its course in the neck, it inclines toward the left side, and at the entrance to the thorax it lies to the left of the trachea. Within the thorax, the esophagus initially lies to the left of the trachea, but it then crosses the trachea to reach its dorsal aspect at the carina. Caudal to the carina, the esophagus lies dorsal to the tracheobronchial lymph nodes. The esophagus then courses caudally, almost in the midline, to pass through the esophageal hiatus of the diaphragm and enter the stomach dorsally. The esophageal muscle in the dog is entirely striated, whereas in the cat the caudal third of the esophagus has smooth muscle fibers.

**Radiography**

Air, fluid, food material, or a combination of these within the esophagus may outline it, at least partially. Although some esophageal abnormalities can often be detected on plain radiographs, the administration of contrast material is necessary for detailed study. Survey radiographs in the lateral and ventrodorsal positions should first be made. Because the esophagus at least partially overlies the spine in the ventrodorsal position, it is also advisable to make a ventral right-left dorsal lateral oblique radiograph. The most useful contrast agent is commercial micropulverized barium sulfate. A barium paste is useful if a special study of the mucosa is required because it adheres to the esophageal mucosa. The paste may be useful if esophagitis or neoplasia is suspected. If the esophageal study is part of a gastrointestinal series, however, the paste should not be used because it is not suitable for outlining the stomach or intestines and does not readily mix with liquid barium. If rupture of the esophagus is suspected, it is preferable to use a watersoluble contrast medium, such as a nonionic organic iodide contrast agent, instead of barium. Iopamidol or iohexol is suitable. The dose is 7 mL/kg body weight (see p. 78). Water-soluble agents do not provide visualization of the esophagus as well as barium does, but
they will be absorbed if they reach the mediastinum, whereas barium will not.

The barium suspension is given at a dosage rate of 3 to 5 mL/kg body weight through the buccal pouch (barium swallow). Radiographs are made as the last of the barium is being swallowed. If the esophagus is grossly dilated, much larger amounts of barium are required to outline its lumen fully. Additional amounts may be given if the first study is unsatisfactory. Lateral and ventrodorsal radiographs and a ventral 15-degree right dorsal-left oblique (V15R-DLeO) study are made. A barium-impregnated meal may be helpful in evaluating swallowing disorders.

The esophagus should be investigated in cases of persistent regurgitation or vomiting. If the animal has difficulty swallowing, contrast studies should be performed with care because of the danger of aspiration of the barium. However, small amounts of agents such as iopamidol, iohexol, or barium are well tolerated in animals with healthy lungs.

**Normal Appearance**

The esophagus is not usually seen on plain films of the neck or thorax; in its normal collapsed state its opacity is the same as that of the neck muscles and mediastinum. It is sometimes seen as a faint soft tissue opacity in the caudal thorax on lateral views. Air or food material within its lumen will partly outline it. Air in the esophagus is frequently associated with esophageal and sometimes gastrointestinal disorders. It is often seen in vomiting, coughing, or dyspneic animals and in animals under general anesthesia. Air in the esophagus, other than in small amounts, always warrants further investigation.

After a barium swallow, some barium lodges in the longitudinal crypts between the folds of the esophageal mucosa and appears as a series of regular parallel lines of almost equal width. The mucosal pattern is often irregular in appearance at the thoracic inlet (Figure 2-13).

In cats, the caudal third of the esophagus has transverse striations in addition to the longitudinal folds. This gives a “herringbone” appearance on barium examination (Figure 2-14).

A pouch, or regional esophageal distention, is often present at the thoracic inlet on contrast studies, especially if the animal’s neck is flexed on the radiograph. This pouch represents a normal redundancy of the esophagus to allow neck movements and should not be mistaken for a diverticulum. In young brachycephalic dogs, there may be regional dilation. Sometimes a small amount of barium is retained for a time in the cranial esophagus in the region of the larynx. This is also normal.

The lateral projection usually gives the most information because in the ventrodorsal position there is considerable superimposition of other structures, especially the spine. Oblique projections are occasionally useful. Air in the mediastinum outlines the esophagus (see Chapter 3).

The evaluation of esophageal function requires fluoroscopy. Fluoroscopically, boluses of contrast medium can be seen being propelled rather rapidly along the esophagus and into the stomach. The rate of travel of a bolus may be somewhat slowed at the entrance to the thorax and over the base of the heart. Barium mixed with food is sometimes preferable for fully evaluating esophageal motility or size.

**Ultrasonography**

The cervical esophagus may be examined from a ventral or left lateral aspect. A transverse image identifies it to the left of the trachea, which is a curved hyperechoic structure with associated acoustic shadowing. The esophagus is a well-defined, round structure with concentric layers, similar to gut, and a central hyperechoic area representing intraluminal air.
Abnormalities

Dilation (Megaesophagus, Esophageal Hypomotility).

Megaesophagus is dilation of the esophagus. It may be congenital or acquired, generalized or local (segmental). A generalized distention is more common. Congenital megaesophagus may be hereditary in cats and within certain breeds of dog such as the German Shepherd, the Labrador Retriever, the Miniature Schnauzer, and the Fox Terrier. The most common congenital condition is vascular ring anomaly, especially persistent right aortic arch. Acquired megaesophagus may be seen in a wide variety of conditions, including neuropathies and myopathies. Neuropathies include myasthenia gravis and feline dysautonomia, Addison’s disease, and diabetes mellitus. Megaesophagus is also seen in some toxic conditions such as organophosphate and herbicide poisoning. It is also seen associated with esophagitis, gastric dilation, volvulus, and hiatal hernia. It may be idiopathic.

Localized dilation may be caused by vascular ring anomalies, foreign body, stenosis, or pressure on the esophagus from an external mass. Neoplasia may result in stenosis and consequent dilation. A correlation between pylorospasm and esophageal dilation has been reported in cats. Megaesophagus is frequently associated with some degree of aspiration pneumonia.

A transitory dilation of the esophagus may occur as a result of general anesthesia or after sedation (see Figure 2-15, J). If megaesophagus is suspected, care should be taken to choose a sedative that does not affect the esophagus.

If the esophagus is dilated with air, the ventral border of the longus colli muscle is visible. The esophageal walls may be seen in the caudal thorax to converge sharply toward the hiatus. Gross dilation can easily be missed because the air-filled esophagus has the same opacity as the underlying lung fields. A dilated esophagus may simulate air within the mediastinum (pneumomediastinum), outlining some of the mediastinal structures and decreasing tracheal contrast. Any persistent obstruction or partial obstruction of the esophagus will eventually result in some degree of dilation cranial to the obstruction.

Clinical signs of megaesophagus include regurgitation of food, weight loss, and often a fetid odor from the mouth. Discomfort after feeding is common. It may be recognized at any age.

Transient esophageal dilation may occur with moderate to severe pulmonary disease. It will resolve with resolution of the pulmonary pathology.

Radiologic Signs

1. Plain radiographs of the thorax show the esophagus to be dilated with air, fluid, food material, or a mixture of these. When the esophagus is dilated with air, it drapes itself over the dorsal trachea, giving a tracheal stripe sign. The edge of the longus colli muscle is seen dorsally. The walls of the esophagus in the caudal thorax are seen to converge at the esophageal hiatus.

2. If the dilation is severe, the trachea and the heart are displaced ventrally.

3. The dilated esophagus widens the mediastinum.

4. A barium study reveals the full extent of the dilation. A large quantity of barium may be required to outline the esophagus fully. Food mixed with barium may be more useful. Barium should not be used if esophageal dilation is evident on survey.
radiographs because of the danger of aspiration pneumonia, which may be lethal.

5. Fluoroscopically, there is an absence of normal peristalsis or the peristaltic waves are weak and inefficient. The esophageal contents move with each heartbeat.

6. Standing lateral studies taken with a horizontal beam often show a fluid level within the esophagus caused by an accumulation of fluid material ventrally and air dorsally.

7. A tracheal stripe sign may be evident.

8. Concomitant pneumonia is a common finding (Figure 2-15).

**Feline Dysautonomia.** Feline dysautonomia (Key-Gaskell syndrome) is a term applied to an uncommon condition affecting the autonomic ganglia of cats that results in varying degrees of esophageal dilation or megaesophagus. Young, mature, domestic, short-haired cats are affected. The etiology is unknown, and the mortality rate is high. Common presenting signs include dysphagia, dilation of the pupils, regurgitation, vomiting, dry nose and mouth, prolapse of the third eyelid, constipation, dyspnea, and bradycardia. Radiographic findings include dilation of the stomach, impaction of the intestine, or dilation of intestinal loops with fluid or gas. On abdominal radiographs,
Figure 2-15, cont’d C and D, Megaesophagus. The trachea is depressed by a grossly dilated esophagus. Food material can be seen within the esophagus in the caudal thorax. A barium study shows the extent of the dilation. E, An 18-month-old Irish Setter. Esophageal dilation (short arrows) may be so extensive that the dorsal thorax appears hyperlucent. A focal alveolar infiltrate is present in the cranio-ventral lung (long arrow), indicating aspiration pneumonia. The stomach is dilated with air and is pushing the left crus (arrowhead) of the diaphragm cranially. This simulates free intraabdominal air. A microchip is evident at the fifth intercostal space superimposed on the cardiac silhouette.

Continued
the condition must be distinguished from intestinal obstruction. Some cats show hindlimb ataxia. Ninety percent of affected cats show some degree of segmental or generalized dilation of the esophagus.

**Stenosis/Stricture.** Esophageal stricture may result from a reflux of acidic gastric contents during general anesthesia, causing mucosal erosion or ulceration and subsequent scarring. Other causes of a stricture are mucosal damage caused by a foreign body, caustic agents, or neoplasia. Stenosis may also be a postsurgical complication. A stenosis that seriously compromises the esophageal lumen will result in dilation cranial to the stenosis. On plain radiographs, abnormal amounts of air are often seen within the esophageal lumen. Fluid or food material may be seen. A barium study will reveal the area of constriction and the extent of the associated dilation, if present. Stenosis can be missed on plain radiographs and is best demonstrated with a barium-food mixture or dynamically by fluoroscopy.

**Neoplasia.** Primary neoplasia of the esophagus is rare in the dog and cat. Osteosarcoma or fibrosarcoma may occur secondary to *Spirocerca lupi* granuloma, seen in the southern United States and the Caribbean. Squamous cell carcinoma is occasionally seen in the cat, with vomiting as a common presenting sign. Partial or complete obstruction is a possible sequel. Eccentric masses, such as those of muscular origin, may not result in dysphagia. A barium study should be undertaken to show irregularity of the outline of the esophageal mucosa or a stricture at the site of the tumor. Fluoroscopy will demonstrate associated functional abnormality (Figure 2-15, I, K, and L).

**Vascular Ring Anomalies.** Congenital anomalies of the vascular system within the thorax may result in vessels or vessel remnants forming bands that constrict the esophagus near the base of the heart. These are referred to as vascular rings. Persistent right aortic arch is the most common anomaly encountered, although double aortic arch and aberrant subclavian arteries are

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*Figure 2-15, cont’d F and G, Megaesophagus. The plain chest radiograph shows widespread infiltration of the lungs from aspiration pneumonia. The barium study shows the esophageal dilation. H, In megaesophagus the esophagus narrows sharply at the hiatus.*
occasionally seen. If the aortic arch is visible on the left side, then the possibility of one of the more uncommon aberrations should be considered. Ultrasonography, angiography, or CT would then be required for a diagnosis. A combination of vessels or vessel remnants in the neighborhood of the esophagus prevents it from expanding properly as food material passes along it. In time, the esophagus dilates cranial to the site of constriction as food material continues to accumulate.

Clinically, the problem becomes apparent shortly after weaning. Regurgitation after feeding and failure to thrive are common presenting signs. Occasionally the dilated esophagus causes a bulge in the lower cervical region. This bulge is more noticeable after feeding. Appetite is maintained. There may be coughing and dyspnea resulting from aspiration pneumonia.

Persistent right aortic arch results when the aorta develops from the right primitive arch rather than the left. The ligamentum arteriosum (ductus arteriosus), in its course between the right-sided aorta and the pulmonary artery, must then cross the esophagus. This results in the esophagus being surrounded by the aorta dorsally and to the right, the base of the heart and the pulmonary artery ventrally, and the ligamentum arteriosum dorsally and to the left. The ligamentum arteriosum then acts as a constricting band that prevents normal expansion of the esophagus. As a result, food material accumulates cranial to the point of constriction. This, in turn, results in a dilation of the esophagus cranial to the base of the heart. Caudal to the heart, the esophagus is usually normal, although vascular ring anomalies may coexist with some degree of megaesophagus. Breeds affected include the German Shepherd, the Irish Setter, and the Boston Terrier.

Radiologic Signs
1. On a lateral view, the dilated portion of the esophagus, cranial to the point of constriction,
is often outlined on plain radiographs by food material, fluid, air, or a mixture of these. It usually has a saccular appearance. If the esophagus is filled with air, a tracheal stripe sign will be evident (Figure 2-16).

2. The trachea and the heart may be displaced ventrally, and the esophagus may be draped over the trachea.

3. The dilation ends over the base of the heart, and the esophageal outline appears normal caudal to the point of constriction.

4. The dilation may extend up into the neck.

5. On a ventrodorsal radiograph the normal shadow of the aortic arch on the left side may be absent, but it may be seen on the right with a persistent right aortic arch anomaly. The trachea may be seen to the left of the midline.

6. There is often evidence of aspiration pneumonia.

7. A barium study will show the area of the esophageal dilation cranial to the base of the heart. Because of the danger of aspiration, barium should only be used if there is a doubt about the diagnosis.

**Foreign Body.** Foreign bodies may be radiolucent or radiopaque. They are most commonly seen within the thoracic esophagus between the base of the heart and the diaphragm. They are also seen at the entrance to the thorax and less commonly at other sites. In cats, the cranial esophageal sphincter is a common site of foreign body entrapment. Irregularly shaped pieces of bone, such as pieces of vertebrae, are the usual offending objects. Esophageal foreign body is encountered much more frequently in dogs than in cats.

The clinical signs vary with the degree of obstruction and the length of time it has been present. With a partial obstruction, there may be little to note except some discomfort when feeding. With acute complete obstruction, the affected animal is uneasy, and saliva is intermittently regurgitated. In the early stages appetite is maintained, but discomfort is evident after eating, and ingested food is quickly regurgitated. Later, as the appetite is lost, regurgitation ceases. Aspiration pneumonia or perforation leading to mediastinitis and pleuritis eventually results in death in most untreated cases. In occasional cases, a diverticulum may develop at the site of the obstruction. This diverticulum allows food material to pass to the stomach. Such cases may persist with intermittent clinical signs.

**Radiologic Signs**

1. A radiopaque foreign body is readily recognizable on a plain radiograph.

2. Intraluminal air, distending the esophagus, is usually visible cranial to a complete obstruction.

3. Varying amounts of fluid are seen cranial to the obstruction.

4. A radiolucent foreign body can be outlined by contrast medium, preferably a barium sulfate paste. Nonionic water-soluble contrast media are preferred if perforation is suspected.

5. An area of soft tissue opacity in the neighborhood of a foreign body or a mediastinal mass suggests perforation with resulting mediastinitis. Pneumomediastinum or pneumothorax indicates that perforation has occurred.
Figure 2-16 A and B, A vascular ring anomaly—in this case, a persistent right aortic arch. Barium shows the marked dilation of the esophagus cranial to the base of the heart and a normal configuration caudally. C, A vascular ring anomaly indicated by air and food material within the cranial thoracic esophagus. D and E, Persistent right aortic arch and segmental megaesophagus in a young dog. There is a large saclike dilation (arrows) of the esophagus in the cranial thorax. This is filled with granular food material and a moderate quantity of gas. The dilated esophagus extends ventrally to the sternum. The trachea (arrowhead) is displaced ventrally and to the right. The segmental esophageal dilation causes lateral displacement of the left cranial lung lobe. No evidence of aspiration pneumonia is seen.
6. Swallowed air or esophageal fluid occasionally outlines a foreign body.
7. If a foreign body has been present for some time, thickening of the esophageal wall may be visible.
8. Over a period of time, a diverticulum may develop at the site of the obstruction. The diverticulum can be demonstrated on a contrast study. See Figure 2-17, A to F.

**Diverticulum.** Diverticula are not common. A *traction diverticulum* results from adhesions and contraction associated with a periesophageal lesion. A *pulsion diverticulum* results from increased intraluminal pressure such as may arise with long-standing foreign body obstruction or esophageal stenosis. It should be remembered that sometimes a pouch is seen at the thoracic inlet on normal studies. The Shar-Pei breed of dog is known to have esophageal redundancy/pouch. This pouch should not be mistaken for a diverticulum. Small diverticula may have little clinical significance. Bilateral symmetric outpouching of the esophagus cranial to the diaphragm has been described. Barium is used to demonstrate a diverticulum (Figure 2-17, G and H).

**Spirocerca Sanguinolenta (Spirocerca Lupi) Infestation.** *Spirocerca sanguinolenta*, a parasite found in southern Europe, Africa, South America, the Caribbean, and rarely in the southeastern United States, invades the esophageal wall during its larval stage. It provokes a granulomatous reaction, which appears on radiographs as an area of increased opacity between the base of the heart and the diaphragm. Affected animals may have difficulty swallowing because of narrowing of the esophageal lumen. New bone formation (spondylitis) is frequently seen on the ventral aspects of the thoracic vertebrae from approximately the seventh to the tenth. Fibrosarcoma or osteosarcoma may develop from the esophageal lesion. A barium study will help determine the degree of occlusion of the esophagus. The clinical signs include regurgitation of food material, which is sometimes blood stained, and weight loss. The signs may simulate those seen with foreign body obstruction (Figure 2-17, I and J).

**Esophagitis.** Inflammation of the esophagus may result from a foreign body, trauma, gastroesophageal reflux, or chemical irritants. Infection is rarely a cause. It is difficult to make a definitive diagnosis of esophagitis radiologically. Irregularity of mucosal folds and segmental narrowing of the esophagus are sometimes noted after a barium swallow. Air is often present within the esophageal lumen. Long-standing cases show some thickening of the esophageal wall. Abnormal peristaltic contractions may be seen on fluoroscopy. The clinical signs are often vague, with dysphagia and blood stains in regurgitated material being among the more common.

**Extrinsic Compression.** Masses within the neck and thorax not associated with the esophagus (e.g., enlarged thyroid, thymus, lymph nodes) may cause pressure on it. Such masses are commonly seen on plain radiographs. Air is often presented cranial to

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*Figure 2-17 A and B, A bone in the caudal third of the esophagus. Abnormalities of the esophagus often provoke the swallowing of air. Here the stomach is distended with air.*
compression. A barium swallow will show the site and degree of compression. The esophageal lumen, though compressed, remains regular and smooth in outline, with no filling defect. Dilation may occur cranial to the point of compression if the condition has been present for some time. Enlargement of the cranial mediastinal and tracheobronchial lymph nodes causes elevation of the esophagus and depression of the trachea.

**Gastroesophageal Intussusception.** Gastroesophageal invagination or intussusception is passage of a portion or all of the stomach into the esophageal lumen. It may be associated with megaesophagus. The most prominent clinical signs are persistent attempts to vomit, depression, and abdominal pain. Most affected animals die within hours of the onset of clinical signs.

**Radiologic Signs**
1. Plain radiographs show an area of increased opacity in the caudal thorax.
2. The esophagus may be dilated with gas cranial to the mass.
3. Often the bubble of gas normally seen in the stomach is small or absent.
4. If barium is introduced, gastric rugal folds are seen within the esophagus.
5. The stomach may cause a complete obstruction of the esophagus, in which case barium will not enter the stomach. The picture will be one of complete esophageal obstruction with an intraesophageal mass.
6. The spleen and pancreas may be involved in the invagination. See Figure 2-18.

**Esophageal Fistula and Esophagobronchial Fistula.** Fistulas are rarely seen and may communicate with the skin, trachea, or a major bronchus. If either esophagotracheal or esophagobronchial fistula is suspected, a water-soluble nonionic iotinated contrast medium can be given by mouth to outline the defect. If this is negative, a barium study may be given. Clinically, an esophageal fistula causes a moist area on the skin in the region of its outlet. An esophagobronchial fistula may be chiefly characterized by bouts of coughing often associated with feeding and recurrent or chronic pneumonia.

**THE STOMACH**

**Anatomy**
The stomach lies in the cranial abdomen caudal to the diaphragm and the liver. It lies between the esophagus and the duodenum. For purposes of description, it is divided into the following four regions:
1. **Cardia:** the portion that blends with the esophagus.
2. **Fundus:** the large blind pouch that lies dorsal and to the left of the cardia.
3. **Body:** the principal portion, extending from the fundus to the pylorus.
4. **Pylorus:** the distal third, approximately. Its proximal portion, the pyloric antrum, is a thin-walled saccule that is continuous distally with the pyloric canal. The pyloric canal is the passage from the stomach into the duodenum. It is surrounded by a thick double sphincter.

The stomach is somewhat J shaped. The greater curvature is the convex edge extending from the cardia to the pylorus. The lesser curvature, the concave side, extending from the cardia on the left to the pylorus on the right, is in the form of a notch—the angular notch. The cardia, fundus, and body are for the most part to the left of the midline. The pyloric antrum and pyloric canal lie to the right side. The body and fundus are in contact with the left lateral lobe of the liver and the left hemidiaphragm. The right side of the liver lies between the pylorus and right hemidiaphragm. The pancreas is in the angle formed between the...
stomach and duodenum. The mucosal surface of the stomach is thrown into folds commonly called rugal folds (plicae gastricae). When empty, the stomach is almost entirely within the rib cage, and its ventral border is approximately one third the depth of the abdomen from the ventral abdominal wall. When full, the stomach reaches the floor of the abdomen and extends a variable distance caudally, where it is related to the transverse colon. In puppies, a full stomach may reach the umbilicus or beyond. In the cat, the stomach lies to the left of the midline, with the pyloric antrum on the midline.

Figure 2-17, cont’d E, An adult Terrier had a bone removed from its esophagus through the mouth. This postremoval study shows poor definition in the area of the caudal mediastinum. Diagnosis: foreign body mediastinitis. F, This puppy was having difficulty swallowing. Plain studies suggested the presence of pleural fluid. Barium was given and is seen in the pleural cavity. The diagnosis was ruptured esophagus. Barium should not be given in cases where esophageal rupture is a possibility. G and H, Esophageal diverticulum. This Terrier had an esophageal foreign body removed via a gastrotomy incision some months earlier. It presented with occasional regurgitation. A barium swallow shows an esophageal diverticulum at the site of the original obstruction.
Radiography
Plain and contrast radiographs are necessary for a full examination of the stomach. Dynamic studies require the use of fluoroscopy. Contrast studies may be done with positive, negative, or a combination of positive and negative agents.

Positive Contrast. Barium or a water-soluble iodide preparation may be used for positive contrast. The best positive contrast material is commercial micropulverized barium sulfate in suspension. Commercial preparations may be given undiluted. Suspensions of pure powdered barium sulfate are not satisfactory; their performance within the alimentary tract is sometimes unpredictable because of their tendency to flocculate. The dose of micropulverized suspension is 2 to 5 mL/kg body weight given slowly into the buccal pouch. Alternatively, it may be given through a stomach tube using a mouth gag. Iohexol is useful in cats, giving a faster transit time and good detail. Barium-impregnated polystyrene spheres (BIPS) are sometimes used to demonstrate delayed gastric emptying time, abnormal intestinal transit times, or partial obstructions. They are orally dispensed in high-fiber food.

It is most important that the animal be properly prepared before a contrast study. The patient should be fasted for at least 12 hours before the examination. Water is allowed. Anticholinergic drugs, alpha agonists, and opioids should be withheld for the previous 24 hours. If an enema is required to clean the colon, it should not be given until the preliminary survey radiographs have been made. The best enema is probably isotonic saline, given at a temperature slightly below body temperature to reduce residual gas. The use of a mild cathartic agent 24 hours before the examination is also helpful. Little or no information can be gained from a contrast study if food material is present within the stomach. The study will be compromised if too much barium is given. Indeed, it is preferable to administer too little rather than too much because more can be given if required. Too much barium obscures all detail.

Anesthetic agents and many tranquilizers may considerably alter gastric emptying time and the transit time of barium through the intestine. Acetylpromazine maleate has been shown to have little effect in this regard. Triflupromazine hydrochloride is said to slow barium passage time in a predictable manner and therefore can facilitate a detailed study of segments of the gastrointestinal tract. Xylazine hydrochloride 2% has been shown to cause gastric and intestinal dilatation, which could be mistaken for paralytic ileus. Its use is not advised in gastrointestinal studies. Medetomidine has similar effects. A ketamine-midazolam combination may be used as a tranquilizer in the cat and reduces transit time.

Plain radiographs should be made immediately before barium is administered to exclude the possibility of the barium masking a foreign body or a lesion. At least one lateral view and a ventrodorsal view are required. After barium administration, opposing lateral and ventrodorsal views are made if a foreign body is suspected. Dorsoventral and oblique

Figure 2-17, cont’d I and J. On the lateral view, a rounded, soft tissue opacity (arrows) is seen in the caudal thorax between the aorta and the caudal vena cava. There is air in the esophagus dorsal to the trachea. On the ventrodorsal view, the mediastinum is widened throughout its length. The trachea is deviated to the left at the level of the second intercostal space. The cause was infection with Spirocerca sanguinolenta (S. lupi). (Courtesy Dr. B. Walsh.)
views may be required for a full study. Barium must be seen to fill all parts of the stomach. After the initial studies, further radiographs are made at 20-minute intervals for up to 1 hour and hourly thereafter until a diagnosis is made or until all the barium has left the stomach. If a full gastrointestinal series is required, further radiographs are made hourly until most of the contrast medium has reached the colon. Depending on the rate of intestinal transit, films may be required more or less frequently. A 24-hour film is sometimes useful if there has been delayed gastric emptying or if a food and barium mixture or BIPS have been given.

If perforation of the stomach is suspected, a watersoluble nonionic organic iodine preparation, 10% weight/volume of iodine, should be used instead of barium. Nonionic agents are preferred to ionic agents because they are not hypertonic at concentrations required for diagnostic use. Such preparations should be given at a dosage rate of 7 mL/kg body weight.

Figure 2-18 Gastroesophageal intussusception. A and B, A 9-week-old German Shepherd had a history of vomiting and respiratory distress for 2 days. Gastric rugal folds can be seen within the thorax. There is an associated megaesophagus. The usual stomach shadow is not seen within the abdomen. C and D, A 7-month-old Siamese had a history of intermittent vomiting a variable time after feeding. The plain lateral film shows a mass in the caudal thorax. The contrast study shows protrusion of the stomach into a dilated esophagus.
They are best given by stomach tube. Water-soluble agents will be absorbed if they reach the mediastinum or peritoneal cavity, whereas barium will not be absorbed. Aqueous iodide agents pass through the alimentary tract faster than barium. They do not give the same clarity of outline. In the distal parts of the intestine they become diluted because of their hypertonicity, and detail is lost. Ionic organic iodide agents are contraindicated in dehydrated subjects and are not advised for cats. They are not suitable for double-contrast studies. For cats, iopamidol or iohexol (240 mg iodine/mL) diluted 1:2 with water may be given at a dosage rate of 8 mL/kg body weight. At least two views are obtained immediately, and later films as required.

**Negative Contrast.** Room air introduced through a stomach tube at a dosage rate of 6 to 12 mL/kg body weight or 30 to 60 mL of a carbonated beverage given through the buccal pouch will provide acceptable negative contrast. Negative contrast alone is not a satisfactory method of studying the stomach. It may be useful in demonstrating a foreign body or in assessing the thickness of the stomach wall.

**Double Contrast.** A combination of positive and negative contrast agents is used in a double-contrast study. Because the stomach almost always contains some gas or swallowed air, virtually all positive contrast studies of the stomach are, to some extent, double-contrast studies. After a barium meal, when most of the barium has left the stomach, air may be introduced through a stomach tube, or a carbonated beverage may be given.

**CT Gastrography.** Patient preparation is as for a contrast study of the upper gastrointestinal tract. General anesthesia is required. CT scanning of the stomach after distention with water at 30 mL/kg allows complete evaluation of the stomach wall. Intravenous water-soluble iodinated contrast medium injection results in relatively uniform enhancement of the stomach wall and distinguishes mass lesions from luminal debris.

**Normal Appearance**
The stomach usually contains some fluid and some gas (air). The gas is often referred to as the stomach bubble. Gas in a hollow organ tends to rise to the highest possible point. The fluid and gas positions vary with changes in the posture of the animal. Thus if a radiograph is made with the animal in right lateral recumbency, the gas will be seen in the fundus and body. Conversely, in left lateral recumbency gas will be seen, for the most part, in the pyloric antrum. On left-right lateral views (right lateral recumbency), the pyloric antrum and distal fundus are seen end-on and often cast quite a dense circular shadow. In this position, fluid accumulates in the pyloric antrum and may be mistaken for a foreign body or a neoplasm. The suspected mass will usually disappear on a right-left lateral view (left lateral recumbency). On lateral views, a line drawn through the fundus, body, and pylorus may be perpendicular to the vertebral column, it may be parallel to the ribs, or may lie somewhere between these two extremes. The position of the stomach varies with respiration. In dogs, on the ventrodorsal view, a line drawn through the fundus and pylorus will be perpendicular to the vertebral column. Lateral and ventrodorsal views are usually adequate as survey radiographs. In obese cats, fat is deposited between the muscularis and submucosa and appears as a lucent band within the stomach wall on radiographs (see Figure 2-12, A, and Figure 2-19, L). Bones in the stomach are not necessarily of clinical significance because they are often successfully digested (see Figure 2-7, J).

After a contrast study, the position of the contrast material within the stomach will depend on the posture of the animal and will be opposite to the position occupied by gas. The contrast material will gravitate to the lowest point within the stomach. In right lateral recumbency the contrast material will be seen in the pyloric antrum; in left lateral recumbency it will be seen in the body and the fundus. In the ventrodorsal position, contrast material will accumulate in the fundus and around the cardia; in the dorsoventral position it will gravitate to the body and pyloric antrum. A right-dorsal left-ventral oblique (right dorsoventral oblique) view shows the pylorus best.

An adequate contrast study of the stomach entails visualization of all regions. In the normal stomach, rugal folds are clearly seen in the fundus and body, whereas few are seen in the pyloric antrum. They vary in size and number and lie closest to one another in a strongly contracted stomach. They should be regular in outline, parallel to one another, and smooth. They may appear linear or tortuous, depending on the degree of distention of the stomach. The spaces between the folds should be about as wide as the folds themselves. There should be no filling defects. Rugal folds are smaller and less numerous in cats.

In a normal animal, properly prepared, barium will appear in the duodenum within a few minutes of its administration. The term emptying time is sometimes used in radiology to mean the time at which the stomach begins to empty in contradistinction to the time taken for complete emptying of the stomach. It is probable that the average time for complete emptying in the fasting animal is about 3½ hours, but it may vary considerably. Retention of barium for more than 12 hours should certainly be considered abnormal. If the stomach is not empty at the beginning of the examination, the time taken for complete emptying will vary with the amount and nature of the stomach contents. In nervous animals, the passage of barium into the duodenum at the beginning of the study may be delayed for 30 minutes or more. In such cases it is often helpful to return the animal to its cage to allow it to settle down and then to continue the examination after approximately 30 minutes. Delayed emptying resulting from nervousness or stress is common and must not be confused with that seen in pyloric malfunction.

Fluoroscopy is required to evaluate the dynamic function but should only be used at specialist centers.
Fluoroscopy will show contractions of the stomach. Peristaltic waves, originating near the cardia, are seen to pass across the body and through the pyloric antrum. The pylorus (arrows) is seen as a narrow passage between the pyloric antrum and the duodenum. The indentations in the wall in the fundic region are caused by mucosal folds. C and D, Lateral recumbent views show changes in outline of the stomach and duodenum with changes in the animal's posture. C, On the left lateral recumbent view, barium is seen in the cardia and fundus with gas in the pylorus. D, A right lateral recumbent view shows barium in the pylorus. The radiograph is mismarked left.

Where available, endoscopy has superseded contrast studies for many conditions except dynamic studies.

**Ultrasonography**

A high-frequency transducer is recommended for evaluation of the superficial parts of the stomach. A sector probe with a frequency range of 7 to 10 MHz is used in cats and small and medium-sized dogs. Large- and giant-breed dogs may require use of a lower frequency transducer to evaluate deeper parts of the stomach. A linear high-frequency transducer
(7 to 15 MHz) may be useful to evaluate the stomach, especially in feline patients and small dogs.

The animal should be fasted. It is occasionally useful to allow the animal to drink water before examination to fill the stomach and proximal small intestine with fluid and displace the gas present. Barium sulfate will disrupt image quality because of beam attenuation. The ventral abdomen is clipped caudal to the costal arch. The animal is placed in dorsal or lateral recumbency, depending on the amount of gas present. Examination in a combination of positions may be required. Imaging the gastric wall from the dependent side can also be helpful. Right lateral recumbency is useful for pyloric examination and left

Figure 2-19, cont’d E and F, These are left lateral recumbent and ventrodorsal views of double-contrast studies of the stomach. Double contrast gives good visualization of the rugal folds. G and H, The stomach and small intestine 2 hours after the administration of barium.

Continued
lateral recumbency for examination of the fundus. Animals are usually positioned in dorsal recumbency with the transducer placed caudal to the costal arch in a sagittal plane. The gastric area can be examined from right to left, angling the beam craniodorsally. The duodenum lies on the right and can be seen leaving the pyloric antrum. The rugal folds are seen, and regular contractions identify the stomach. Peristaltic activity can be assessed, usually five contractions per minute. The gastric wall between the rugal folds, when relaxed, measures approximately 3 to 5 mm in thickness in dogs and 2 mm in cats.

A high-resolution 7.5-MHz transducer is required to identify the five ultrasonographic layers of the stomach, which have alternating echogenicity. They are (1) the hyperechoic serosa and subserosa, (2) hypoechoic muscularis propria, (3) hyperechoic submucosa, (4) hypoechoic mucosa, and (5) the hyperechoic lumen/mucosal interface. In obese cats, a radiolucent band representing fat deposition is occasionally seen between the muscularis and submucosal layers of the stomach wall.

When a lower frequency transducer is used, the gastric wall appears as a hypoechoic structure.
Chapter 2 • The Abdomen

83

the stomach is empty, the rugal folds may be seen as a star or wagon wheel shape in cross-section with a central fluid or gas echogenicity. The presence of mucus, food, or gas in the stomach can cause various artifactual problems; consequently, a complete examination and accurate evaluation can be difficult. The gastric contents are predominantly fluid and therefore anechoic, but hyperechoic gas bubbles can be seen oscillating in the fluid. The instillation of intraluminal fluid may occasionally be advantageous in imaging the gastric wall (Figure 2-19, I to K).

Abnormalities

Foreign Body. Many foreign bodies are radiopaque and therefore readily seen on plain radiographs of the abdomen. Radiolucent objects are occasionally encountered. Both right and left lateral recumbent views should be used because the movement of gas within the stomach may cause it to outline a radiolucent foreign body in one position and not in another (see Figure 2-26, U to W). Foreign bodies are best demonstrated by positive contrast, although they are sometimes outlined by gas within the stomach. Double contrast may be used. Small amounts of barium should be used because too much may obscure the outline of the foreign body. Frequently the foreign body is most clearly seen when most of the barium has left the stomach. It is then outlined by residual barium adhering to it. Foreign bodies are usually movable within the stomach. A foreign body may obstruct the pylorus, provoking persistent vomiting. Gastric distention may result, but this is rare. Intermittent obstruction of the pylorus by a foreign body may provoke occasional vomiting. A foreign body may provoke gastritis. A foreign body may occasionally be present without any clinical signs (Figure 2-20, A to I). Thin, linear, metallic foreign bodies are occasionally seen in the region of the pylorus in medium and large dogs. These are presumed to be needles that are embedded in or have migrated through the stomach wall. They do not appear to cause any clinical problems.

Ultrasonography. Ultrasonography may be useful in identifying foreign bodies, depending on their shape and echogenic properties. They may be seen clearly because they are usually hyperechoic and

Figure 2-20 Foreign bodies. A and B, A radiopaque plastic foreign body is seen in the stomach. C, On the plain left lateral view, gas within the pyloric region of the stomach partly outlines a foreign body (arrows). D, After administration of barium, the object is more clearly seen on the ventrodorsal view (arrows). It was a rubber ball.

Continued
cast acoustic shadows, but they can be obscured by even a small volume of luminal gas. The presence of intraluminal fluid is helpful because it may outline the foreign body. Foreign bodies sometimes move in the stomach when the animal's position is changed (Figure 2-20, G and J).

**Gastritis.** Gastritis is not easy to diagnose radiographically with certainty. The gastric wall may be thickened. Increased production of mucus may cause flocculation of barium. Rugal folds become thicker with gastritis. An inflamed stomach empties more rapidly than a normal one. Endoscopy is the preferred method of diagnosis.

**Ultrasonography.** A diffuse or localized gastric thickening (more than 7 mm) may be identified. Localized thickening with or without wall layer disruption, with adhered hyperechoic gas bubbles, suggests gastric ulceration. Primary neoplasia is the most common cause of ulceration in companion animals. Bubbles attached to the ulcerated mucosa are seen if the affected part of the stomach wall is dependent and fluid overlies the gas bubbles. Generalized thickening or hypertrophy of the wall and rugal folds with some loss of wall definition has been associated with chronic gastritis. Localized thickening with peristaltic disruption is also associated with pancreatitis.

**Gastric Dilation and Volvulus (Torsion).** Dilation of the stomach may result from an obstruction of the outflow tract or from atony of the stomach wall. Acute gastric dilation may occur with or without torsion. Chronic dilation also occurs, such as the result of prolonged partial obstruction of the pylorus. A dilated stomach will displace the intestines caudally. Swallowed air from esophageal abnormalities or dyspnea may cause a mild degree of gastric distention. An esophageal dilation may sometimes be present. Some tranquilizers, particularly xylazine, provoke gastric dilation. In simple dilation, the pylorus remains in its normal position on the right side.
This is an important observation in differentiating gastric dilation from gastric torsion (Figure 2-21, A and B).

Dilation with torsion is most frequently seen in large, deep-chested breeds of dogs in middle to old age, although it has been reported in small dogs and cats. Intermittent volvulus can occur without dilation (Figure 2-21, D to F). The etiology of gastric dilation or volvulus is obscure. Body conformation, dietary factors, paralysis of gastric motor function, pyloric dysfunction with gastric retention, excessive water intake, and overeating before exercise have all been suggested as possible causative factors. A hereditary factor may exist. Dilation precedes torsion. The dilation causes the greater curvature of the stomach to move ventrally and to the right, producing a stretching and eventual relaxation of the gastrohepatic ligament. The pylorus then moves dorsally, cranially, and to the left.

A right lateral recumbent view will show gas in the displaced pylorus and thus help identify it. A dorsoventral view will illustrate the pylorus on the left side. Torsion in the opposite direction is uncommon. Torsion of the stomach results in torsion of the gastroesophageal junction. As a result of the torsion the gastroesophageal inlet and the pyloric outlet both become obstructed. Esophageal dilation is common. Movement of the greater curvature draws the spleen...
toward the right side and interference with its circulation causes it to enlarge; it may also undergo torsion. Clinically, complete torsion of the stomach is an emergency condition. Repeated attempts at vomiting, dehydration, depression, and eventual collapse occur. The abdomen is distended. Various degrees of partial torsion may present with a history of intermittent episodes of discomfort associated with eating and tympany (Figure 2-21).

Radiologic Signs
1. A large, gas-filled, distended stomach is seen on plain radiographs. The stomach may be so dilated that it appears to fill almost the entire abdomen.

2. The intestines are displaced caudally.
3. Usually a fold of the stomach wall can be seen on the lateral view crossing the distended stomach. This fold represents the division between the compartments of the twisted stomach—"compartmentalization" (Figure 2-21, C).
4. The pylorus is displaced dorsally, cranially, and to the left. Its recognition in this abnormal position helps distinguish torsion from simple dilation. It may be identified on a right lateral recumbent view.
5. The duodenum and small intestine may contain large amounts of gas.
6. The spleen is enlarged and is displaced a variable degree to the right. It is often difficult to identify.

Figure 2-21 A and B, Gastric dilation. This is a simple gastric dilation that occurred after anesthesia. C, Gastric torsion. A 13-year-old female Doberman presented with vomiting and abdominal pain. The stomach is grossly distended. Granular food material is visible ventrally. A fold of the stomach wall causes the stomach to be divided into two compartments. D to F, A partial rotation of the stomach. D, On the plain radiograph, the stomach appears folded on itself and is in an abnormal position.
7. The liver and vena cava appear smaller than usual because of compromised venous return.

8. In some patients with gastric dilation and volvulus, necrosis of the gastric mucosa allows gas to pass to the submucosal tissues. A thin curvilinear gas shadow may be noted within the stomach wall separating the mucosal and muscularis layers (Figure 2-21, G and H).

9. Gas may also be seen within the liver. It appears as linear gas shadows similar to air bronchograms (see Chapter 3, p. 225). This may represent gas within the portal veins or intrahepatic biliary ducts. This is a poor prognostic sign.

**Displacement.** The stomach can be displaced in a number of ways by masses within the abdomen. Enlargement of the liver, pancreas, or spleen can cause displacement. Less common causes are masses in the transverse colon or mesentery. Enlargement of the liver causes the stomach to be displaced caudally and usually dorsally. Localized masses within the liver have a variety of effects on the stomach depending on their location. Masses in the right liver lobes tend to displace the pylorus caudally and to the left; masses in the left liver lobes displace the fundus and body of the stomach caudally and to the right. The stomach may be displaced cranially as a result of diaphragmatic

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**Figure 2-21, cont’d D to F,** Partial rotation of the stomach. **E and F,** Contrast studies confirm the diagnosis. The pylorus is displaced dorsally and cranially and toward the left side. **G and H,** Gastric dilation and volvulus with gastric wall necrosis in a dog. **G,** There is moderate to severe dilation of the stomach with gas and food material also present. There is gas within the peritoneal cavity, which enhances the visibility of the serosa of the ventral part of the stomach. There are several abnormally shaped gas bubbles in the ventral abdomen overlying the stomach wall and spleen. Caudal to the stomach, serosal peritoneal detail is reduced because of the presence of fluid. There is moderate gaseous dilation within the caudal esophagus. **H,** A close-up view of the cranial ventral abdomen. A thin, linear gas bubble (arrows) is seen within the ventral part of the gastric wall. This finding indicates necrosis and perforation of the gastric wall with secondary peritonitis. This is a grave prognostic sign.
Gastroesophageal Invagination or Intussusception. See the section on the esophagus (p. 75) for a discussion of gastroesophageal invagination or intussusception.

Neoplasia. Neoplasia of the stomach is relatively rare in dogs. Adenocarcinoma is the most common malignant tumor in dogs and lymphosarcoma the most common in cats. Leiomyomas and leiomyosarcomas have been reported. Neoplasms of the pancreas may invade the stomach. The clinical signs of neoplasia are usually a history of vomiting over a period of time and the appearance of blood in the vomitus. The diagnosis of neoplasia may be difficult. Survey radiographs often show no abnormalities. Contrast gastrogastroscopy is more sensitive, but many lesions can be missed.

Radiologic Signs
1. Absence of or gross distortion of the normal pattern of rugal folds.
2. Thickening of the gastric wall.
3. The presence of an intraluminal mass, sometimes outlined by gas within the stomach.
4. Failure to outline the stomach fully on barium examination—a so-called filling defect.
5. Ulceration of the gastric mucosa. Barium may fill the ulcer crater and persist there, unchanged in outline, over a series of radiographs.
6. Localized rigidity of the stomach wall. A failure to transmit peristaltic waves may be noted on serial radiographs as an unchanging part of the stomach wall, or it may be observed fluoroscopically. Observed changes should be demonstrated on several films to preclude the possibility of mistaking normal features associated with contractions of the stomach for abnormalities.
7. Loss of distensibility of the stomach.
8. A negative radiographic examination of the stomach does not preclude the possibility of neoplasia. See Figure 2-22, A to G, N, and O.

Ultrasonography. Tumors that involve the pylorus can be identified in the majority of cases. There is particular difficulty in imaging the gastric body, and neoplastic disease can be overlooked in this area. Thickening of the gastric wall together with disruption of the wall layers is more suggestive of neoplasia than of inflammation. The thickening may be generalized or localized, symmetric or asymmetric. Loss of motility in the thickened areas is significant. Gastric carcinomas cause moderate to severe thickening of the stomach wall. The normal layers are obliterated but may be replaced by three alternating dark and bright bands referred to as pseudolayering. Gastric lymphomas in the dog and cat are typically hypoechoic, with circumferential thickening or an eccentric mass and regional lymphadenopathy. Hypoechogenic submucosal masses arising from the muscle layer are usually myogenic tumors and are often located in the pyloric region. Neoplasia in the region of the pyloric antrum may cause disruption to gastric outflow, and the consequent retention of fluid may outline the lesion, particularly if it is intraluminal. A negative ultrasonogram does not preclude the presence of neoplasia because most lesions in dogs affect the lesser curvature and are obscured by gas (Figure 2-22, J to M, and P).

Gastric Ulceration. Contrast studies are required to demonstrate gastric ulceration. Seen in profile, gastric ulcers appear as outpouchings from the wall of the stomach. Seen en face, they appear as circular areas of contrast medium. These represent depressions in the mucosa in which contrast material has been retained. A radiolucent halo representing edema of the stomach wall may be seen around the ulcer. Endoscopy may be more informative (Figure 2-22, H and I).

Benign ulceration of the stomach is not common. It has been reported in the pyloric canal and duodenum. It may be caused by some types of oral medication. Gastric ulceration is most often caused by malignancy.

Ultrasonography. Localized gastric wall thickening particularly affecting the mucosa with disruption of the mucosal/lumen interface is seen. Hyperechoic foci in this area representing gas bubbles or blood clots may be identified.

Pyloric Obstruction. Pyloric obstruction may be attributable to a number of causes. Acute obstruction may show no radiologic changes. Acute obstruction is often caused by a foreign body or inflammation. Gastric foreign bodies may lodge in the pyloric region. The empty or fluid-filled pylorus should not be mistaken for a foreign body. Chronic pyloric obstruction is more commonly caused by narrowing of the pyloric outlet. It may be caused by hypertrophy, fibrosis, stenosis, or neoplasia. Other causes of pyloric obstruction are pylorospasm and gastric torsion. Extrinsic causes such as hepatic or pancreatic masses may cause pressure on the pylorus, inhibiting the passage of food through it.

Pyloric stenosis may be associated with neurogenic dysfunction or hypertrophy of the circular muscle. Hypertrophy may be congenital or acquired; thus pyloric obstruction may be seen at any age. Neoplasia of the pylorus may be intrinsic, or it may be from invasion by a neoplasm in an adjacent organ. Irrespective of the cause, prolonged pyloric dysfunction results in prolonged gastric retention of ingesta and dilation. The presence of food material in the stomach of an adequately fasted animal should suggest gastric retention.

Clinically, affected animals vomit after the ingestion of solid food. Projectile vomiting has been described. If the condition persists, the affected animal will lose...
Figure 2-22. Gastric neoplasia. A to D, Gastric ulceration in a case of reticulum cell sarcoma. The dog presented with a history of weight loss and anorexia for 6 weeks. Barium is seen to be retained in an ulcer crater on several ventrodorsal radiographs made over a period of approximately 90 minutes. The ulcer remains fixed in position and shape (arrows). The radiolucent area about the ulcer, sometimes called the ulcer halo, represents swelling and edema of the surrounding gastric mucosa. E, A 10-year-old Golden Cocker Spaniel presented with repeated bouts of vomiting. A barium swallow demonstrates a curved, indented filling defect on the greater curvature of the stomach. This was a consistent finding on serial studies. The gastric wall is grossly thickened. At surgery a diffuse, infiltrative gastric carcinoma was found.

Continued
Figure 2-22, cont'd  
F and G, A 12-year-old mixed-breed dog had a history of anorexia, vomiting, and weight loss for 3 months. The stomach wall appears fixed in contour, and a normal rugal fold pattern is absent. At fluoroscopy, no gastric peristalsis was seen. When the pyloric canal was placed in the dependent position, barium flowed freely through it into the small bowel. Stomach wall masses project into the gastric fundus and antrum (straight arrows). A single ulcer crater is seen in profile on the lesser curvature (curved arrows). The diagnosis was diffuse adenocarcinoma with ulceration.  
H and I, Double-contrast gastrography of a dog with uremic gastritis and an antral ulcer. H, A large ulcer is filled with barium on the lesser curvature of the gastric antrum (arrows). Barium fills the gastric fundus (F). I, This is an enlargement of the ulcerated area. The ulcer crater is filled with barium (straight arrows). Barium fills the grooves (curved arrows) between the elevated rugal folds. The advantage of double-contrast gastrography is that mucosal detail can be seen. (F to I, courtesy Dr. W. H. Rhodes.)
weight and may become dehydrated. Pyloric obstruction has been described in young cats in association with dilation of the esophagus.

Pylorospasm may be caused by nervousness. During radiography, some nervous animals may retain barium in the stomach for long periods because of the stress of the examination and the upsetting effects of unfamiliar surroundings. It is often helpful to return the animal to its cage for 30 minutes if the stomach is not emptying properly. The examination is continued after that time. On reexamination, if the barium has passed freely into the duodenum, a diagnosis of pyloric dysfunction is not warranted. Pylorospasm may also be overcome by the administration of a spasmolytic or sedative agent. If, despite cage rest and the use of a spasmolytic drug, the barium does not pass into the duodenum for an abnormally long time, say an hour or more, and then a diagnosis of pyloric dysfunction should be considered.

Fluoroscopy is of particular value in evaluating pyloric function. Although a diagnosis of pyloric dysfunction can be made relatively easily, differentiation of its various possible causes can be difficult.

Radiologic Signs
1. The stomach is enlarged and often dilated in longstanding cases.
2. There may be food material in the stomach even after prolonged fasting.
3. A large amount of fluid is often present in the stomach.
4. Mineralized opacities are sometimes seen in the stomach proximal to an obstruction. Such opacities are often called the gravel sign and are most frequently associated with chronic partial obstruction.
5. There is delayed initial emptying of contrast from the stomach.

Figure 2-22, cont’d J and K, This dog had a history of chronic vomiting. Radiographs (not shown) showed signs of gastric outflow obstruction. These are sagittal sonograms of the midbody (L) and pyloric region (K) of the stomach. Gas (G) and fluid are seen in the gastric lumen (Lu). The layers of the stomach wall are thickened and disrupted. An undulating mass (short arrows) is seen extending into the lumen. The stomach wall (W) measures 1.2 cm between the markers. This was a gastric neoplasm. Cr, Cranial; L, liver; W, wall; Lu, lumen. L and M, Gastric tumor. Cross-sections of the body of the stomach (L) and the pyloric (M) region. L, Circumferential thickening of the gastric wall (S) with prominent rugae and irregular disruption of the layers (W). L, Lumen. M, Local thickening of the gastric wall with a mass (M) projecting into the lumen (S). The wall thickness is 1 cm. This was a carcinoma.
6. Fluoroscopically, after the administration of barium peristaltic waves can be seen pushing the barium up to the pyloric canal, but little or no barium passes into the duodenum.

7. Occasionally a thin streak of barium is seen to pass into the narrowed pyloric canal—the so-called string sign. If barium fills only the entrance to the lumen of the pylorus, the resulting appearance has been called a beak sign. A teat sign is an outpouching of the pyloric antrum along the lesser curvature caused by a peristaltic wave pushing contrast in a peristaltic pouch up against a mass lesion in the pylorus. It is important that the animal be properly fasted before the radiographic examination. In a properly fasted animal, barium should be seen in the duodenum within minutes of its administration. In cases of pyloric dysfunction, barium may be retained within the stomach for several hours.

Distention of the stomach may sometimes be appreciated because of the food material within it (Figure 2-23, A to E).

Ultrasonography. Congenital hypertrophic pyloric stenosis usually causes symmetric thickening of the pylorus. Pyloric neoplasms may cause chronic partial obstruction. Pyloric contractions with minimal progression of gastric contents into the duodenum may be observed (Figure 2-23, F and G).

**Hypertrophic Gastropathy.** Hypertrophic gastropathy affects the muscularis layers of the stomach wall and sometimes the mucosal layer. Small-breed dogs are most commonly affected. The lesion results in chronic partial obstruction of the pylorus causing severe dilation of the stomach, which may occupy the entire cranial abdomen. The stomach contents are usually a fluid opacity with a small quantity of gas. An accumulation of granular mineral opaque material may be present in the gastric body and pyloric antrum.

Ultrasonography. Ultrasound is well suited to evaluate the pylorus because the fluid gastric contents provide an acoustic window. It may be helpful
Figure 2-23 A and B, Gross distention of the stomach. This distention results from prolonged interference with gastric emptying. A mixture of barium and food is present within the stomach, and there is barium in the intestine. C to G, Chronic, partial pyloric outflow obstruction in an 11-year-old female neutered Chow Chow with a history of chronic vomiting and weight loss. C, Right and D, left lateral recumbent and E, ventrodorsal views. There is moderate dilation of the stomach, which extends caudally to the umbilicus on the lateral views. The dilated stomach causes caudal displacement of the large and small intestines. The stomach is filled with a large amount of fluid and a small to moderate amount of gas. An accumulation of granular material of mineral opacity is present in the distal part of the gastric body and the pyloric antrum. On the left lateral view, gas within the stomach rises and fills the pyloric antrum.

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to place the patient in right lateral recumbency to displace gas from the pylorus. There is usually circumferential thickening of the muscularis layer, or less often the mucosal layer. Normal layers are intact. Gastric carcinoma can cause similar lesions but will usually result in blurring or obliteration of wall layers. The cranial abdomen should be evaluated for the presence of local lymph node enlargement and hepatic nodules that may indicate metastasis (Figure 2-23, F to H).

THE SMALL INTESTINE

Anatomy

The small intestine extends from the pylorus to the ileocolic junction. It occupies the ventral portion of the abdomen, caudal to the stomach and liver. It measures approximately three and a half times the length of the body in the living animal.

The duodenum is the first part of the small intestine. Its cranial portion is continuous with the pylorus, from which it courses at first laterally and then caudally to form the cranial duodenal flexure, which lies at approximately the level of the ninth or tenth rib. The cranial part is sometimes called the duodenal cap or bulb. In the cat, the duodenum courses caudolaterally from the pylorus. From its cranial flexure, the duodenum courses dorsally and caudally to approximately the level of the sixth lumbar vertebra, where it turns medially to form the caudal duodenal flexure. The proximal portion is known as the descending duodenum. Dorsally and laterally it is in contact with the liver and medially with the pancreas. From the caudal flexure, the ascending duodenum runs obliquely cranially and to the left, and then it courses ventrally to become continuous with the jejunum at the duodenjejunal junction. The duodenum has a short mesentery and is relatively fixed in position. The descending and ascending duodenum together form the duodenal loop.

The jejunum and ileum form most of the small intestine. They are supported by a long mesentery and are freely movable within the central abdomen. No clear division exists between the jejunum and the ileum. The term ileum is applied to the short, usually contracted, terminal part of the small intestine. It ends at the ileocolic junction, which lies within the duodenal loop or ventral to the ascending portion of the duodenum. The jejunum and ileum form numerous coils in the midventral abdomen.
Radiography
On plain lateral and ventrodorsal radiographs of the abdomen, the small intestine can be recognized because of the mixture of gas and food material within it. The small intestine of the cat contains less gas than that of the dog.

Detailed studies of the small intestine require the use of contrast medium. Preparation of the animal and the administration of contrast medium are carried out as described for the examination of the stomach. The dosage rate of contrast medium used should be at the upper end of the scale recommended for gastric studies. Five to 12 mL/kg body weight of a 30% weight/volume of micropulverized barium suspension has been recommended for dogs and up to 12 mL/kg body weight for cats. Most commercially available barium suspensions are 60% or 100% weight/volume, which is too opaque on radiographs. The higher dosage rates give better filling of the small intestine and are used in small- to medium-sized dogs. If perforation of the intestine is suspected, a water-soluble iodide preparation should be used instead of barium.

After a barium meal is given, lateral and ventrodorsal radiographs are made immediately and thereafter every 20 minutes for the first hour and then hourly until a diagnosis has been made or until most of the barium has reached the colon. Timing of radiographs should be adjusted if contrast passage is either too rapid or too slow. Too much contrast material, or preparations that are too concentrated, may mask intestinal detail. If a nonionic organic iodide preparation is used at a dose rate of 7 mL/kg, radiographs should be made immediately after administration, after 5 minutes, every 15 minutes thereafter up to 1 hour, and then hourly until the colon is visualized. The use of organic iodide preparations often causes the urinary tract to be outlined as a result of absorption of the contrast medium.

Fluoroscopy is used to study function and to determine whether normal peristalsis is present.

Normal Appearance
On plain radiographs, the serosal surface of the intestine can be seen in animals that have sufficient intraabdominal fat to provide contrast. The diameter of the intestine is variable. It has been suggested that in dogs it may be up to twice the width of a rib and should not exceed the height of the central portion of the second lumbar vertebral body, or the ratio of the maximum diameter of the intestine to the height of the midbody of the fifth lumbar vertebra should not exceed 1:1.6. In cats, the small intestine diameter should be less than twice the height of the body of the fourth lumbar vertebra or less than 12 mm. The small intestine is distributed evenly throughout the midventral abdomen, filling space not occupied by other organs.

The duodenum is fairly fixed in position and is usually not seen on plain radiographs. The jejunum and ileum have a wide range of movement. They are readily displaced by other organs or by masses within the abdomen. Gas and fluid are seen within the lumen of the small intestine.

The duodenal loop is easily recognized on contrast studies. Sharply defined barium-filled outpouchings are frequently seen along the antimesenteric border of the duodenum. These outpouchings are normal features and have been called pseudoulcers (Figure 2-24, A). They are not seen in cats. They are the result of mucosal thinning and pouching over submucosal lymphoid follicles and should not be confused with true ulcers, which are rare. In cats, the normal duodenal pattern is segmented and is said to resemble a string of pearls (Figure 2-24, B).

The mucosal pattern of the small intestine is not as well marked in the dog and cat as it is in humans. Barium studies show a smooth or finely villous or fimbriated pattern. The mucosal surface may appear to have a slightly roughened edge, and often a faint halo surrounds the contrast column, more marked when organic iodide preparations are used. In a normal study, the contrast material fills the lumen and remains homogeneous in appearance. It maintains a continuous column as it passes along the intestine. The caliber of the bowel should be uniform, although a full duodenum may be slightly wider than the jejunum or ileum. Peristaltic waves are seen as narrowed or indented areas of contraction on radiographs. Serial studies should be made to ensure that such contractions change in size and position. No filling defects should be present. The usual transit time of barium through the small intestine varies from 2 to 4 hours. Transit time is faster in cats and with organic iodide preparations (see Figure 2-19, G and H).

Fluoroscopically, peristaltic waves are seen to pass along segments of the intestine, pushing the barium ahead of them. Secondary waves cause some of the contrast material to flow in a retrograde direction, thus imparting a churning motion to the intestinal contents. It has been said that reverse peristalsis does not occur in the normal duodenum.

Ultrasonography
The ability to image the small intestine depends on the amount and type of material in the lumen. The pattern of wall layers is similar to that described for the stomach, and a high-resolution transducer is a prerequisite (see Figure 2-19, I). The descending duodenum can be identified in the right cranial abdomen as it extends caudally from the stomach. The intestinal wall measures 2 to 3 mm in thickness and up to 5 mm in the larger breeds of dog. The duodenal wall measures up to 5 to 6 mm (Figure 2-24, C). Measurements made on transverse views are more reliable. Intestinal motility is readily identifiable, with the contents moving to and fro; the contents range from hyperechoic (gas) to anechoic (fluid).

Abnormalities
In studies of the small intestine, plain radiographs often give some indication of abnormality, and they should be studied routinely before contrast studies are done. Opposing lateral studies are useful.
Ileus. Ileus, or failure of intestinal contents to pass along the intestine, may have a number of causes. Mechanical (or obstructive) ileus is caused by some physical impediment to the passage of material along the bowel. Mechanical obstruction may be attributable to any of the following causes: foreign body, intussusception, intestinal abscess, incarcerated or strangulated hernia, volvulus, parasites, adhesions, postoperative stricture, impaction, inflammatory or traumatic lesions, neoplasia, or congenital defects. Pressure from extrinsic masses rarely causes intestinal obstruction because of the mobility of the jejunum.
and ileum. The features of a mechanical ileus are as follows:

(a) A sentinel loop is present.
(b) The diameter of the intestinal lumen is greater than normal.
(c) A gas and fluid mixture is present.
(d) The problem is localized.

Functional (adynamic or paralytic) ileus results in loss of peristaltic activity. It may be from chronic obstruction, neurologic disorders, trauma, peritonitis, or enteritis. An ileus is said to be dynamic when some peristaltic activity is present. The features of functional ileus are as follows:

(a) The intestinal lumen is often normal in diameter.
(b) Almost the entire length of the tract may be involved.
(c) Loops of bowel are usually fluid filled, with little gas present.

Postoperative ileus is not as common in the dog as it is in humans.

Clinical signs of obstruction include vomiting, anorexia, depression, diarrhea, distended abdomen, and abdominal pain. Affected animals may adopt an abnormal posture. The obstruction may be palpable through the abdominal wall. Obstruction of the proximal intestine provokes a more acute reaction than does obstruction of the distal intestine. Dehydration with electrolyte imbalance may be a significant factor, especially with obstruction of the proximal intestine.

Radiologic Signs
1. Moderate or severe dilation is seen of a loop or loops of bowel filled with gas or a combination of gas and fluid. Loops filled with fluid alone may not be visible because they do not contrast with what surrounds them. A single distended loop of bowel is sometimes referred to as a sentinel loop because it should signal the possibility of an obstruction. In some cases of obstruction, gas-filled bowel loops are not evident. This is particularly true for obstructions in the proximal intestine because the gas may be vomited.
2. A radiopaque foreign body, if present, will be seen radiographically.
3. Dilated loops of bowel often lie parallel to one another, creating a “layering” of the bowel. The term stacked loops has been used to describe this appearance. Such a finding suggests a dynamic ileus (Figure 2-25, A and B).
4. A standing lateral view often shows gas-capped fluid levels within the intestine (Figure 2-25, C).
5. The level of obstruction can often be gauged from the length of gas-filled intestine seen proximal to the point of obstruction. The bowel distal to the obstruction may be empty.
6. On barium examination, there is delayed gastric emptying and slow passage of contrast medium along the intestine. A radiolucent foreign body may be outlined by barium. Fluid present in the bowel dilutes the barium. There may be hyperperistalsis proximal to the obstruction.
7. String foreign bodies, more common in cats, cause bunching or plication of the bowel on contrast examination. Loops of bowel are gathered together in the midabdomen. In obese animals, the intestines may appear bunched centrally. This should not be mistaken for an abnormality. Barium sulfate should not be used as a contrast agent when linear foreign bodies are suspected because there is a possibility of intestinal perforation and peritonitis in such cases (Figure 2-26, M to P).
8. Luminal gas bubbles have abnormal shapes, triangular or comma shaped, and are eccentrically located rather than in the center of the bowel loop.
9. A partial obstruction may be detected only on contrast examination.
10. Generalized distention of all intestinal loops is suggestive of chronic distal obstruction or adynamic ileus.
11. With a chronic obstruction, a segment of intestine proximal to the site of obstruction will dilate over a period of time. Food material accumulates within it. A gravel sign may develop (see p. 92). The degree of dilation may be severe, and long-standing cases may simulate megacolon in appearance (see Figure 2-28).
12. On barium examination, there is delayed gastric emptying and slow passage of contrast medium along the intestine. A radiolucent foreign body may be outlined by barium. Fluid present in the bowel dilutes the barium. There may be hyperperistalsis proximal to the obstruction. Barium studies are generally not required except for radiolucent foreign bodies and proximal duodenal obstruction.

Swallowed air, often seen with esophageal abnormalities or respiratory distress, may be present in considerable amounts in the small intestine. It does not grossly distend the intestine and should not be misread as a sign of obstruction.

It is probably inadvisable to proceed with a barium examination when distended loops of intestine have been demonstrated on plain radiographs. Such cases require surgical exploration, and any information gained by a contrast procedure is unlikely to influence management of the case. Furthermore, the administration of barium further distresses the animal, frequently provokes vomiting, and may complicate the surgery.

Ultrasonography. Depending on the cause, segmental or generalized dilation of the bowel loops may be seen, and motility will be reduced or absent in the immediate vicinity of an obstruction. It is important to differentiate the small intestine from the large intestine, which may be difficult when the motility of the small intestine is reduced or absent. Foreign bodies are usually hyperechoic and throw marked acoustic shadows. Fluid may surround them and thus aid in their identification. Segmental narrowing with distention proximally may be seen with neoplastic infiltration or scar formation (Figure 2-25, D to F; also see Figure 2-26, J, Q1 to Q4, and T; and Figure 2-30, F to H).
Figure 2-25  A, Dilated loops of small intestine indicative of acute obstruction. The dilated loops lie in layers. B, If barium is administered to an animal with an acute obstruction, the barium mixes with the fluid in the dilated intestine. It may not reach the point of obstruction. Such studies rarely yield information of significant value. C, This is a standing lateral view with a horizontal beam. Gas-capped fluid levels in the small intestine of a dog with postoperative ileus. There is some fluid and free gas within the abdominal cavity.
Foreign Body. Foreign bodies may be radiopaque or radiolucent. They may cause partial or complete obstruction of the intestine.

Radiologic Signs
1. If the foreign body causes a complete obstruction, the radiologic signs will be those described for obstruction. However, dilated loops of intestine are not always seen with an obstructing foreign body, even when the obstruction appears complete. Dilation is more marked, with obstructions in the distal intestine. Vomiting may reduce or eliminate the distention with more proximally located foreign bodies, particularly when located in the descending duodenum.

2. Radiopaque foreign bodies are seen on plain radiographs. Radiolucent objects may be outlined by gas within the intestine. Some soft tissue opacity foreign bodies have a characteristic appearance. Corn cobs have numerous small gas bubbles in a honeycomb-like pattern. Peach and apricot pits/stones have an ovoid central lucent zone and thin irregular linear gas shadows from gas trapped in the grooves of the pit. Avocado seeds/stones have similar central lucent zones but have smooth surfaces. Wine corks are slightly lucent compared with soft tissue and contain fine, linear gas shadows. Fabric often has a striated or cross-hatched appearance.

3. Barium may be required to demonstrate a radiolucent foreign body. If the obstruction is not complete, the foreign body is often more clearly seen after the main column of barium has passed, when it will be outlined by traces of barium adhering to it.

4. If a foreign body is long and pliable, such as a piece of string, the intestine tends to push together along the foreign body. This results in a gathering together of the coils of the intestine in the midabdomen. This gathering together may be palpable through the abdominal wall. The resulting appearance has been compared to accordion pleats and has also been called plication or bunching (Figure 2-26, M to P).

5. Most foreign bodies are found in the jejunum (Figure 2-26, A to I, K, L, R, S, and U to X). Many foreign bodies pass through the intestine without causing any clinical signs.

Ultrasonography. Large foreign bodies that cause complete obstruction and subsequent fluid retention proximally may be outlined by the intestinal lumen.
Figure 2-26 A and B, A radiopaque foreign body is causing an acute obstruction in the distal small intestine. C, A plain radiograph of the abdomen of the dog with a history of vomiting shows an indistinct, circular, radiolucent shadow in the dorsal abdomen (arrows). There is no gas in the proximal duodenum. D, A barium study outlines a foreign body (arrows) in a duodenum dilated with fluid. The obstructing object was a rubber ball.
Figure 2-26, cont’d. 

E and F, Intestinal obstruction in a dog. This was a rubber ball (arrows) within the jejunum. A gas bubble within a dilated small bowel segment is partly superimposed on the ball on the lateral view. The dilated segment of small bowel appears quite short in this dog. This ball is comparable in opacity to fluid/soft tissue. Balls that have a mineral opacity or are hollow are more readily detected. Those of a soft tissue or fat opacity are more easily missed. 

G to I, Chronic, distal small-intestinal obstruction in a dog. Both right (G) and left (H) lateral views show multiple moderately to severely dilated small-bowel segments, which are filled with a mixture of gas and fluid. Multiple mineral opacity, disklike, and half-moon-shaped objects are seen within one segment of small intestine in the caudoventral abdomen, just right of the midline (I). These are antacid tablets administered by the owner. They are the wrong shape for urinary calculi. There is also moderate generalized enlargement of the liver, which causes caudal and dorsal displacement of the stomach and small intestine. The caudoventral liver margin is markedly rounded.

Continued
Distinct circular or linear shapes and the presence of acoustic shadowing may help identify foreign bodies. Linear stringlike foreign bodies may cause a concertina pattern, with the foreign body seen as a hyperechoic structure within the lumen. Swallowed balls have variable sonographic appearances with distinct semicircular margins (see Figure 2-20, G and J, and Figure 2-26, Q3, Q4, and T).

**Intussusception.** Intussusception is an invagination of a portion of the intestine into the distal segment adjacent to it. It is most commonly seen in young dogs and is often associated with hypermotility of the intestine, enteritis, or parasitism.

The clinical signs are vomiting, abdominal pain, the passage of mucus that may be bloodstained, the passage of blood, and frequently a palpable mass in the
The most common intussusception is ileocolic, although it may occur within the small or large intestine. Cecolic intussusception has also been described. The invaginated portion of intestine is called the intussusceptum; the portion of intestine into which another portion has invaginated is called the intussuscipiens.

In middle-aged and older patients, intussusceptions are often associated with intestinal neoplasms. The primary mass lesion may be small and located within the intussuscipiens and may not be detected. Careful attention should be directed to the mesenteric and ileocolic lymph nodes in older patients with intussusceptions because enlargement of the lymph nodes may indicate the presence of metastasis.

An intussusception may cause a complete or partial obstruction. A partial obstruction may cause no...
clinical signs and may pass undetected. However, the narrow passage through the intussusception inhibits the normal passage of ingesta and, over a period of time, the intestine proximal to the intussusception will dilate. The dilation may become so large as to mimic a megacolon. Clinical signs of obstruction will eventually become apparent.

A contrast study is usually necessary to outline an intussusception. In cases of suspected intussusception, barium given by mouth is not as satisfactory as a barium enema. The time taken to demonstrate the intussusception is much longer with a meal than with an enema—often several hours—and the administration of barium by mouth may provoke vomiting. Barium given by mouth may fail to outline an intussusception. If possible, barium enemas should be observed fluoroscopically. If fluoroscopy is not available, frequent radiographs should be made as the enema is administered (see p. 110). An enema sometimes reduces an intussusception, but in such cases there is often a recurrence within hours (Figure 2-27, A to J).

A pneumocolon—a negative (air/gas) contrast study—may be useful to determine the position of the colon and diagnose intussusception. A pneumocolon is relatively easy to perform and can provide useful information in cases of suspected obstruction, especially intussusception. Introducing air allows confirmation of the position of the colon and whether a suspect segment of bowel is dilated small intestine or large intestine. In some cases the air outlines the intussusceptum within the colon. No patient preparation is required. The patient is positioned in dorsal recumbency, a male urinary catheter is placed in the rectum, and air is gently injected into the colon. The volume used is variable. Air is introduced until it begins to leak from the anus. A ventrodorsal radiograph and at least one lateral radiograph are then made. Both left and right lateral radiographs may be helpful in some cases. The position of the colon is more easily defined on the ventrodorsal view, where, if normal, it appears as a gas-filled structure shaped like a question mark (Figure 2-27, L to Q).
Radiologic Signs
1. If there is complete obstruction, radiologic signs will be evident. Dilated gas- and fluid-filled loops of bowel are seen proximal to the intussusception. The distal intestine may be empty.
2. The mass of the intussusception may be dense enough to cast a soft tissue mass shadow in the central abdomen.
3. Thin lines of gas may be seen outlining the intussusceptum. The gas lies between the intussuscipiens and the intussusceptum.
4. A barium enema will outline the intraluminal mass. Barium will fill the rectum and distal colon normally but will be prevented from filling the proximal colon by the advancing intussusception. Barium tracks up between the intussuscipiens and the intussusceptum, outlining the intraluminal mass of the intussusceptum.
5. Barium percolates between the intussuscipiens and the intussusceptum, outlining circular mucosal folds in the intussuscipiens—the “coiled spring” pattern.
6. Occasionally, gas in the intussuscipiens may outline the intussusceptum (Figure 2-27). On plain radiographs the normal cecum, the ascending colon, and the transverse colon may not be seen.

Ultrasonography. The ultrasonographic pattern depends on the plane of orientation in respect to the intussusception, the length of tissue involved, and the length of time the animal was affected. The intussuscipiens is often swollen and edematous and appears as a hypoechoic rim. The typical appearance in cross-section is that of concentric hypoechoic and hyperechoic rings, which are caused by invaginated layers of the hyperechoic intussusceptum and hypoechoic intussuscipiens. This is often termed the ring or bull’s eye sign. Invaginated mesentery appears as a hyperechoic semilunar-shaped structure. Congested veins may be seen within it. In longitudinal section, the intussusception is seen as a series of linear hyperechoic and hypoechoic streaks or lines. There is often an associated fluid accumulation proximally and, in acute cases, hyperperistalsis, whereas in more chronic cases there is lack of peristalsis (Figure 2-27, K).

Intestinal Stricture. The bowel may be constricted as a result of intrinsic causes, previous enterotomy and scarring, or pressure from without. Stricture from extrinsic pressure is unusual because the small intestine tends to become displaced rather than compressed by extrinsic masses. Peristaltic contractions
should not be mistaken for strictures. They will alter in appearance from one radiograph to another. If a stricture has been present for some time, the intestine proximal to it dilates and becomes filled with impacted food material, which is often dense enough to be radiopaque. If there is no visible dilation of the bowel, a stricture can be demonstrated with barium or a mixture of barium and food material. Serial radiographs should be made to demonstrate the unchanging nature of the narrowed segment. Chronic stricture will result in radiologic signs of chronic intestinal obstruction (Figure 2-28).

Ultrasonography. If outlined by fluid, the site of stricture may be identified. Sonographic signs of intestinal obstruction will be evident.

Displacement. The small intestine is freely movable within the abdomen and thus is easily displaced by extrinsic pressure. With physiologic enlargements, such as a full stomach, a pregnant uterus, or a distended bladder, the degree and direction of displacement will depend on the organ involved and the size of the enlargement. Pathologic enlargements of intraabdominal structures such as those resulting from neoplasms or distention may displace the intestine, as may diaphragmatic rupture (hernia). The manner in which the intestine is displaced is often a diagnostic aid in determining the site of an enlargement (see Figure 2-2, A to E).

Enteritis (Inflammatory Bowel Disease). Enteritis or inflammatory bowel disease is often difficult to diagnose on radiographic evidence alone, because the signs are not specific. Eosinophilic gastroenteritis, intestinal histoplasmosis, granulomatous enteritis, lymphocytic-plasmacytic infiltration, intestinal lymphangiectasia, and other inflammatory bowel conditions all cause thickening of the intestinal wall and may be demonstrable radiographically with positive contrast medium. A reliable evaluation of the thickness of the intestinal wall on plain radiographs is not possible. Because fluid and soft tissue have the same radiographic opacity, a mixture of gas and fluid within the bowel can give a false impression of intestinal wall thickness. A fluid opacity superimposed on the opacity of the wall may make the wall appear thicker than it actually is.

Radiologic Signs
1. Abnormal amounts of gas are seen widely distributed throughout the intestine but not dilating it.

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Figure 2-26, cont’d U to W, Pyloroduodenal fabric foreign body in a dog. U and V, On the right lateral (U) and ventrodorsal (V) radiographs, the distal part of the gastric body and pyloric antrum are filled with mixed-opacity material that appears similar to food. W, However, on the left lateral view the mixed-opacity material (arrows) appears fixed to the lesser curvature of the pyloric antrum and is surrounded by air along its cranial, ventral, and caudal borders. At surgery, a piece of fabric was found at the pyloroduodenal junction. This case demonstrates the importance of obtaining left and right lateral recumbent views.
Swallowed air should not be mistaken for endogenous gas. In enteritis, gas is present in long, narrow streaks, whereas swallowed air tends to be present in sufficient quantities to fill the intestinal lumen without dilating it. Furthermore, swallowed air is usually present in the stomach as well as in the intestine.

2. A mixture of gas and fluid in the intestine may have a bubbly appearance.

3. Rapid passage of barium through the intestine indicates hypermotility and may be associated with enteritis. Fluoroscopic examination will show increased peristaltic activity.

4. Barium may fail to fill the lumen of the intestine because of exudation. Barium often leaves a streaky appearance along affected lengths of the intestine.

5. Irregularities in mucosal pattern, including ulceration and uneven distribution of barium, may be seen.

6. Thickening of the intestinal wall may be concomitant with inflammatory change. This sign requires contrast to demonstrate it.

7. Small, nodular filling defects have been described associated with enteritis (Figure 2-29, A).

Ultrasoundography. Normal bowel wall thickness and layering are evident in animals with viral and bacterial enteritis. If ileus ensues, bowel distention and lack of peristalsis become evident. Duodenal wall thickening may be seen secondary to pancreatitis or inflammatory bowel disease. Infiltrative disease such as plasmocytic lymphocytic enteritis and lymphangiectasia may cause thickening of the bowel wall, but usually without disruption of the wall layers. Lymphadenopathy may be seen (Figure 2-29, B to D).

Neoplasia. Intestinal neoplasia appears to be more common than gastric neoplasia, although both are relatively rare in the dog and more common in the cat.
Adenocarcinoma and lymphosarcoma are the most commonly encountered tumors. The clinical signs are indefinite but persistent. Weight loss over a period of time, inappetence, vomiting, and diarrhea are often associated with a developing neoplasm. There may be blood in the feces. Ascites may be evident.

**Radiologic Signs**
1. Plain radiographs may show signs of intestinal obstruction.
2. On barium studies, irregularities within the intestine such as ulceration, obstruction, or constriction can be seen.

**Figure 2-27 A to D, Intussusception.** A and B, Plain radiographs of a dog with an intussusception show gas crescents (arrows) trapped between the intussuscipiens and the intussusceptum. C, An acute intestinal obstruction with gross dilation of loops of small intestine. This proved to be an intussusception. D, An intussusception is clearly outlined by a barium enema. Its distal limit is indicated by the arrows. Proximally, the characteristic “coiled spring” appearance of intussusception can be seen. This is caused by barium within folds in the intussuscpiens. (Some barium is present in the stomach and duodenum.)
3. Adenocarcinomas in the wall of the intestine tend to produce annular constricting lesions, narrowing the intestinal lumen.
4. Annular bowel neoplasms often produce an “apple core” or “napkin ring” appearance on contrast studies.
5. Lesions of lymphosarcoma are more diffuse, affecting longer segments of the intestinal wall.
6. Intraluminal masses produce constant filling defects on barium examination (Figure 2-30, A to E). Many conditions affecting the small intestine show no definite radiographic changes.

Ultrasonography. Intestinal neoplasms may be infiltrative or mass lesions. Infiltrative lesions cause mild to moderate thickening of the intestinal wall.
The normal layers are blurred or obliterated. Intestinal masses due to lymphoma or mast cell tumor are usually hypoechoic in appearance. The mass lesions have well-defined serosal borders and may be circumferential or eccentric. The wall layers are usually obliterated. At the periphery of the lesion, the wall layers may be intact but partially blurred. The lumen of the intestine appears as a bright, irregularly shaped hyperechoic band within the mass. The bowel proximal to the lesion may be dilated if the mass causes an obstructive ileus. There is usually moderate to severe enlargement of the local lymph nodes. The surrounding mesenteric and omental fat may appear hyperechoic. Mass lesions caused by carcinomas are usually smaller than lymphoma lesions and affect a shorter length of small bowel. Pseudolayering may be seen with carcinomas (see p. 91). Smooth muscle tumors have a mixed echogenicity and are usually eccentrically located.

There may be food or fluid retention proximally. Peristalsis is often disrupted in the affected segment. If the lesion is intraluminal, it may be outlined by fluid. Extramural masses may disrupt the external contour of the intestine and may cause localized inflammation and bunching of the intestines. If gas-filled loops are seen passing into and through a mass, the mass may involve the mesentery or the intestinal wall (see Figure 2-26, J, and Figure 2-30, F to H).

THE LARGE INTESTINE
Anatomy
The large intestine is composed of the cecum, the colon, the rectum, and the anal canal. In the dog, the cecum is a diverticulum of the proximal colon, with which it communicates through the cecocolic valve; this valve lies to the right of the midline at approximately the level of the third lumbar vertebra. It does not communicate directly with the ileum. The cecum is twisted on itself in a corkscrew shape. It lies within the duodenal loop. In the cat the cecum is a straight, blind pouch.

The colon is divided into ascending, transverse, and descending parts. It is shaped like a question mark or a shepherd's crook. The right colic, or hepatic, flexure unites the ascending and transverse portions, and the transverse and descending parts form the left colic, or splenic, flexure. The ascending colon lies to the right of the midline ventral to the right kidney. It is related to the right limb of the pancreas dorsally and to the duodenum on the right. To the left and ventrally it is in contact with the small intestine; cranially, it touches the stomach.

The transverse colon is related to the stomach cranioventrally and to the left limb of the pancreas craniodorsally. It lies cranial to the root of the mesentery. Caudally it is in contact with the small intestine.
INTUSSUSCEPTION

This is a transverse ultrasound image of an intussusception. The multiple eccentric, alternating dark and bright bands represent the two layers of bowel wall forming the intussuscipiens. The intussusceptum is eccentrically located within the intussuscipiens (asterisk). The tissue adjacent to the intussusceptum is mesentery. The small, round, hypoechoic structures within the mesentery are congested vessels (arrows).

L, Pneumocolon in a dog. This dog presented for evaluation of vomiting. Survey abdominal radiographs showed fecal-type material in the right caudal abdominal quadrant that did not appear to be contained within the colon. A pneumocolon was performed to determine the position of the colon. A radiopaque catheter is visible (arrow) in the middle part of the descending colon. There is good distention of the transverse and ascending colon with gas. The ascending colon extends further caudally than normal. Fecal material can be seen within this segment of the large intestine, partly outlined by the gas that was injected. This was determined to be an anatomic variant and of no clinical significance.

The descending colon lies to the left of the midline and extends from the left colic flexure to the pelvic inlet. Dorsally it is in contact with the iliopsoas muscle; cranially, it is related to the left kidney and ureter. Medially it is related to the ascending duodenum; laterally it is related to the spleen. Elsewhere it is bounded by the small intestine. Caudally it lies dorsal to the bladder and uterus. The descending colon is sometimes longer and more tortuous than usual, in which case it may lie partially on the right side. It is then referred to as a redundant colon.

The rectum is the terminal portion of the colon, beginning at the pelvic inlet and ending at the anal canal. Ventral to the rectum is the vagina in the female and the prostate gland and urethra in the male.

Radiography
The large intestine is usually seen on plain radiographs because of feces and gas within it. Detailed studies require a barium enema.

Before a barium enema is performed, the animal should be fasted for 18 to 24 hours. A mild cathartic is given 12 hours before the procedure. General anesthesia or deep sedation is usually required to eliminate straining. The colon should first be thoroughly washed out with saline at a temperature somewhat below body temperature. Tepid solutions are said to result in less gas accumulation within the colon than solutions at body temperature. Plain radiographs in lateral and ventrodorsal recumbency are then made. A cuffed catheter is used to introduce the barium suspension. Cutting off the tip of the catheter may help reduce spasm. Inflation of the catheter bulb prevents backflow of the barium suspension.

The concentration of the suspension should be approximately 15% to 20% weight/volume, and it may be prepared from any of the commercial liquid suspensions of barium recommended for study of the upper gastrointestinal tract. Gravity flow from a large container is more satisfactory than using an enema syringe. The amount of suspension is approximately 10 to 20 mL/kg body weight, given slowly. It should be a little below body temperature. If fluoroscopy is available, the colon should be monitored as it fills. If fluoroscopy is not available, frequent radiographs should be made during the procedure.
Figure 2-27, cont’d M to Q, Intussusception outlined by a pneumocolon technique. M, The initial right lateral radiograph shows a severely dilated, gas-filled, inverted U-shaped segment of small intestine in the cranial abdomen. There are several moderately dilated small-intestinal segments in the ventral abdomen. These are filled with feces-like material. N, Normal cecal gas shadows are absent on the ventrodorsal projection. O to Q, A male urinary catheter was placed in the colon and room air injected. This fills the colon. O, The distal end of the intussusceptum is seen as a convex soft tissue structure (arrows) in the ascending colon on the right lateral view. P, On the left lateral view, gas rises into the right half of the abdomen, resulting in more complete filling of the ascending colon. The gas outlines the distal end of the intussusceptum (arrows) and also dissects between the intussusceptum and the intussuscipiens. Q, On the ventrodorsal view, a thin linear gas shadow is seen within the lumen of the intussusceptum (arrows).
The Abdomen

113

Figure 2-28 A and B, Plain radiographs of the abdomen show a large mass of impacted ingesta with enteroliths within the small intestine. The small intestine was grossly distended and impacted proximal to a constriction in the ileum. This type of mineralized material is associated with chronic intestinal obstruction. This 5-year-old mongrel bitch had been losing weight over a period of 5 months. The stricture of the ileum found at surgery was believed to be associated with an earlier intussusception.

to assess the degree of filling of the colon. The colon should be filled completely to its physiologic capacity but not overdistended. Radiographs made in the ventrodorsal position are best for evaluating the degree of filling. When the colon has been filled, left and right lateral and ventrodorsal radiographs are made. The colon is then evacuated, and postevacuation films are made.

Finally, air, in sufficient volume to fill the colon, is introduced through an enema syringe, and radiographs are made in right and left lateral and ventrodorsal recumbency. These are double-contrast studies because some barium adheres to the wall of the colon. Care should be taken not to mistake residual fecal debris for abnormalities in inefficiently prepared patients.

**Pneumocolon.** Air alone is sometimes used. The colon is evacuated by an enema, and air is gently introduced through a cuffed catheter. If the study is intended solely to identify or locate the colon, an enema may not be required. A large urinary catheter can be used to introduce air. The colon is inflated to its physiologic limit but not distended (see Figure 2-27, L).

A barium enema may be carried out in an emergency without full preparation, such as if an intussusception is suspected, and when the interest in such cases is not in a detailed examination of the wall of the colon. Endoscopy and ultrasound have almost completely replaced contrast studies in evaluating the colon.

**Normal Appearance**

On plain radiographs, the colon is seen with varying degrees of clarity, depending on the contents. On the lateral view, the colon lies roughly parallel to the spine in the dorsal third of the abdominal cavity. On the ventrodorsal view, the ascending colon is seen to the right side and the descending colon to the left.

In the cat, the cecum is not usually seen. In the dog, the cecum can be identified to the right of the midline because it usually contains some gas. A barium enema reveals a smooth mucosal surface. On double-contrast studies, small circular opacities are often seen. These opacities represent barium accumulations in small depressions associated with lymphoid tissue. Longitudinal mucosal folds are seen after evacuation of barium. Care should be taken not to mistake small fecal remnants adhering to the colonic wall for abnormalities (Figure 2-31).

**Ultrasonography**

Because the large intestine usually contains a considerable quantity of gas, ultrasonographic examination is limited. It is located adjacent to the bladder. Peristalsis
is not a feature. The wall thickness is thinner than that of the small intestine.

**Abnormalities**

**Fecal Retention (Constipation).** Fecal retention is evidenced by the persistent presence of fecal material in the colon and rectum. The feces may be very dense, approaching the opacity of bone. Fecal impaction may result. One should be slow to make a diagnosis of constipation purely on radiographic evidence. Dogs and cats may void hard feces. Constipation is not present until the stimulus to defecate has been entirely lost (Figure 2-32).

**Megacolon.** Megacolon is a condition in which there is gross dilation of the colon. Part of or the entire organ may be affected. Congenital megacolon (Hirschsprung’s disease) results from the absence of myenteric ganglion cells in the segment of colon just distal to the dilated portion. The muscle in the involved segment is in a permanent state of contraction, obstructing the passage of feces. The colon proximal to the contracted segment dilates over a period of time, and the wall may hypertrophy. Mechanical megacolon may result from any prolonged obstruction to the passage of feces through the distal colon or rectum, such as a large callus on a healed pelvic

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**Figure 2-29** A, Excessive amounts of gas in the small intestine without dilation suggest enteritis. B, This dog had inflammatory bowel disease. A sonogram of the abdomen shows longitudinal and transverse sections of the small intestine (I). The intestinal layers are visible. The intestinal wall thickness is increased and measures 6 mm between the markers. Fluid and gas are seen in the lumen. Cr, Cranial.
fracture. Both dogs and cats can be affected with megacolon.

The age at which the condition is recognized will depend on the cause and severity of the obstruction. It is often first recognized in adult life. The clinical signs include recurrent constipation, the passage of blood-stained mucus, tenesmus, and occasional diarrhea even in the presence of masses of hard feces.

The dilated, hard colon can be palpated through the abdominal wall.

Radiologic Signs
1. Masses of radiopaque feces or fecal pellets are seen in a dilated colon.
2. The dilation ends abruptly at the aganglionic segment if aganglionosis is the cause.

Figure 2-29, cont’d C, These mesenteric lymph nodes (L) were part of a string along the length of the small intestine (I). They are enlarged. The dog had inflammatory bowel disease. D, Magnified view of one of the lymph nodes (L and black arrows). Each marker along the side of the image represents 1 cm. Cr, Cranial; I, intestine; S, spleen.
3. The aganglionic segment and the rectum are usually empty, which helps distinguish the condition from simple fecal impaction, in which feces are often seen in the rectum.

4. In mechanical megacolon, dilation ends at the point of obstruction.

5. A barium enema will indicate the point of obstruction or confirm the presence of a terminal aganglionic contracted segment. It is rarely necessary (Figure 2-33, A to C).

In most cases the diagnosis can be made from plain radiographs. Muscular spasm may cause contraction of the intestine around an enema catheter. This type of contraction should not be mistaken for permanent contracture. Such spasms are transient.

Dilation of the colon resulting from chronic obstructive constipation is sometimes seen in dogs and is referred to as pseudomegacolon or obstipation. It is a form of mechanical megacolon and may be caused by old healed pelvic fractures, prostatomegaly,
Figure 2-30, cont'd  D to F, Small-intestinal mass in a cat.  

**D,** The lateral radiograph shows indistinct increased soft tissue opacity in the midabdomen. This causes ventral and caudal displacement of some of the small intestine. Serosal detail in the midabdomen is reduced.  

**E,** On the ventrodorsal view, a well-defined ovoid mass (arrows) is present in the right midabdomen, caudal to the right kidney and lateral to the spine. The small intestine is displaced to the left. Large osteophytes are seen on all aspects of both hip joints. Incidentally, there is hip dysplasia and severe secondary degenerative joint disease of both femoral heads.  

**F,** There is an eccentric mass in the wall of the small intestine. The mass has a uniform hypoechoic appearance, with complete obliteration of normal small-intestinal wall layers. The mass measures approximately 1.7 cm in depth (cursors). The small-intestinal lumen appears as an irregular, ragged hyperechoic line, deep to the eccentric mass lesion. A diagnosis of lymphoma was obtained by ultrasound-guided fine-needle aspiration.  

**G,** Jejunal lymphoma in a cat. There is an asymmetric, hypoechoic mass originating within the wall of the small intestine. There is moderate thickening of the wall in the near field (cursors 1) and severe thickening of the wall in the far field (cursors 2). Normal wall layering has been obliterated.  

**H,** Jejunal lymphoma in a cat. There is moderate thickening of the intestinal wall (0.74 cm for near wall). The normal layers have been effaced and replaced by three poorly defined bands in the wall nearest the transducer. This appearance is referred to as pseudolayering and should not be mistaken for normal layers.
neoplasia, strictures, or foreign bodies. No contracted distal segment is present. Prolonged fecal retention on a regular basis from any cause will eventually lead to dilation of the colon. Fecaliths may form (Figure 2-33, D and E).

**Colitis.** Colitis, an inflammation of the colon, may be acute or chronic, ulcerative or granulomatous. The principal clinical signs are straining (tenesmus), diarrhea (often blood stained), and the frequent passage of small amounts of feces with or without mucus. A combination of proctoscopy, radiography, and fecal examination is usually needed to make an accurate diagnosis. A barium enema examination is necessary to demonstrate the radiologic changes.

**Radiologic Signs**
1. Thickened mucosal folds
2. Narrowing of the colonic lumen
3. Spasm of segments of the colon
4. Dilation of segments of the colon
5. Mucosal serrations; that is, an irregular, serrated appearance of the colon (Figure 2-34, A to D)

Ulceration (ulcerative colitis) may or may not be present. In acute colitis there may be no visible radiographic changes.

Ultrasonography. If the colon contains fluid, it may be seen as an anechoic structure, and the fluid may outline an intraluminal mass. Hyperechoic flocules (gas) may be seen moving in the fluid (Figure 2-34, E and F).

**Foreign Body.** Foreign bodies in the colon and rectum are seldom of clinical significance because they are usually passed or are easily removed. If a foreign body is causing difficulty, it may be important to be sure of its position. Radiography can be used to identify its position with accuracy. At least two views at right angles to one another are necessary. On occasion, sharp pieces of bone or pointed foreign objects become lodged in the colon or rectum (Figure 2-35, A and B).

**Displacement.** The colon may be displaced by masses adjacent to it, such as enlarged medial iliac (sublumbar) lymph nodes, an enlarged ovary or uterus, renal enlargement, a distended bladder, neoplasia of the sublumbar muscles or vertebrae, or an enlarged prostate gland. A redundant colon should not be mistaken for a displaced colon. Abdominal masses such as bladder enlargement, enlargement of the prostate, or paraprostatic cysts can displace the colon dorsally. Vaginal masses may displace the rectum dorsally (see Figure 2-63, A to C).

**Intussusception.** Intussusception has been discussed in connection with the small intestine. If the...
Figure 2-32, A and B, Fecal retention in a dog. Fecal material can be identified in the colon and rectum. The presence of quantities of fecal material in the colon and rectum does not necessarily imply that the animal is constipated. House-trained dogs may show fecal retention on radiographs if they have not had an opportunity to defecate before radiography.

A pneumocolon is a quick and easy technique for the diagnosis of colonic intussusception. Ultrasonographic examination is carried out as described for the small intestine.

Neoplasia. Neoplasia of the large intestine is not common in dogs or cats. Adenocarcinoma, carcinoma, and lymphosarcoma are occasionally encountered. Benign adenomatous polyps in the colon and rectum have been reported. The clinical signs vary with the type and location of the tumor. Blood in the feces, constipation, or diarrhea and tenesmus are common presenting signs. Annular constrictions resulting from neoplasia may result in pseudomegacolon. A barium enema examination will outline areas of constriction or ulceration. Filling defects are seen. Double-contrast studies are valuable for outlining polyps. Neoplastic masses may occasionally be identified on ultrasonographic examination. Thickening of the wall is difficult to appreciate because of intraluminal gas (Figure 2-36, A and B).
Figure 2-32, cont’d C to F, Obstipation. C and D, This is an 11-year-old cat that presented with tenesmus for 8 days. The lateral abdominal radiograph shows the colon contains dense fecal material and the lumen is distended ventral to the last two lumbar vertebrae. The rectum is empty. A spiculated mineral opacity is evident at the cranioventral margin of the pelvis. Uroliths are present within the urinary bladder and in both kidneys. D, The ventrodorsal projection of the pelvis shows that there is an aggressive proliferative periosteal reaction involving the right ilium. The pelvic inlet is narrowed. Constipation caused by narrowing of the pelvic inlet is sometimes termed obstipation. This was an osteosarcoma. E and F, Obstipation from old pelvic fractures. On the ventrodorsal view, the pelvic diameter is seen to be narrowed.

**Imperforate Anus, Atresia Recti, Atresia Coli.** Imperforate anus, atresia recti, and atresia coli are rare congenital conditions. Radiography is used to demonstrate the extent of the deficiency. In the case of imperforate anus, a blunt metallic probe is placed against the anal dimple, and a lateral radiograph is made with a horizontal beam and with the animal’s pelvis and hindlimbs elevated. This position ensures that the gas in the intestine will rise to outline the caudal limit of the bowel. An estimate can then be made of the distance between the probe and the gas. A similar technique can be used in cases of atresia coli.
and recti; a long blunt metal probe is gently inserted through the anus as far as it will go. Care should be taken not to damage the intestine.

The Rectum. The rectum may be the seat of a number of abnormalities such as diverticulum, neoplasia, and displacement. Rectal tears are rare. Rectal neoplasms tend to be annular invasions of the wall, causing stricture (Figure 2-36, A and B).

Rectal diverticulum is often associated with perineal hernia, although it may occur as a separate entity. The diverticulum is of the pulsion type (see p. 74). Accumulated feces in the diverticulum are often seen on plain radiographs, particularly on the ventrodorsal view (Figure 2-36, C).

The rectum may be displaced by intrapelvic masses such as an enlarged prostate, vaginal masses, pelvic or soft tissue neoplasms, traumatic lesions, or intrapelvic

Figure 2-33 A and B, Megacolon. The colon is distended and impacted with hard, dense fecal material. The terminal aganglionic segment and the rectum are empty. The prostate gland is enlarged and intraabdominal. It narrows the lumen of the rectum. However, this enlargement would not account for the degree of impaction. C, Gross megacolon. D, A 6-year-old dog with tenesmus. A large fecolith lies in the colon in the caudoventral abdomen. E, A fecolith in the colon. The terminal colon is compressed and depressed by sublumbar lymph node enlargement. The bladder is displaced cranially by a soft tissue opacity caudoventral to the fecolith, which was an enlarged prostate gland.
A barium enema fails to fill the ascending colon and cecum fully despite the fact that some barium has reached the ileum. The colonic mucosa is irregular in appearance. The dog was infested with *Trichuris vulpis*. C and D, Barium enema radiographs of a 2-year-old female Boxer that had intermittent, bloody diarrhea for the previous 6 months. C, The barium-filled descending colon (right ventrodorsal oblique positioning) is distensible but exhibits diffuse, superficial mucosal ulcerations (arrows). The partially filled ileum has a smooth mucosal pattern. D, A close-up of the postevacuation barium enema radiograph of the descending colon reveals prominent tortuous mucosal folds that produce a rugose pattern. The folds appear finely nodular, and there are numerous flecks of barium clinging to small superficial ulcers (arrows). Large intestinal biopsy disclosed chronic histiocytic ulcerative colitis. (C and D From Gomez JA: The gastrointestinal contrast study: methods and interpretation, *Vet Clin North Am* 4:805, 1974.)
abscession (see Figure 2-63, A and B). Air in the anal sacs may occasionally be seen on either side of the rectum and caudal to or superimposed on the tuber ischii (see Figure 2-35, C).

Because of the pelvic bones, ultrasonography is unrewarding in examining intrapelvic structures. A caudal approach placing the transducer in the peri-anal region may occasionally afford access to a lesion.

THE ADRENAL GLANDS

Anatomy
The adrenal glands lie on the craniomedial aspect of each kidney. They lie in the retroperitoneal space. The left adrenal gland lies below the transverse process of the second lumbar vertebra and the psoas minor muscle. It is related to the abdominal aorta medially. Caudally it is related to the renal artery and vein. Ventrally it is covered to a variable extent by the spleen. Laterally it is related to the left kidney. The right adrenal gland lies near the hilus of the right kidney under the last rib, the psoas minor muscle, and the right crus of the diaphragm. Medially it is related to the caudal vena cava. Ventrolaterally it is covered by the right kidney. The cranial two thirds of the gland is covered by the right lateral lobe of the liver. Each gland is crossed dorsally by the ipsilateral phrenicoabdominal artery and ventrally by the phrenicoabdominal vein. Each gland consists of a cortex and a central medulla (Figure 2-36, D). The normal adrenal glands are not seen on plain radiographs of the abdomen.

Ultrasonography
For ultrasound examination a 5- or 7.5-MHz transducer is required. The ventral abdomen is clipped, as are both flank areas over the last two intercostal spaces on the right side and caudal to the last rib on the left side. A flank approach avoids the superimposition of intestinal gas on the adrenal gland. The right adrenal gland may require an intercostal approach. The left adrenal gland is roughly peanut shaped and lies lateral to the aorta between the cranial mesenteric and renal arteries and craniomedial to the left kidney. The right adrenal gland is comma shaped with a marked angulation at its midpoint. It lies between the caudal vena cava and the craniomedial aspect of the right kidney. The left gland is larger than the right. When imaging, locate the left kidney and sweep cranially and medially. Search the area between the kidney and the aorta on the left side and the kidney and the caudal vena cava on the right. The adrenal glands are usually hypoechoic, but occasionally a hyperechoic medulla is seen. Transverse and longitudinal scans should be made. The glands may be difficult to find in obese animals, and gastrointestinal gas may obscure them (Figure 2-36, E).

Adrenomegaly. The length of an adrenal gland is proportionate to body weight. The width is less variable and is therefore a more reliable criterion for assessment of adrenomegaly. The normal width is approximately 6 to 7 mm. When enlarged, a gland is usually isoechoic with the renal cortex. It becomes rounded. One or both glands may be affected. Gross enlargement of the adrenal gland tends to displace the cranial pole of the kidney ventrally and laterally (Figure 2-36, K to M).

Cushing’s Syndrome (Hyperadrenocorticism). Cushing’s syndrome is the term applied to abnormalities resulting from a chronic excess of glucocorticoids (hyperadrenocorticism). Hyperadrenocorticism may be pituitary dependent (PDH) as a result of excessive secretion of adrenocorticotropic hormone (ACTH)—Cushing’s disease—or due to a functional cortical tumor of the adrenal gland or long-term administration of exogenous corticosteroids. The excess in pituitary secretion may be the result of pituitary hyperplasia or neoplasia resulting in adrenocortical hyperplasia. An excess of glucocorticoids may also result from adrenocortical adenoma or carcinoma.
One or both adrenal glands may be affected. Mineralization in the gland together with signs of Cushing’s syndrome is highly suggestive of neoplasia (Figure 2-36, F and G).

Clinically, affected animals are usually in the middle to older age groups. The usual presenting signs are muscle wasting, obesity, alopecia, polydipsia, and polyuria. There is often increased appetite. As the condition progresses, the animal may develop a potbellied appearance from atrophy of the abdominal muscles and redistribution of fat within the abdomen. The pendulous abdomen may reduce the degree of caudal displacement of the stomach as a result of liver enlargement. There is lethargy, muscle weakness, and frequently panting. There may be dystrophic mineralization of soft tissues. This occurs commonly in the lung and appears as a diffuse, moderate, unstructured interstitial pattern. It is often not sufficiently opaque to suggest mineralization. There may be mineralization of the great vessels, visible as parallel opaque lines. Calcinosi cutis may also occur in long-standing cases.

Radiologic Signs
1. Moderate to severe generalized hepatomegaly.
2. Abdominal distention (potbelly).
3. Calcinosi cutis.
4. Bronchial, vascular, and pulmonary calcification.
5. The kidneys may show an increased opacity caused by nephrocalcinosis.
6. There may be a generalized decrease in bone opacity (osteopenia).
7. Mineralization of the adrenal gland (Figure 2-36, F and G).
8. Fat is selectively deposited dorsal to the caudal lumbar spine and pelvis and in the inguinal regions.
9. In cases of adrenomegaly, a soft tissue mass may rarely be seen displacing the kidney ventrally and laterally.

Ultrasonography. Adrenomegaly can cause the glands to be hyperechoic. Bilateral enlargement is suggestive of pituitary-dependent hyperadrenocorticism. Unilateral change is occasionally associated
with PDH, making a differential diagnosis from neoplasia difficult. The adrenal glands may be normal in size in some cases of PDH (Figure 2-36, A and L). An adrenal mass lesion suggests adrenal tumor hyperadrenocorticism. Determination of the cause of Cushing’s syndrome requires biochemical tests, and imaging provides only circumstantial evidence.

**Addison’s Disease.** Addison’s disease is caused by hypoadrenocorticism. The principal clinical signs are lethargy, weakness, and collapse. The radiologic signs include microcardia, a decrease in visible pulmonary vessels, reduced size of the caudal vena cava, pulmonary hyperinflation, and occasionally megaesophagus. On ultrasonography the adrenal glands may be

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**Figure 2-36 A and B,** A persistent filling defect in the rectum (arrows) from an undifferentiated carcinoma. The patient was a 9-year-old spayed female dog with a history of difficult defecation and dribbling of urine. **C,** A rectal diverticulum is outlined by a barium enema (arrows). Continued
smaller than usual. Small adrenal glands may also result from steroid medication.

**Neoplasia.** An adrenal mass may occasionally be seen as a soft tissue mass in the dorsal abdomen overlapping or lying caudal to the kidney. Mineralization in the adrenal gland has been described as an incidental finding and is common in older cats. It may be mistaken for nephrolithiasis (Figure 2-36, F to I).

**Radiologic Signs**
1. A soft tissue mass in the right or left cranial dorsal abdomen.
2. Lateral, ventral, and caudal displacement of the ipsilateral kidney.
3. If the lesion is malignant and has invaded the ipsilateral kidney, there will be enlargement and displacement of that organ.
4. Mineralization within the mass.

**Ultrasonography.** Usually only one gland is affected by neoplasia. If the gland width is more than 2 cm, the possibility of neoplasia is increased. Disruption of the outline resulting in asymmetry is sometimes seen. However, there is considerable overlap in size between PDH-affected glands and those affected with neoplasia. With neoplastic disease, echogenicity is variable. Focal hyperechoic nodules and acoustic shadowing associated with calcification and/or an enlarged gland may indicate neoplasia, either benign or malignant. Malignant adrenal neoplasms such as carcinomas and pheochromocytomas are locally invasive. The tumor infiltrates local vessels such as the caudal vena cava, renal veins, and phrenicoabdominal veins. Invasion of the ipsilateral kidney, epaxial musculature, and lumbar spine have also been reported. The presence of a thrombus within the caudal vena cava adjacent to an adrenal mass is considered evidence of malignancy. Invasion of vascular structures, especially the caudal vena cava, may result in acute hemorrhage into the retroperitoneal space and collapse. Invasion of the lumbar spine may cause compression of the spinal cord and clinical signs similar to those noted with thoracolumbar disk prolapse.

Such cases may present with spinal or abdominal discomfort or, in the case of hemorrhage, as a collapsed patient. Tumor types cannot be determined by ultrasound. Evaluation of other abdominal organs for metastases is advisable. Pheochromocytoma is a rare tumor of the adrenal gland (Figure 2-36, K, M to S).

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**THE URINARY SYSTEM**

The urinary system is composed of the kidneys, ureters, bladder, and urethra.

**THE KIDNEYS**

**Anatomy**

The kidneys are bean shaped in appearance and are located in the retroperitoneal space in the cranial abdomen, one on either side of the aorta and caudal vena cava. They lie obliquely tilted in a craniodorsal
to caudoventral direction. The left kidney is less firmly attached to the dorsal wall than the right and hence is more variable in position. The right kidney lies more cranially than the left and is in contact with the renal fossa of the caudate lobe of the liver. Its cranial pole is within the rib cage, and it is usually bisected by the thirteenth rib. It is related to the right adrenal gland. Medially it is close to the caudal vena cava; ventrally it is in contact with the right limb of the pancreas and the ascending colon.

Cranially the left kidney is in contact with the spleen, the greater curvature of the stomach, the pancreas, and the left adrenal gland. Dorsally it is related to the sublumbar muscles; caudally it is in contact with the descending colon. Medially it is related to the descending colon and the ascending duodenum. Ventrally it is related to the descending colon.

Each kidney consists of a peripheral cortex surrounding a medulla, which in turn surrounds the renal sinus—which contains fat, vessels, and nerves—and the renal pelvis. The portion of the medulla closest to the renal sinus that projects into the renal pelvis is called the renal crest or renal papilla. The pelvis collects urine from the collecting ducts of the kidney from where it travels via the ureter to the bladder. An opening on the medial aspect of the kidney called the hilus carries the renal artery and vein, the ureter, lymphatics, and nerves. Five or six diverticula extend the pelvis into the renal parenchyma. Both kidneys move somewhat during respiration.

The kidneys of the cat are more freely movable than those of the dog because of their longer attachments. They are rounder and plumper than those of the dog. The kidneys may be displaced caudally by a full stomach or cranially by a gravid uterus.
Radiography

The kidneys are clearly seen in approximately 50% of plain studies of the abdomen of the dog. The left kidney is more often completely outlined by fat, whereas in many dogs only the outline of the caudal pole of the right kidney can be seen. When the kidneys are the prime source of interest on plain radiographs of the abdomen, visualization can be enhanced by adequate patient preparation. Food is withheld for 12 hours, and a cleansing saline enema is given approximately 2 hours before the examination. The enema should be at less than body temperature to reduce gas accumulation within the bowel. Water is allowed. Right-left lateral and left-right lateral recumbent together with ventrodorsal radiographs should be made. The kidneys are usually seen on plain radiographs of the abdomen of the cat; in this species failure to see them warrants further investigation.

Figure 2-36, cont’d E5, Normal left adrenal gland in a dog. This is a dorsal plane reconstruction of an abdominal CT. The gastric fundus contains fluid that appears slightly hypoattenuated compared with the stomach wall, liver, and spleen. The body of the spleen is caudal and lateral to the gastric fundus. Part of the head of the spleen is caudal and medial to the gastric fundus. The left renal vein extends from the renal hilus to insert into the caudal vena cava (CVC). Just cranial to the left renal vein, lateral to the caudal vena cava, and medial to the cranial pole of left kidney (LK), the left adrenal gland is visible (arrows). It is a soft tissue structure of comparable attenuation to the vessels and kidneys. The left ureter, a thin, slightly hyperattenuating linear structure, is seen extending caudally and medially from the left renal hilus. RK, right kidney. E6, Normal right adrenal gland in a dog. This is a sagittal plane reconstruction of an abdominal CT in an adult. The plane of this image is just to the right of midline. The bright, hyperattenuating structures are transverse sections of ribs and transverse processes of lumbar vertebrae. The caudal vena cava (CVC) is a well-defined linear structure extending from the caudal border of the liver to the edge of the image. The right adrenal gland (arrows) is dorsal to the caudal vena cava and closely opposed to it. F and G, Lateral and ventrodorsal views showing a mineralized mass of the right adrenal gland (arrows). Diagnosis; adrenal neoplasia.
Intravenous Urography (Intravenous Pyelography, Excretory Urography). Because plain films give only a limited view of the kidneys, contrast radiography is often used for more detailed studies. The patient is prepared as for plain radiography. The patient should be adequately hydrated. The bladder should be emptied because this is said to induce diuresis. Deep sedation or general anesthesia, unless contraindicated because of the patient’s condition, facilitates the procedure. Survey radiographs should be made before the use of the contrast agent. Pneumocystography before intravenous urography helps outline the terminal ureters more clearly.

The radiographic technique should be adjusted when performing an excretory urogram. The reasons for this are twofold. Injection of iodinated contrast results in overall increased opacity of all tissues, which requires a slightly greater exposure to achieve acceptable film quality. Second, the radiographic technique should be adjusted to accentuate the contrast provided by iodine. This is best achieved by slightly reducing the kilovoltage used for survey radiographs and increasing the milliampere seconds.

Several preparations of water-soluble iodinated contrast media are available commercially. Nonionic preparations such as iopamidol or iohexol are used. Ionic agents such as sodium iothalamate or sodium diatrizoate may be used if available. Untoward reactions after injection are rare, although vomiting occasionally occurs after rapid injections. Systemic hypotension and contrast-induced renal failure are potential complications. Monitoring the patient’s

Figure 2-36, cont’d H and I, Adrenal neoplasia. This 14-year-old Yorkshire Terrier presented with bilateral hair loss, hyperpigmentation, and anorexia. An abdominal mass was palpable. H, A large soft tissue mass is seen in the midabdomen. Both kidneys are visible dorsal to the mass. The gas-filled cecum overlies the mass on the lateral view. I, On the ventrodorsal view the cecum is displaced laterally by the mass, which lies centrally in the midabdomen. On ultrasonography, the mass had a mixed echogenicity with a distinct border. It was 7 cm in length. J, Adrenomegaly. Pituitary dependent hyperadrenocorticism (Cushing syndrome) in a dog. This is a sagittal plane image of the left cranial abdominal quadrant. The left adrenal gland is a bilobed, peanut-shaped structure. The depth at the caudal pole is slightly greater than 0.8 cm (cursors). Two short parallel lines seen adjacent to the central narrowing of the adrenal gland represent part of the phrenicoabdominal vein.

Continued
Figure 2-36, cont’d K, Adrenomegaly. The left adrenal gland (arrows) has an enlarged and bulbous cranial pole. Diagnosis: adrenal mass. L, The transverse plane of this adrenal gland shows the width of the cranial pole (arrows), which is 1.2 cm. Diagnosis: hyperadrenocorticism. A, Adrenal gland; L, liver; CR, cranial. M, Adrenal nodule in a dog. A sagittal plane ultrasound image of the left adrenal gland shows a well-defined, hyperechoic nodule within the cranial pole of the gland. A thin rim of hypoechogenic cortex surrounds the nodule. This suggests that the lesion may be in the medulla. The patient had no clinical or biochemical evidence of adrenal disease. N, Malignant adrenal tumor in a dog. This is a sagittal plane image of the right cranial abdominal quadrant in a dog. There is liver tissue in the near field. The bright, curved, echogenic line on the lower left side of the image is the lung/diaphragm interface. The caudal vena cava (CVC) extends from left to right across the image. A mixed echogenic thrombus is present within the lumen of the caudal vena cava. The thrombus is large and dilates and distorts the lumen of the caudal vena cava. The presence of vascular invasion is a reliable sonographic sign of malignancy. O, Adrenal adenoma in a dog. This is a dorsal plane reconstruction of part of an abdominal CT in a dog. Iodinated contrast medium was injected intravenously. There is enhancement of the left kidney (LK), more marked in the cortex. The left renal vein (L renal V) is seen as a curved hyperattenuating (bright) structure extending from the renal hilus to the caudal vena cava (CVC). Cranial to the left renal vein and lateral to the caudal vena cava, a well-defined ovoid mass (asterisk) of mixed attenuation is seen. The histologic diagnosis after surgical excision was adrenal adenoma. P, Adrenal adenoma in a dog. Transverse CT image of the abdomen at the level of the left kidney in a bone window. A water-soluble iodinated contrast medium has been injected intravenously. There is opacification of the aorta (AO-arrow), which is immediately ventral to the lumbar vertebrae. Ventral and to the right of the aorta is the caudal vena cava (CVC, arrow). There is contrast opacification of kidneys. A mass (asterisk) is present between the aorta, caudal vena cava, and left kidney (LK). This mass has a heterogeneous appearance, with minimal peripheral contrast enhancement. The mass is well defined, and there is no evidence of invasion of adjacent tissues or vascular structures. The histologic diagnosis after surgical excision was adrenal adenoma. RK, Right kidney.
blood pressure during an intravenous urogram is recommended. Increasing opacity of the renal silhouettes with no evidence of contrast output in the ureters or urinary bladder may be caused by contrast-induced renal failure or contrast medium-induced hypotension. Treatment is directed at supporting the cardiovascular system by administeringpressor agents and fluids and inducing diuresis. If the problem is recognized quickly, treatment is usually successful. Preplacement of an intravenous catheter ensures that immediate treatment can be given if necessary. Antianaphylactic agents should be available. Nonionic agents may be given to uremic patients unless there is severe dehydration. However, patients with severe renal disease have limited capacity to concentrate contrast in urine, and the study may be nondiagnostic. Increasing the dose beyond the recommended level does not usually improve opacification except in uremic patients. Perivascular injection may result in sloughing of the surrounding tissues. The use of contrast medium may affect urinalysis results and urine cultures for some time after the study.

Renal angiography and tomography have also been used to study the kidneys. Intravenous urography is, however, the most practical method, except where specialized facilities are available.

**High-Volume Slow Infusion.** Contrast material, 1200 mg iodine/kg body weight, is mixed with an equal volume of a 5% dextrose-saline solution. The dose should not exceed 35 g of iodine. This dose is given intravenously over a period of 10 to 15 minutes. Lateral and ventrodorsal radiographs are made at the end of the infusion, and a compression device is applied. Further radiographs are made after 10 minutes, and the compression band is then released if kidney function appears to be normal. Transit times of the contrast agent may vary. The terminal ureters can be demonstrated on oblique views after the compression
has been removed. This method is preferred for the demonstration of ectopic ureter. It is also useful in cases of renal failure. The ureters are visible for a longer time than with other methods. It produces good visualization and requires fewer radiographs than does the rapid infusion method.

**Low-Volume Rapid Infusion.** If the procedure is an elective one, the patient should be prepared carefully, including a cleansing enema. If the procedure is an emergency one for which no preparation can be undertaken, the possibility of artifacts from fecal material should be kept in mind. Deep sedation or general anesthesia (preferably) should be used. A plain ventrodorsal radiograph should be made to check the adequacy of the exposure and to exclude the presence of obvious pathologic changes that could make the study unnecessary.

A dose of water-soluble iodinated contrast material may be rapidly infused into a peripheral vein after the animal has been placed in dorsal recumbency over the cassette. The dose recommended is 850 mg of iodine per kilogram of body weight, with the maximum dose not exceeding 35 g of iodine. Ventrodorsal radiographs are then made as quickly as possible and again at 5 minutes, 10 minutes, 15 minutes, and 30 minutes after the injection. Transit times of the contrast agent may vary. Further radiographs may be made if indicated. Oblique views with approximately a 30-degree tilt from ventrodorsal are necessary to outline the terminal ureters. A left ventral-right dorsal oblique view will show the right ureter, and a right ventral-left dorsal oblique view will show the left ureter.

Compression may be applied to the caudal abdomen to improve opacification of the ureters. It should not be used if there is obstruction to the outflow from the bladder because of the danger of rupture. If compression is to be used, it should be applied before the injection is made. The dose is reduced to 425 mg iodine/kg body weight. A standard compression device may be used, or foam rubber pads may be bandaged tightly over the ventral aspect of the abdomen cranial to the pubis. Because compression may cause some distortion of the ureters, it is advisable to make further radiographs immediately after the compression has been removed.

**Normal Appearance**

The paired kidneys lie in the retroperitoneal space and have a soft tissue opacity. They are somewhat bean shaped. The clarity with which the kidneys are seen on plain radiographs depends on the amount of perirenal fat present and on the absence of food material within the alimentary tract. The radiographic appearance of the kidneys varies with changes in the animal's posture. With the patient in lateral recumbency, the uppermost kidney rotates on its long axis, profiling the hilar notch. Both lateral views are therefore recommended for optimal demonstration of both kidneys. Movements of the diaphragm during respiration cause a change in position of the kidneys. On lateral views, the kidneys are often partially superimposed on one another, with the cranial pole of the left kidney overlapping the caudal pole of the right. With the patient in right lateral recumbency, the right kidney may be displaced cranially. The superimposition of the kidneys on one another therefore is less when the animal is in right lateral recumbency. If only one lateral view is to be made, right lateral recumbency is preferred. The renal positions are more variable in the cat. Retroperitoneal disease may result in loss of outline of the kidneys.

The right kidney lies in the area from the thirteenth thoracic vertebra to the third lumbar vertebra. Because it overlies the liver, its cranial pole may be obscured unless penetration is adequate and there is sufficient perirenal fat to provide contrast. The left kidney lies in the area from the second to the fifth lumbar vertebrae. In the cat, the kidneys are situated more caudally, and their position is more variable than in the dog.

The normal canine kidney is approximately 2.5 to 3.5 times the length of the body of the second lumbar vertebra as seen on the ventrodorsal view. The normal feline kidney is approximately 2.4 to 3.0 times the length of the body of the second lumbar vertebra as seen on the ventrodorsal view, or 30 to 45 mm. Measurements related to the vertebral bodies are not to be considered accurate. Normal kidneys may be larger or smaller than the lengths suggested. However, normal size does not necessarily mean normal function, and small size may not be associated with renal failure. Abnormality should be suspected in the dog if a kidney is less than 2.5 or more than 3.5 times the length of the second lumbar vertebra. Normal kidneys have a smooth regular outline. But the fact that kidneys may appear normal on plain radiographs does not preclude the possibility of disease.

On contrast studies, both kidneys should be well visualized, with the renal cortices diffusely opaque. They should be smooth in outline. The pelvic recesses (diverticula) are paired collecting channels that extend into the medulla from the pelvis of the kidney; these should be seen together with the pelvis. The ureters should be seen. If compression is not used and the ureter is not dilated, peristaltic waves in the ureter may cause only segments of it to be visualized on any one film. On compression films, the entire ureter is seen. Compression causes a degree of dilation of the ureters, but this dilation can be evaluated on postcompression studies. Radiographs made during the stage of opacification of the kidneys are called nephrograms. With a rapid infusion technique, an arterial phase may be seen on the first radiograph made after the injection. During the pyelogram phase, contrast medium is in the pelvic diverticula, pelvis, and ureters (Figure 2-37, A to C).

On fluoroscopy, peristaltic waves are seen in the ureters. The proximal portion of the ureter is seen to fill with contrast medium, and a peristaltic wave then sweeps it into the bladder. Alpha agonists such as xylazine or medetomidine may abolish normal peristalsis.

The excretion of contrast medium depends on the glomerular filtration rate. Failure of the kidney to
Figure 2-37  A, An arteriogram of normal kidneys. (There is an electrocardiogram cable on the left side of the cranial abdomen.) B, The nephrogram phase of an intravenous urogram. This radiograph was made 10 seconds after the injection of positive contrast medium. The cortex can usually be distinguished from the medulla because of its rich blood supply and hence increased contrast concentration. C, The pyelogram phase. Paired collecting channels (diverticula) extend into the medulla from the pelves of the kidneys. D, Normal canine kidney, sagittal view. The kidney cortex is usually hypoechoic compared with the liver. The medulla is hypoechoic or even anechoic compared with the cortex. The renal capsule is seen as a distinct hyperechoic rim but is usually not visualized at the margins of the kidney. The corticomedullary junction is a well-defined structure. The renal pelvis is hyperechoic. E, Sagittal view through a feline kidney (arrows), which is rounded and plumper than the canine kidney. C, Cortex; M, medulla; Cr, cranial. F, Longitudinal plane through the left kidney showing the arcuate vessels (A) at the corticomedullary junction. The plane of section is slightly oblique, which makes the caudal pole seem much smaller than the cranial pole. C, Cortex; M, medulla; Cr, cranial.
Figure 2-37, cont’d  

G, The renal pelvis (arrow) is hyperechoic because of the presence of fat. This dog was on intravenous fluids, which tend to increase the relative size of the renal medulla. c, Cortex; p, pelvis; m, medulla. 

H, This 2-year-old Boxer was thin and failing to gain weight. Blood biochemistry levels (urea and creatinine) were elevated. Ultrasonography of the kidney shows that the kidney is small (arrowheads). The corticomedullary junction is poorly defined. Both kidneys had similar changes. Diagnosis: renal dysplasia. 

I, Renal dysplasia. This 9-month-old Dalmatian had a history of vomiting for the previous 8 days. Polydipsia had been evident for some time. Renal ultrasonography shows the kidney (arrowheads) to be small with a hyperechoic cortex. Cr, Cranial. 

J, This Labrador had signs of nephritis. The left kidney was enlarged. This is a sagittal scan through the right kidney (K), which is very small, measuring only 3 cm (between the markers) and hyperechoic. Corticomedullary definition is absent. Cr, Cranial. 

K, This is a sagittal plane image of a kidney of a 4-year-old cat with cholangiohepatitis. A distinct hyperechoic border or rim is seen at the corticomedullary junction. It is often seen as an incidental finding in cats and has been called the medullary rim sign. 

L, This is a dorsal plane image showing a faint hyperechoic border or rim at the corticomedullary junction. This medullary rim sign was an incidental finding in this cat.
excrete contrast medium satisfactorily may indicate loss of kidney function. However, this is a crude test of kidney function; other methods should be used to evaluate kidney function properly. A thorough clinical and laboratory investigation should precede radiography in all cases of suspected renal dysfunction.

**Ultrasonography**

A 5- or 7.5-MHz transducer is required for renal ultrasonography. The kidneys may be examined from a ventral approach with the animal in dorsal recumbency. However, intraabdominal gas can interfere with the imaging technique. The kidneys can be consistently visualized by a paralumbar approach with the animal in alternate lateral positions. The hair is clipped over the last two intercostal spaces on the right and just caudal to the last rib on the left. The skin is cleaned and acoustic gel applied. A 7.5-MHz transducer is preferable for this examination because the kidneys are in the near field. Standard transverse and sagittal planes of the kidney should be made. A third plane of section, the dorsal plane, is obtained by directing the ultrasound beam parallel to the lumbar vertebrae and at right angles to (perpendicular to) the transverse plane of the kidney. The kidneys may be examined from underneath or by a dependent approach with a table with a cutout section if colonic gas is interfering with the examination.

The renal shape, size, and architecture can be evaluated. Renal length varies considerably in normal dogs because of body size variation. It is less variable in cats. The right kidney lies within the renal fossa of the caudate liver lobe. The left kidney lies behind the last rib and may be medial to the spleen. The echotexture is fine and slightly granular and is markedly hypoechoic compared with the spleen. The renal cortex in dogs is hypoechoic or isoechoic compared with the liver and is always hypoechoic in relation to the spleen. In cats, the echogenicity is often hyperechoic when compared with the liver and may be isoechoic compared with the spleen. The renal medulla is hypoechoic or anechoic in relation to the renal cortex. Comparison with the liver and spleen is of value only if these organs are normal and are imaged at the same depth. The renal medulla is divided into segments by the diverticula and the vessels. The renal pelvis is hyperechoic because of the presence of fat and fibrous tissue. The renal vein may be identified in this region.

The corticomedullary junction is defined by the presence of bright hyperechoic specks that represent the arcuate vessels. The confirmation of renal disease often requires fine-needle aspiration or tissue core biopsy (see Chapter 6, p. 551) (Figure 2-37, D to H).

**Abnormalities**

Radiographic examination does not always reveal characteristic signs of kidney or ureteral disease. It can, however, provide information regarding the number, size, position, shape, and opacity of the kidneys. How the findings compare with those of normal studies can then be assessed. When variations from the normal are seen, they must be explained on congenital or pathophysiologic grounds. It would be unrealistic to attempt to correlate all the possible changes encountered with pathologic aberrations or physiologic variations. This discussion is therefore confined to manifestations of abnormality seen in the more common conditions.

Provided exposure factors are correct, absence of a renal shadow on plain radiographs may mean hypoplasia of the kidney, absence of the kidney, insufficient perirenal fat to provide contrast, or retroperitoneal disease that results in a lack of contrast. In deep-chested dogs, the cranial abdominal muscles may obscure the kidneys. Absence of a renal shadow on contrast studies may mean absence of a kidney, insufficient contrast medium, impairment of the blood supply to the kidney, or inability of a kidney to excrete contrast medium.

**Changes in Opacity.** Increased renal opacity may be diffuse or focal. A diffuse increase in opacity, also called nephrocalcinosis, may be seen in hyperadrenocorticism, chronic renal disease, hypervitaminosis D, and nephrotoxicity. Focal increases in opacity are usually associated with calculi (nephroliths), osseous metaplasia of the renal pelvis, or dystrophic mineralization as result of neoplasia or hematoma. Renal calculi are usually magnesium, ammonium, or phosphates.

Reduced renal opacity is rare but may be a result of vesicoureteral reflux after pneumocystography or abscess formation.

Comparative echogenicity depends on the same machine settings of depth, gain, power, and frequency. A distinct hyperechoic border or rim is sometimes seen at the corticomedullary junction. It is often seen as an incidental finding in cats and occasionally in dogs. It has been called the medullary rim sign (Figure 2-37 K and L).

**Enlargement.** Gross enlargement of the kidneys with a smooth margin may be unilateral or bilateral and attributable to a variety of causes, including hydronephrosis, cysts, neoplasia, perinephric pseudocysts, amyloidosis, or glomerulonephritis. Mild enlargement may be seen in acute renal failure, acute pyelonephritis, ethylene glycol (antifreeze) poisoning, and portosystemic shunts.

Renal enlargement with an irregular outline may be seen in neoplasia (primary or metastatic), abscess, feline infectious peritonitis, hereditary cystadenocarcinoma in German Shepherds, renal cyst, or polycystic kidney disease.

An enlarged left kidney displaces the descending colon ventrally and medially and the small intestine medially and caudally. An enlarged right kidney displaces the descending duodenum and the ascending and transverse colon medially and ventrally.

**Reduced Size.** Small kidneys are usually the result of chronic renal disease. In juvenile animals, small kidneys are usually caused by renal dysplasia or familial renal disease. Many pathologic processes, when
they reach a chronic, irreversible stage, may eventually cause the kidneys to become small and irregular in outline. Such kidneys are referred to as \textit{end stage}. These small, irregular kidneys can be detected on plain radiographs. Excretion of contrast medium is often poor. Small, regularly shaped kidneys may be associated with renal hypoplasia or specific types of renal disease, such as glomerulonephritis or chronic renal infarcts. In renal dysplasia, the kidneys are small and irregular in outline.

\textbf{Ultrasonography.} End-stage kidneys are usually small and irregular and have an increased cortical and medullary echogenicity with poor corticomedullary distinction. They are often difficult to find (Figure 2-37, \textit{J}). In ethylene glycol (antifreeze) poisoning, the medulla appears hyperechoic compared with the cortex, which is hypoechoic.

\textbf{Displacement.} The left kidney can be displaced by a splenic mass or an enlarged adrenal gland. The right kidney may be displaced by an enlarged liver or an enlarged adrenal gland. Both kidneys may be displaced ventrally by masses originating in the retroperitoneal space.

\textbf{Congenital Defects.} One or both kidneys may be absent (agenesis), congenitally deformed, dysplastic, polycystic, misplaced (ectopia), very small (hypoplasia), or nonfunctional. If one kidney is nonfunctional or absent, the other one may be hypertrophied. Congenital hydronephrosis has been described with hypertrophy of the opposite kidney. These defects are best demonstrated by contrast studies or ultrasound. Unilateral congenital defects may cause no clinical signs, although they may predispose the kidney to disease processes.

\textbf{Ultrasonography.} Ultrasonography can confirm the presence or absence of a kidney. A diffuse increase in echogenicity of the renal cortex is seen with renal dysplasia. If severely affected, kidneys may be difficult to find within the perirenal fat, which is also hyperechoic (Figure 2-37, \textit{H} and \textit{I}).

\textbf{Hydronephrosis.} Hydronephrosis, a dilation of the renal outflow tract, may be congenital or acquired. Acquired hydronephrosis results from partial or complete obstruction of the urinary outflow tract, usually obstruction of a ureter. The obstruction may be caused by impingement on a ureter by an abdominal mass, ureteral calculi, stricture of a ureter, neoplasia of the bladder in the area of the trigone, or accidental ligation of a ureter during surgery. Hydronephrosis may be associated with congenital ureteral ectopia. Long-standing cases of ectopic ureters may have moderate to severe pelvic dilation/hydroureter, especially if there is concurrent pyelonephritis. Urine continues to be formed in the presence of an obstruction. This results in dilation of the outflow tract, and the increased pressure gradually causes atrophy of the renal parenchyma. Ultimately, the kidney becomes a large fluid-filled sac and urine formation ceases. There may be no clinical signs if sufficient kidney function is maintained by the opposite kidney and if there is no infection.

\textbf{Radiologic Signs}
1. The enlarged kidney is often seen as a round, smooth abdominal mass with fluid or soft tissue opacity.
2. The kidney displaces adjacent organs and extends ventrally into the abdominal cavity. It must be distinguished from other possible causes of abdominal masses.
3. Intravenous urography will outline the normal kidney.
4. There will be no excretion of contrast medium through the affected kidney if urine production has ceased.
5. Varying degrees of parenchymal opacification are seen depending on how much of the kidney is still functional.

\textit{Hydroureter} (distention of the ureter) is seen proximal to the point of a ureteral obstruction, with a dilated kidney pelvis in cases in which urine excretion is still occurring (Figure 2-38, \textit{A} to \textit{K}).

\textbf{Ultrasonography.} There is a marked dilation of the renal pelvis by anechoic fluid of variable volume depending on the severity of the condition. The degree of distention depends on the cause of the obstruction and the duration of the problem. The dilated ureter is usually visualized as an anechoic tubular structure running caudally to the bladder from the renal pelvis. The ureter can be traced to the dorsal bladder wall if the obstruction is at the level of the trigone. Mild pelvic dilation and hydroureter may be seen with ureteral ectopia. With a long-term disease, the renal architecture is progressively replaced by anechoic fluid. Animals on fluid therapy may have slight enlargement of the renal medulla (Figures 2-38, \textit{L} and 2-42, \textit{H}).

\textbf{Pyelonephritis.} Pyelonephritis is a supplicative inflammation of the kidney. The clinical signs are indefinite, and urinalysis and urine culture are needed for a definitive diagnosis of urinary tract infection. The radiologic signs are usually not specific—irregular kidney outline and, in chronic cases, a decreased kidney size. Intravenous urography may show dilation and distortion of the kidney pelvis and recesses with atrophy and asymmetry of the kidney cortex and dilation of the proximal ureter (Figure 2-38, \textit{I} and \textit{J}).

\textbf{Ultrasonography.} Ultrasonography may show some pelvic dilation and distortion of the collecting system, increased echogenicity in the renal medulla and pelvis, and variable size and shape to the renal contour. A hyperechoic rim around the renal crest and focal hypechoic/hyperechoic areas in the renal cortex with focal hypechoic areas in the medulla may be seen (Figure 2-38, \textit{M} to \textit{O}).

\textbf{Renal Abscess.} Renal abscess is uncommon. Renal enlargement may be seen on the radiographs.
Figure 2-38 A and B, Hydronephrosis and hydroureter. The radiographs were made 15 minutes after rapid injection of contrast medium. The left ureter is grossly dilated, as is the left renal pelvis. C and D, A large hydronephrotic right kidney (arrows). It presents radiographically as an intraabdominal mass. The contrast studies show normal excretion of contrast medium on the left side and no excretion of contrast medium on the right. The cause of the hydronephrosis was clamping of the ureter with a hemostatic clip during surgery for a postovariohysterectomy granuloma. Numerous hemostatic clips are seen.

Continued
Figure 2-38, cont’d E, Intravenous urogram of bilateral hydronephrosis and hydroureter in a 7-month-old female Golden Retriever. The renal pelves, diverticula, and associated ureters are filled with contrast medium and are grossly dilated. F and G, Intravenous urogram of left unilateral hydronephrosis in a 10-month-old mixed-breed male dog. F, Both kidneys have been outlined by dashed lines to exaggerate their contours. The right kidney (R) is normal, and contrast medium is seen in the ureter emerging from it (black arrows). G, The left kidney (L) is grossly enlarged. The left kidney has only a thin rim of functional cortex containing contrast medium (white arrows); the remainder of it is a large, fluid-filled, dilated sac. The caudal pole of the right kidney overlies the cranial pole of the left, and the right ureter (black arrows) contains contrast medium. H, A nonfunctioning left kidney. Compression was used to improve visualization. This accounts for the right ureter appearing wider than usual. (E to G Courtesy Dr. W. H. Rhodes.)

Depending on the extent of the disease, ultrasonography will demonstrate focal hypoechoic areas. Hyper-echoic floccules may be seen. The whole kidney may be involved, with large septated cavities. Distal acoustic enhancement is not as marked as with renal cysts (Figure 2-38, P; also see Figure 2-40, C).

Renal Calculi. Calculi are seen as mineralized opacities within the kidney. They tend to be centrally located. Occasionally a single, large calculus is seen, shaped like the kidney pelvis. Such a calculus is referred to as a stag staghorn calculus. Radiopaque calculi are triple phosphate (ammonium, magnesium,
Figure 2-38, cont’d  I and J, Dilation of the ureters and kidney pelves in a dog with pyelonephritis. This was a 4-month-old puppy with a history of hematuria and vomiting for 8 days.  K, A 5-year-old Rottweiler presented with vomiting and diarrhea. It was depressed, dehydrated, and dribbling urine. An abdominal radiograph shows a distended bladder, and gas outlines the stomach. The kidneys are grossly enlarged and are superimposed on the gastric silhouette. Ultrasonography showed both kidneys to be hydronephrotic. The hydronephrosis was from ureteral obstruction caused by a prostatic carcinoma.
Figure 2-38, cont’d L, This Rottweiler presented with a history of hematuria. The right kidney (arrows) has a dilated renal pelvis (p), and the ureter (u) is also distended. The medulla is enlarged with only a thin rim of cortical tissue present. The ureter was obstructed by a neoplasm at the neck of the bladder. M to O, This Greyhound presented with a history of hematuria and recurrent cystitis. M, Sagittal sonogram of the right kidney (arrows) from the right paralumbar fossa. The normal renal architecture is completely disrupted. Hyperechoic areas are seen in the renal medulla (m). The paired diverticula (d) are profiled by the anechoic area, which represents an abscess (a). N, The left kidney (arrows) from the left paralumbar fossa. The renal medulla (m) is hyperechoic compared with the renal cortex (c). The renal pelvis (p) contains some echogenic urine. O, The bladder contains echogenic material (b). The bladder wall is thickened, and the serosal surface is outlined by echogenic intraperitoneal fluid (f). Diagnosis: pyelonephritis, cystitis, and peritonitis. P, This 8-year-old female Rottweiler presented with pyrexia, anorexia, and abdominal pain. The lateral radiograph shows an enlarged left kidney. Ultrasonography indicated that this was a renal abscess.
Rupture of the Kidney. Rupture of the kidney may occur as a result of trauma. On plain radiographs, a retroperitoneal opacity that obliterates the psoas shadow may be evident. It may extend ventrally, compressing the abdominal contents. On intravenous urography, free contrast medium will be seen retroperitoneally in the area usually occupied by the kidney. If the renal artery is damaged, excretory function may be impaired or completely inhibited. Intracapsular hemorrhage, if severe, will cause an apparent increase in size of the kidney but no specific sign of hemorrhage (Figure 2-40, A).

Ultrasonography. There is disruption of the renal architecture, with anechoic areas representing fresh renal hemorrhage. Perirenal anechoic areas may also be seen, representing intracapsular or perirenal hemorrhage. With time, the anechoic areas become smaller and hyperechoic and variable in echotexture (Figure 2-40, B and C).

Neoplasia. Neoplasia of the kidney is not common. It may be benign or malignant, primary or secondary. Carcinoma arising from the tubular epithelium is the most common neoplasm in dogs. Lymphosarcoma is the most common neoplasm in cats, and involvement of both kidneys may occur. Feline renal lymphosarcoma often occurs in conjunction with the gastrointestinal form. A variety of other malignant tumors have been reported, including hemangiosarcoma, fibrosarcoma, transitional cell carcinoma, squamous cell carcinoma, and teratoma. Benign tumors include fibromas, adenomas, and lipomas.

The radiographic demonstration of neoplasia depends on whether demonstrable changes in size and function are present. The findings may not be specific. Neoplasia should be considered in the differential diagnosis if renal enlargement is present or if the kidney is irregular in outline. Carcinomas often involve only one pole of the kidney. Intravenous urography will show changes in size, shape, collecting
system architecture, and opacification (Figure 2-40, D, K, and L).

**Ultrasonography.** Full examination of the kidney in all three ultrasonographic planes is necessary if small neoplasms are not to be missed. Even so, focal lesions less than 1 cm in diameter may be missed unless high-frequency transducers are used. Neoplastic changes may be focal or multiple. Lymphoma usually has a reduced cortical echogenicity or focal hypoechoic areas with no distal acoustic enhancement. A solitary neoplasm is usually of mixed echogenicity, with focal hyperechoic areas, and it may have replaced most of the renal architecture. Fine-needle aspirate or tissue core biopsy is required for a definitive diagnosis (see Chapter 6, p. 551). If the disease is a diffuse infiltrative process, it may affect both kidneys (Figure 2-40, E to J, M).

**Renal Cysts.** Cysts may be single or multiple. They may be congenital or be acquired as a result of inflammation or obstruction of tubules. The clinical significance of cysts depends on the amount of functional kidney tissue present. Whether cysts can be identified on plain radiographs depends on whether the kidney outline has been altered. Contrast studies will outline changes in shape and demonstrate nonfunctional areas within a kidney. A cystic area will fail to opacify, and pressure from a cyst may distort the collecting system.

Radiographic examination alone seldom yields sufficient specific information to make a diagnosis of renal cysts. Cysts may be difficult to differentiate from neoplasia.

**Poly cystic kidney disease (PKD),** in which parts of the renal parenchyma are replaced by cysts, is sometimes seen in young dogs and cats. It is a heritable disorder in Persians and Himalayan cats. It is usually bilateral. Clinically affected animals show varying signs of renal failure. Not all animals with PKD develop clinical signs.

*Perinephric or perirenal cysts or pseudocysts* may surround normal or nonfunctional kidneys. On plain radiographs they appear as intraabdominal masses that cannot be distinguished from enlarged kidneys or other intraabdominal masses. Contrast studies may show a functional kidney within the mass (Figure 2-41, A).

**Ultrasonography.** Renal cysts are anechoic, smooth-margined, round defects in the renal tissue with distal acoustic enhancement. They are usually eccentric in position. If they lie near the periphery of a kidney, they can deform the renal outline (Figure 2-41, B and C). In severe cases of PKD, the cyst may completely efface normal renal architecture.
Perinephric or perirenal cysts are large, anechoic, fluid-filled areas surrounding the kidney that appear relatively hyperechoic.

**Nephritis.** Nephritis is not usually diagnosed on radiographs. The kidney may be enlarged in acute inflammation. Small, nodular kidneys may indicate chronic interstitial nephritis. Kidney size may be reduced in some cases of nephrosis.

**Ultrasonography.** Acute nephritis may cause no observable changes in the kidneys. Therefore negative findings do not preclude the presence of disease. Acute or chronic glomerulonephritis may cause a band of increased echogenicity in the outer medulla or at the corticomedullary junction (medullary rim sign). A similar change has been reported with hypercalcemic nephropathy. The clinical significance is questionable because it is often seen in normal animals.

Nephritis caused by leptospirosis may alter the sonographic appearance of the kidneys, although some dogs show no changes. In some patients the kidneys appear normal. Nonspecific abnormalities that may be seen include perirenal fluid accumulation, increased cortical echogenicity, and mild pelvic dilation. A hyperechoic medullary band halfway between the pelvis and cortex is seen in approximately one third of cases.

Feline infectious peritonitis and tubular necrosis may not affect renal echogenicity. In chronic interstitial nephritis, there is a poor corticomedullary junction. A diffuse hyperechoic cortex is typical of any chronic renal disease, and a fine-needle aspirate or

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*Figure 2-40* A, Rupture of a kidney. On this intravenous urogram, contrast medium (arrows) is seen to leak out into the retroperitoneal space from a ruptured kidney or ureter. Contrast medium is seen in the ureter of the normal kidney. B and C, This 6-year-old dog was involved in a road traffic accident 10 days previously. It presented with a temperature of 103°F, vomiting, and abdominal pain. B, A longitudinal sonogram of the right kidney demonstrates an anechoic area (arrows) dissecting between the renal capsule and the renal cortex (c). C, Scanning medially, a large, variably echogenic and predominantly hypoechoic area can be identified. Hyperechoic flocules are scattered throughout this hypoechoic region. Diagnosis: infected hematoma.

*Continued*
tissue core biopsy is required for a definitive diagnosis (Figure 2-41, D).

**Infarction.** Regions of infarction can be demonstrated as nonfunctional triangular areas by contrast medium. The findings are not specific because there are many possible causes of nonfunctional areas within the kidney.

**Ultrasonography.** Acute renal infarcts appear as hypoechoic cortical foci that bulge slightly. A chronic renal infarct appears as a triangular hyperechoic region in the renal cortex, with the apex of the triangle directed toward the corticomedullary junction and with a shallow concave defect at the capsular surface (Figure 2-41, E).

**THE URETERS**

**Anatomy**

The ureters are paired tubular structures that carry urine from the kidneys to the bladder. They begin at the renal pelves, where they lie outside the peritoneum, and they course caudoventrally to the bladder, turn ventrally, and enter the bladder through oblique, slitlike openings at the trigone. The distal ureters are within the peritoneum.

**Normal Appearance**

Normal ureters are not seen on plain radiographs or on ultrasonography. They are outlined by contrast medium during intravenous urography coursing between the kidney pelves and the bladder. Fluoroscopic studies show boluses of urine containing contrast medium being propelled along the ureters and into the bladder at the trigone. These waves should not be mistaken for filling defects in the ureter on radiographs.

**Ultrasonography**

The expulsion of urine from the ureters into the bladder (ureteral jets) is occasionally seen in normal animals. Their visibility is enhanced by a difference in the specific gravity of ureteral urine and the bladder contents. This may be achieved by instilling saline into the bladder or inducing diuresis and then carefully scanning the caudal bladder area. Pulses of urine are seen jetting into the anechoic bladder. They may be more easily seen with color flow Doppler (Figure 2-42, F). Debris or sediment in the bladder may also make them easier to see. The presence or absence of the ureteral jets entering the bladder may be useful in the diagnosis of ureteral ectopia. High-resolution transducers and considerable ultrasonographic experience are required.
Abnormalities

Ectopic Ureter. Congenital ectopic ureter may be the cause of urinary incontinence in young dogs. Ectopic ureter in the male is not as common as in the female. In the female, an ectopic ureter may open into the vagina, urethra, neck of the bladder, uterine body, or uterine horn. Ectopic ureter may be unilateral or bilateral. It is frequently associated with some degree of dilation (megaloureter or hydroureter). Urinary tract infection may be present. It may be associated with other congenital anomalies of the urinary tract. A hereditary factor appears to be involved, at least in some breeds. Incontinence is not always a feature of the condition in the male because the ectopic ureter may open into the urethra and the urine may flow back into the bladder.

Clinically affected female animals are persistently incontinent; if both ureters are affected, micturition does not take place. The urine often leaks from the vagina when the animal is lying down.

Radiography. An ectopic ureter may be demonstrated by intravenous urography. Concomitant pneumocystography aids in identifying the caudal ureters. A high-volume technique is said to give better filling of the ureters. To maximize visibility of the ureters, good patient preparation is necessary—that is, fasting for 24 hours before the study and a cleansing enema. Lateral, ventrodorsal, and ventrodorsal oblique views should be made. A right ventral, 30 degrees left dorsal oblique view profiles the left ureter, and vice versa.

The diagnosis of ectopic ureter may be difficult. The abnormal ureter will be seen to bypass the bladder and empty into the vagina. Usually some degree of dilation exists. A ureter may enter the bladder at the normal site and pass within the submucosa to an abnormal opening site. Ectopic ureter has been reported in the cat, but it is rare (Figure 2-42, A and C to E).

Retrograde vaginourethrography (vaginography) has been used as a method of diagnosing ectopic ureter. With the patient under general anesthesia, a contrast-filled cuffed catheter is inserted into the vestibule. The cuff is inflated, and a bowel clamp is applied across the lips of the vulva. Sufficient contrast medium is injected to distend the vagina. The contrast medium used is any of those recommended for intravenous urography diluted to 10% weight/volume of iodine.
A dosage rate of 1.14 mL/kg has been recommended. The contrast medium enters the ectopic ureter from the vagina when the vagina is filled. Such studies are not always easy to interpret. Rupture of the vagina may occur in some breeds, such as the Rough Collie, but is not a cause of serious concern (Figure 2-42, B). CT is a superior technique to diagnose ectopic ureters. It eliminates the problem of superimposition of other body structures, especially the large intestine. The patient is placed in sternal recumbency on the CT table. The study is facilitated by moderate filling of the bladder with urine. After intravenous injection of a bolus of the iodinated contrast medium, repeated CT scans of the caudal abdomen and pelvis are performed. The ureters fill with contrast and are easily identified. Definitive determination of the site of ureteral implantation may require multiple scans.

Ultrasonography. Hydronephrosis or hydroureter is often seen. The dilated ureter may be traced caudally and be seen to bypass the trigone. However, it often tunnels through the bladder wall to the urethra. With gray-scale or color flow Doppler techniques, the presence or absence of ureteral jets can often be assessed. Considerable experience is necessary (Figure 2-42, F).

Ureteral Calculi. Although ureteral calculi are uncommon, a small calculus passing down from the kidney to the bladder may occasionally obstruct a ureter. It is most often seen in older cats, which usually have concurrent chronic renal failure. The uroliths are usually of mineral opacity and most easily identified on survey abdominal radiographs. A careful search is necessary to detect the presence of such a calculus on a radiograph because it may be only a few millimeters in diameter. Adequate patient preparation is vital to eliminate the possibility of material in the intestine being mistaken for a calculus. Alternatively, such material may superimpose on a calculus, causing it to
be missed. Intravenous urography will demonstrate an obstruction (Figure 2-42, G). Ultrasound-guided positive contrast pyelography may be helpful.

**Ultrasonography.** Ultrasound reveals mild or moderate dilation of the renal pelvis, which may contain a number of uroliths. The proximal ureter may also be dilated and can sometimes be followed distally to the obstructive urolith (Figure 2-42, H).

A diagnosis of ureteral obstruction is most readily obtained by the technique of *ultrasound-guided pyelography*. For this technique, the patient is sedated or anesthetized, the skin overlying the kidney is surgically prepared and, with ultrasound guidance, a hypodermic needle is placed in the renal pelvis. Urine is aspirated, and a similar volume of iodinated contrast medium is injected. Lateral and ventrodorsal radiographs are made. If the obstruction is complete,
no contrast is seen to enter the urinary bladder or fill the distal ureter (Figure 2-42, I to M).

**Rupture of the Ureter.** Ureteral rupture is usually the result of trauma to the abdomen. Rupture occurs most frequently near the kidney or near the bladder. Contrast radiography is the most reliable method of assessing ureteral integrity. On intravenous urography, contrast material will be seen to leak from the affected ureter at the site of the rupture. Rupture may be followed by stenosis and hydronephrosis. Plain radiographs may show retroperitoneal leakage as an increased opacity in the retroperitoneal space. If urine leaks into the peritoneal cavity, it will cause peritonitis.

**Ultrasonography.** Anechoic fluid may be seen in the perirenal or retroperitoneal areas outlining the kidneys.

**Hydrourerter (Megaloureter).** Hydrourerter, a dilation of the ureter, may be congenital, or it may be the result of blockage from the presence of a calculus or other obstruction. It may be secondary to infection. It may also result from damage to the ureter, resulting in stricture. This condition is often associated with an ectopic ureter. Contrast studies show a dilated ureter proximal to the point of obstruction. If the condition persists, hydronephrosis will follow. Blockage of the ureter may also result from pressure on it by an abdominal mass or from a bladder abnormality such as neoplasia that inhibits ureteral emptying. Obstruction may occasionally result in atrophy of the kidney without hydronephrosis, in which case the kidney will be smaller than normal (see Figure 2-38).

Ultrasoundography. A distended proximal ureter can be identified as it leaves the kidney pelvis. It is identified as a tubular anechoic structure running caudally from the renal pelvis. If the site of obstruction is a ureteral calculus, the proximal border of a hyperechoic calculus may be outlined by urine. Unless the ureter is grossly distended, its midportion may be obscured by intestinal gas. Distally, the distended ureter is found on the dorsolateral aspect of the bladder.

**Ureterocele.** Ureterocele is a dilation of the distal ureter within the bladder wall. It may obstruct the ureter, or it may cause incontinence by interfering with the function of the bladder sphincter. A contrast study is necessary to demonstrate it. The contrast medium produces a typical “cobra head” appearance at the site of the dilation.

**Ultrasonography.** The dilated terminal ureter may be identified as an intramural anechoic structure in the region of the bladder neck. The condition may be unilateral or bilateral, and the terminal ureter may
Figure 2-42, cont’d C to E, This puppy had urinary incontinence. A low-volume, rapid-infusion intravenous urogram was performed to assess the ureters. A small quantity of negative contrast was introduced into the bladder by a urinary catheter so that the ureters could be more easily seen. The bladder lies completely within the pelvis (black arrow). Some positive contrast is also present within the vagina. C, On the lateral radiograph, a ureter (long arrow) is dilated in its terminal section and is seen to pass dorsal to the bladder neck. D, On the ventrodorsal projection, both ureters are seen. The left ureter (medium arrow) is normal in size. The right ureter (long arrow) is dilated distally and passes beyond the bladder and enters the vagina. E, An oblique projection with the animal tilted to the left profiles the right ureter (long arrow), which is clearly seen bypassing the bladder (short arrow). Diagnosis: right ectopic ureter, intrapelvic bladder. F, This is a transverse abdominal scan of a bladder from the ventral abdomen. Using color flow Doppler, the right ureteral jet can be seen discharging urine from the ureteral papilla into the bladder and creating a Doppler signal (red jet). This technique can be useful to identify the ureteral entrances into the bladder. (See Color Plate 2-42, F.) Continued
appear to lie within the bladder lumen. A hydroureter may be identified proximally.

THE BLADDER
Anatomy
The urinary bladder is a hollow organ located in the caudal abdomen. It varies in size and position depending on the amount of urine it contains. When empty, it may lie partially within the pelvis. The bladder of the cat lies more cranial than that of the dog and is rounder. Dorsally, the bladder is related to the rectum, descending colon, and small intestine in the male and to the uterus and the uterine broad ligament in the female. Ventrally, when distended, it is related to the ventral abdominal wall. Cranially, it is related to the small intestine. The bladder is extraperitoneal but is covered with peritoneum. The bladder wall has
three layers: mucosa, submucosa, and muscle. The trigone is a triangular bundle of muscle fibers dorsally placed, extending from the bladder neck to the entry points of the ureters. One ureter may enter the bladder further caudally than the other. The bladder is maintained in position by two lateral ligaments and a ventral ligament. These ligaments attach to the lateral walls of the pelvis and to the pelvic symphysis and the ventral abdominal wall.

The bladder in the female lies somewhat more cranially than in the male.

**Radiography**

When the bladder contains some urine, it is seen on plain radiographs. Fat in the omentum and the bladder ligaments aid in providing contrast, as do the small and large intestines. A distended bladder may reach the umbilicus.

Detailed study requires the use of contrast medium. Adequate patient preparation enhances the study. The animal should be fasted for 18 hours, if possible, and a cleansing enema, not soapy, given before the contrast is carried out. The temperature of the enema solution should be a little below body temperature. Sedation is advisable. Plain radiographs in the lateral and ventrodorsal positions should be made before the contrast medium is introduced, and the bladder should be emptied. The injection of 5 to 10 mL of 2% lidocaine hydrochloride without epinephrine into the urethra and the bladder helps reduce pain and spasm. The most common indications for contrast studies of the bladder are hematuria and difficulty in or increased frequency of micturition. Various techniques are available to outline the bladder.

**Positive Contrast Cystography.** The bladder is evacuated. Any aqueous organic iodide medium recommended for urography is suitable. The contrast medium should be diluted with sterile water or saline to a concentration of 10% to 20% weight/volume of iodine. The contrast medium is injected through a urinary catheter until the bladder is moderately distended. This usually requires approximately 6 to 12 mL/kg body weight of diluted contrast material. Intravenous injection of contrast medium will also outline the bladder as it is being excreted (Figure 2-43, A to C).

**Double-Contrast Cystography.** A small quantity of 20% weight/volume of water-soluble iodinated contrast medium is first instilled into the evacuated bladder. In dogs the dose of positive contrast is 1 to 5 mL and in cats 0.5 to 1 mL. The animal should be rolled...
over to coat the bladder mucosa. Lateral and ventrodorsal radiographs are made. The procedure should be carried out with the animal in left lateral recumbency to reduce the danger of pulmonary embolism, which may be fatal if air is being used. The bladder is then emptied and moderately inflated with gas (air, carbon dioxide, or nitrous oxide), and further radiographs are made. The volume of air is 1 to 5 mL/kg body weight depending on the size of the dog or cat. Double-contrast cystography gives the most information about the mucosal surface and the thickness of the bladder wall (Figure 2-43, D and E; also see Figure 2-50).

The standard views used for cystography are the lateral and the ventrodorsal. The lateral view is often the most helpful. Oblique views are useful when it is necessary to outline the entire bladder. One should avoid giving an opinion on bladder studies unless the bladder has been adequately distended. During contrast studies, retrograde opacification of the ureters may occur (vesicoureteral reflux) and should not necessarily be considered abnormal, particularly in dogs younger than 3 months (Figure 2-43, F).

During retrograde studies the urinary catheter may rarely enter an ectopic ureter rather than the urethra. Contrast material will then be seen within the ureter and kidney. If air is being used as the contrast medium, fatal air embolism may result.

**Pneumocystography**

Air, carbon dioxide, or nitrous oxide, at a dosage rate of 6 to 12 mL/kg body weight, is injected into the evacuated bladder through a flexible urinary catheter or a Foley catheter, a three-way stopcock, and a large syringe. The procedure should be carried out with the animal in left lateral recumbency to reduce the danger of pulmonary embolism, which may be fatal if air is being used. This risk can be reduced by the use of nitrous oxide or carbon dioxide. The danger of air embolism is possibly greater in cats than in dogs. Air should not be used in the presence of hematuria or in recently traumatized animals. If air embolism
occurs, the animal should be placed in left lateral recumbency with the head lower than the body for 60 minutes. Appropriate emergency measures should be used. The bladder should be moderately distended, the degree of filling being monitored by abdominal palpation. Care should be taken to avoid overdistention. Recoil pressure on the plunger of the syringe or an escape of air around the catheter is an indication that sufficient air has been injected. Flexible male catheters are suitable for both males and females (Figure 2-44; also see Figure 2-43, C).

Normal Appearance
An empty bladder may not be visible on plain radiographs. The bladder may not be seen because of intraabdominal fluid, insufficient intraabdominal contrast, bladder rupture, superimposition of thigh muscles, or abnormal location in a hernia. The bladder may be seen when it contains urine and when there is little or no intraabdominal fluid. It is seen as a pear-shaped soft tissue opacity in the caudal abdomen, with its narrow end (neck) toward the pelvis. It is best seen on a lateral view. When the bladder contains urine, it is intraabdominal. When it is full, it displaces the small intestine cranially and the descending colon dorsally. The bladder is located farther cranially in the female. In the cat it is always intraabdominal because of a long urethra.

After contrast cystography, the bladder should be uniformly distended, and there should be no filling defects or leakage into the abdominal cavity. The wall should be thin and regular in outline. Underinflation may simulate bladder wall thickening. Particularly in
young animals, contrast medium may occasionally be seen in the ureters after retrograde cystography. The prostate ducts will usually not be opacified if the prostate is normal, although this is not an invariable rule.

**Ultrasonography**

The animal may be examined while it is in a standing position or in dorsal or lateral recumbency after standard preparation of the skin and the application of an acoustic gel. A 7.5-MHz transducer is usually adequate for general examination of small- to medium-sized dogs. A 5.0-MHz transducer is required for large dogs, particularly if the bladder is grossly distended. A high-resolution transducer, preferably a linear probe, will be required for evaluation of the bladder wall and to identify the three layers of the bladder wall clearly. The power of the transducer should be reduced to avoid artifacts (see Figure 1-14, B). Overdistention of the bladder results in thinning of the bladder wall, and changes may be overlooked.

**Figure 2-44** A and B, A normal pneumocystogram in a dog. The bladder wall is smooth and thin. C, In this study, air has passed from the bladder into the ureters and renal pelves. The bladder is displaced cranially by an enlarged prostate gland.
Ideally, the bladder should be moderately distended for examination, but in certain disease processes this may not be possible. Instillation of saline may be useful, but only after a careful initial study of the organ. Care must be taken not to introduce air bubbles with the saline. Artifacts produced by the bubbles are highly echogenic and may mask or be mistaken for the saline. Artifacts produced by the bubbles are highly echogenic and may mask or be mistaken for abnormalities (Figure 2-45, E). It therefore follows that the examination should be carried out before urinary catheterization for either samples or radiographic contrast studies. Marked distention of the bladder will cause problems in imaging the far wall, which may lie outside the focal zone of the transducer. The bladder should be examined from the apex caudally in both transverse and longitudinal planes, sweeping cranially and laterally and ensuring that the whole organ is studied. Concurrent abdominal palpation or ballottement is often useful, particularly in determining whether a lesion is fixed in position or moving within the lumen. Alternatively, the animal’s position may be changed. Reverberation, side-lobe, and slice-thickness artifacts may simulate abnormalities.

When containing urine, which is anechoic, the bladder is normally identified in the caudal abdomen as an echolucent structure. The wall is hyperechoic and smooth. The curved margins fade out of the image. The transducer position, or plane, must be changed to evaluate the edges. The bladder wall thickness varies with the degree of distention. The vertex and trigone areas are usually slightly thicker than the rest of the wall. The wall thickness of the distended bladder varies between approximately 1.0 and 2.0 mm (Figure 2-45, A).

A focal thickening in the area of the dorsal trigone may be seen. This is the ureteral papilla, which is the site at which the ureters enter the bladder. The entrance of the ureters into the area of the trigone can be positively identified as a bright jet or stream of echoes representing a pulse of ureteral fluid being propelled into the anechoic lumen of the bladder. This phenomenon can be enhanced by introducing saline into the bladder to change the specific gravity of the urine. The use of a diuretic before ultrasonography will also help identify the ureteral jets. Identification of these jet streams using gray-scale or color flow Doppler has been described as a method of establishing whether ureteral ectopia is present (see Figure 2-42, F).

The colon may cause an indentation into the bladder lumen. Transducer pressure often causes distortion of the wall. Air and mineral material within the large intestine can cause multiple hyperechoic and reverberation artifacts. Scanning from the lateral aspect of the abdomen may help avoid the colon and is often performed as an additional imaging plane. Slice-thickness artifacts may cause pseudosegmental or simulate mass lesions. Reverberation artifacts from the skin or adjacent intestine may cause aberrant echoes in the bladder lumen. Imaging in several different planes will confirm an abnormal bladder shape or intraluminal lesion. Occasionally a standoff is useful to bring the near wall of the bladder close to the focal zone of the transducer. A standoff also helps avoid reverberation artifacts produced by the skin.

Abnormalities

Congenital anomalies of the bladder are rare.

Vesicoureteral Reflux. Overinflation of a normal bladder may provoke reflux. Reflux of urine from the bladder into one or both ureters is often seen in young dogs during contrast studies, but the incidence decreases after approximately 3 months of age. It is more frequently seen in lateral recumbency. In young dogs, vesicoureteral reflux is probably of no significance. In older dogs, it may be a complicating factor in cystitis because refluxed urine provides a continuing source of kidney infection. Persistent reflux may result in an ascending infection of the ureter and kidney (pyelonephritis) (see Figure 2-43, F).

Sphincter Mechanism Incompetence. Animals clinically affected with sphincter mechanism incompetence are able to void normally but leak urine when resting or sleeping. This anomaly may be congenital in some female dogs. After ovariohysterectomy, the bladder neck usually lies in the intrapelvic region. Positive contrast retrograde urethrography may reveal an abnormally short or absent urethra or an intrapelvic location of the bladder. Accurate lateral positioning is important. Absence of the sphincter, causing incontinence, is occasionally encountered (Figure 2-45, B to D).

Filling Defects. Filling defects in contrast medium may be due to calculi, blood clots, air bubbles, tumors, and polyps. On a recumbent view of the abdomen, cystic calculi are seen at the center of the bladder because they gravitate toward the most dependent part. Blood clots can change location depending on the position of the animal, or they can be fixed as they adhere to the bladder wall. Clots are variable in shape and size. They may be cylindrical in shape if formed in the ureter as a result of upper urinary tract hemorrhage. Flushing the bladder with water or saline may dislodge them. If air bubbles are present in a positive contrast study, they will be seen at the highest point, which may be central or peripheral. Bubbles tend to accumulate at the edge of the contrast pool in a double-contrast cystogram. Tumors and polyps appear as fixed, persistent filling defects in the bladder wall. Tumors are most frequently found in the area of the bladder neck, polyps most commonly at the apex. Changes in the posture of the animal may help differentiate air bubbles, calculi, and clots (see Figure 2-51, A to C).

Cystitis. The principal clinical signs of cystitis are frequent attempts to micturate, with the passage of small amounts of urine. The urine may be cloudy or bloodstained. Deep palpation of the caudal abdomen may be resented. No radiographic changes may be seen in cases of cystitis. In chronic cystitis the bladder wall is thickened, often in its cranioventral region, and shows a
Figure 2-45  A, Normal bladder (B) on a caudal midline transverse ultrasonogram. Arrows, Bladder wall; C, colon; R, right. B, Intrapelvic bladder. This retrograde vaginourethrogram in a 6-year-old female German Shepherd shows the bladder neck lying within the pelvic inlet. The vagina and urethra are clearly seen. C and D, An intrapelvic bladder. A 4-year-old male working Sheepdog had a history of recurrent urinary tract infection. C, An intravenous urogram was performed. The ureters are normal. The bladder lies within the pelvis. D, A retrograde urethrogram was then performed because the bladder had failed to distend. The bladder still lies within the pelvic inlet, and the proximal urethra is undulating and distended, presumably because of the caudal location of the bladder.
decreased capacity to distend. Sometimes the bladder is small as a result of inflammation or when there is polyuria. Wall thickness may be evaluated by pneumocystography or by double-contrast cystography. In older animals, ureteral reflux may be associated with cystitis. Rarely, the bladder wall may become mineralized.

Neoplasia should be considered in the differential diagnosis of localized or diffuse thickening of the bladder wall. Mucosal irregularity and ulceration are frequently seen in chronic cystitis. Emphysema of the bladder wall has been described as associated with diabetes mellitus, but it is not always present. Cystitis may be associated with the presence of polyps (see Figure 2-45, F; Figure 2-46, A, B, and F; and Figure 2-51, D and E).

Ultrasoundography. In cystitis the bladder wall is usually seen to be diffusely thickened. This thickening may be most obvious in the cranioventral region. The bladder wall may appear thickened if it is not distended with urine. The wall may be hyperechoic and have an irregular mucosal margin that is present even when the bladder is distended. If the inflammation is acute, on recovery the bladder wall echogenicity may return to normal. If it contains little urine, examination is difficult. In cystitis, the urine is usually echogenic and gives a swirling effect. This is because of the presence of cells or a high protein content (see Figure 2-51, F). The introduction of normal saline with no air bubbles may be used to distend the bladder. This distention may cause discomfort, in which case sedation or general anesthesia may be required (Figure 2-46, D to I).

In chronic polypoid cystitis, small pedunculated masses project into the lumen. Differentiation of this condition from neoplasia can be difficult. Neoplastic masses usually have a wide base at their attachment to the wall (Figure 2-46, C to I).

With emphysematous cystitis, multifocal hyperechoic echoes are seen in the wall, with marked reverberation and acoustic shadowing caused by
intramural gas. These shadows are fixed and affect all the wall margins. In some cases, there is luminal gas rather than intramural gas that cannot be differentiated from free intraluminal gas bubbles resulting from catheterization or cystocentesis based on appearance alone. Free gas bubbles are hyperechoic foci that move and oscillate in the lumen and rise to lie in the upper (nondependent) area of the bladder lumen, forming a reverberation or comet-tail artifact (see Figure 2-45, E and G).

**Calculi.** The clinical signs of cystic calculi are similar to those described for cystitis. Large or multiple calculi can sometimes be palpated through the abdominal wall.
In dogs, phosphate calculi are the most frequently encountered, although urate, cysteine, oxalate, and mixed calculi are also found. Other types, such as xanthine and carbonate, are less common. Silica calculi have been reported. Phosphates, oxalates, and carbonates are radiopaque. Cysteine and urate calculi are radiolucent, and positive contrast studies may be necessary to demonstrate them. Urate calculi have been reported associated with hepatic dysfunction and are common in Dalmatians. Urate calculi may cause signs of lower urinary tract disease and may be the only presenting signs of portosystemic shunts in young adult dogs (1 to 5 years old). Overlying opacities in the intestines can be mistaken for calculi. Proper patient preparation should preclude this error. The calculi found in bitches are often larger than those found in male dogs because calculi are more readily passed through the comparatively wide female urethra. Dystrophic calcification of the bladder wall has been described. Its peripheral location and linear outline help distinguish it from calculi (Figure 2-46, B).

Radiopaque calculi usually pose no problems of identification. They are seen as mineral opacities, usually located in the most dependent part of the bladder, that is, centrally as the animal is lying on its side. If radiolucent calculi are suspected, positive contrast and double-contrast studies should be performed. With positive contrast, calculi appear as filling defects within the contrast medium. They may be masked if too much contrast medium is used or if it is too concentrated. Air bubbles, introduced into the bladder with the contrast medium, may simulate calculi, as may blood clots within the bladder. Blood clots can often be flushed out.

Cystic calculi in cats are not common. Most calculi are phosphate in nature and are radiopaque. They may appear as fine, sandlike deposits in the most dependent part of the bladder. Clinically there may be blood in the urine and difficulty in micturition. The bladder wall is often thickened as a result of a concomitant cystitis.

A careful examination is often necessary to detect the presence of small calculi because they can be easily missed or be hidden by intestinal contents in an inadequately prepared patient (Figure 2-47, A to E; also see Figure 2-53, A, C, and D).

Ultrasonography. Ultrasonography identifies all calculi, whether radiolucent or radiopaque. Calculi are frequently identified as hyperechoic foci or masses within the bladder lumen. Acoustic shadowing is usually marked, particularly with high-frequency transducers. However, a small calculus may not generate an acoustic shadow. The calculi gravitate to lie in the dependent portion of the bladder and change position with ballottement of the body wall or with movement of the animal. If they are present with a concomitant inflammatory process, they may be attached to the bladder wall. These attached calculi are difficult to differentiate from dystrophic mineralization of the
A B

Figure 2-47  A and B, A large single calculus in the bladder of a dog. Such large calculi are more commonly seen in females (there are fractures of the pubis and sacrum). C, Multiple cystic calculi. D, Calcifications in the omentum may simulate cystic calculi. A contrast study or ultrasonography should be performed to positively identify opacities within the bladder. Six round mineral opacities are seen centrally located within the bladder. E, This is a domestic short-haired cat with a history of dysuria, hematuria, and pollakiuria. This lateral radiograph shows multiple, variably sized, irregularly shaped mineral opacity uroliths within the urinary bladder. No uroliths are seen in the kidneys, ureters, or urethra. A small gas bubble is seen in the center of the urinary bladder. This is the result of a cystocentesis.
bladder wall, which also has a fixed location (Figure 2-47, F to H).

Sediment may be seen lying in the dependent portion of the bladder. When disturbed, it moves as a cloud and resettles with a distinct horizontal border. It is sometimes an incidental finding (see Figure 2-46, C and I). It may indicate the presence of infection, and in cats it may be indicative of urolithiasis. Sloughing of the bladder mucosa is recognized by identifying a thin linear echogenic line that parallels the bladder wall. Blood in the urine appears as sediment or small masses representing clots (see Figure 2-46, D).

Urethral calculi may be identified as hyperechoic structures within a widened urethra. The urethra is distended proximally if there is complete obstruction. Very small calculi may not cast an acoustic shadow.

**Neoplasia.** Hematuria is the common presenting sign of bladder neoplasia with frequency and/or painful micturition. Female dogs are affected more commonly than males.

Neoplastic growths are not usually seen on plain radiographs unless there is associated calcification. Malignant tumors are more common than benign ones. Papillomas and leiomyomas are the most common benign neoplasms, whereas transitional cell carcinoma is the most common malignant tumor. Squamous cell carcinoma, adenocarcinoma, fibrosarcoma, rhabdomyosarcoma of German Shepherds, and other neoplasms are less commonly encountered. Secondary invasion of the bladder by a neoplastic growth is rare in dogs and cats. Extension of urethral or prostatic tumors cranially into the bladder neck is possible. The regional lymph nodes and the lungs are common sites of metastases of bladder tumors. Malignant tumors are highly invasive, and local spread to the ureters, urethra, prostate, rectum, and vagina is possible. Obstructive lesions may result. Hydronephrosis or hydrourereter may occur from blockage of a ureter by a tumor mass in the area of the trigone. Cystography is usually necessary to demonstrate a neoplasm of the bladder. Neoplasia is not common in cats (Figure 2-48, A to J).
Blood clots within the bladder may be mistaken for tumor masses. Flushing the bladder will remove the clots or alter their appearance. Apparent filling defects may be caused by pressure from the small or large intestine. Pressure defects have smooth edges and disappear when the bladder is fully distended.

Pulmonary metastases are uncommon at the time of clinical presentation. Hypertrophic osteopathy (see Chapter 4, p. 438) has been reported to be associated with neoplasia of the bladder.

Radiologic Signs
1. With positive contrast cystography, a filling defect is seen caused by the tumor mass protruding into the lumen of the bladder or eroding the bladder mucosa.
2. On pneumocystography, the mass will be seen protruding into the bladder.
3. Infiltrative tumors that cause thickening of the bladder wall must be distinguished from thickening associated with chronic inflammation. Localized thickening is more suggestive of neoplasia.

Figure 2-48 Neoplasia of the bladder. A and B, This 11-year-old bitch presented with cystitis, a swollen vulva, and a distended abdomen. The intravenous urogram shows a large filling defect around the neck of the bladder and in the dorsal bladder wall. Nodular opacities project into the lumen. The ventrodorsal view shows that the defect is mostly on the left side and that the bladder wall is thickened (arrows). This was an inoperable transitional cell carcinoma. C and D, A large filling defect is seen in the caudal region of the bladder, encircling the bladder neck. The mass was a bladder carcinoma.
Figure 2-48, cont’d E. This 14-year-old male dog had difficulty defecating. The prostate was enlarged and tender. The pneumocystogram shows cranial displacement of the bladder with a very wide prostatic urethra. A filling defect can be seen at the neck of the bladder (arrow). The apparent irregularity of the wall is likely due to the neck.
Figure 2-48, cont’d I and J, This 11-year-old male Labrador presented with a history of pain while urinating or defecating. I, A lateral abdominal radiograph shows a soft tissue mass at the pelvic inlet. A diffuse, sandlike opacity is apparent scattered throughout the caudal abdomen. J, A positive contrast cystogram illustrates multiple filling defects projecting into the lumen of the bladder. Contrast reflux is evident in the prostate. The mineralized material seen in I was dystrophic calcification in a transitional cell carcinoma. K, A Boxer with hematuria. A large, mixed, echogenic mass (m) occupies the left side of the bladder wall and projects as an irregular margin into the lumen (arrows). Diagnosis: transitional cell carcinoma. L, This 10-year-old Kerry Blue presented with a history of frequent urination. A large mass (m and arrows) with a variable echotexture occupies the bladder with no evidence of urine surrounding it. Diagnosis: transitional cell carcinoma.

type. Ultrasound-guided fine-needle aspiration of abnormal lymph nodes is often helpful. An additional method of extracting some tissue for analysis is to use ultrasonography to direct and accurately locate a urinary catheter within the bladder or urethral lumen. The catheter is seen as two hyperechoic parallel lines. The catheter tip is directed immediately adjacent to or against abnormal tissue. Some tissue is then aspirated onto the catheter tip. Cellular tissue will be located in the catheter (Figure 2-48, K to S).

Rupture. Rupture of the bladder may result from trauma, urethral obstruction or, rarely, from a difficult parturition. Rupture is often associated with road accidents. The fact that urination has been observed does not exclude the possibility of bladder rupture. The rupture is usually along the ventral wall and often associated with a tear in the peritoneum, allowing urine to enter the peritoneal cavity. A positive contrast study with the catheter tip located at the tuber ischii should be carried out on every animal that has sustained injury to the pelvis if the bladder is not seen on plain radiographs or when abdominal serosal detail is poor. A water-soluble iodinated contrast medium preparation, 25 to 50 mL of a 10% weight/volume solution, should be used as an initial dose. If urethral catheterization is difficult or painful, an excretory urogram may be performed. However, a urethral tear may be missed with this procedure. Pneumocystography is not advised. It is unsatisfactory because air will fail to distend the bladder, and air embolism may be a hazard (Figure 2-49).
Figure 2-48, cont’d. M, A female Jack Russell Terrier presented with a history of polyuria. A large mass (arrows) occupies the bladder. Diagnosis: carcinoma. N to Q, An 8-year-old crossbred female had hematuria. Transverse (N and P) and sagittal (O and Q) sonograms were made through the caudal and cranial portions of the bladder (B). The bladder is small with a hypoechoic, undulating mass that extends cranially and laterally. The serial studies show the extent of the mass. This bladder tumor (M) involves most of the dorsal part of the bladder (arrows). The trigone was involved, resulting in bilateral hydronephrosis. This was a carcinoma. Cr, Cranial.

Radiologic Signs
1. The bladder shadow is absent or small and contracted.  
2. Fluid within the peritoneal cavity causes a loss of intraabdominal detail. The amount of fluid present will depend on the length of time the rupture has been present and the degree of peritonitis provoked.  
3. A functional ileus may be present secondary to peritonitis.  
4. Positive contrast cystography will show leakage of contrast material into the peritoneal cavity or retroperitoneal space.  
5. Intravenous urography will show whether there has been concomitant damage to the kidneys and ureters.  
6. In many cases there will be associated pelvic fractures.
Ultrasonography. Unless the bladder wall is completely disrupted, it is virtually impossible to locate the source of the leakage by using ultrasonography alone. Free fluid in the peritoneal cavity outlines the serosal surface of the bladder, and there is usually some urine within most ruptured bladders. The integrity of the wall is difficult to appreciate because of echo fade or dropout seen at the curved margins. Introducing agitated saline into the bladder while examining the bladder wall may permit a jet of fluid to be seen escaping into the abdominal cavity. A urinary catheter is placed in the proximal urethra or the bladder neck. The catheter should be prefilled with saline and a very small air bubble. A syringe is filled with fluid such as saline or Ringer’s lactate, although colloid solutions are preferred. The contents of the syringe are rapidly pushed back and forth through a three-way stopcock to a second syringe, resulting in small bubble formations in the fluid. The fluid is then injected through the urinary catheter while the bladder is observed with ultrasound. The fluid appears intensely echogenic on ultrasound images. Any leakage due to rupture of the urinary bladder is readily detected.

However, a positive contrast retrograde urethrocystogram would probably be more useful. Focal thickening or omental adhesions may be seen at a site of rupture. Mucosal disruption may be seen as a focal collection of anechoic fluid dissecting through the bladder wall.

Diverticulum. A diverticulum is a protrusion of the bladder mucosa through a tear in the wall. It may be the result of trauma. Acquired diverticula as a result of mural deficits or iatrogenic causes may occur anywhere in the bladder wall. A diverticulum is best demonstrated by a positive contrast study, on which it will be seen as an outpouching of the bladder wall. Urine is sometimes retained within a diverticulum; in such cases the positive contrast medium will be seen as a persistent opacity in the affected area of the bladder wall. Small congenital diverticula are sometimes seen at the site of attachment of the urachus as the result of a urachal remnant at the cranioventral aspect of the bladder (Figure 2-50).

Ultrasonography. Diverticula appear as anechoic outpouchings or as focal elongations of the wall.

Hemorrhage. Cystitis is sometimes accompanied by intraluminal hemorrhage. Trauma or neoplasia may also cause bleeding. Blood clots may form in the bladder and appear as radiolucent defects on a positive contrast study. These blood clots may be mistaken for neoplastic growths. They are, however, movable within the bladder because they are not usually attached to the wall. They can be flushed out with saline, or at least their radiographic appearance will be altered. Flushing will not affect the radiographic appearance of a neoplasm (Figure 2-51, A to C).

Ultrasonography. Blood clots appear as heteroechoic flocculating structures that do not cast acoustic shadows and that gravitate into the dependent part of the bladder. Large, organized clots have a lacelike consistency. Clots appear more hypoechoic...
when recent and increase in echogenicity with time. If pedunculated, they move to and fro, particularly with ballottement of the bladder wall. They may be difficult to differentiate from polyps or neoplastic lesions, particularly if they are of a compact consistency. Color flow Doppler evaluation will usually show blood flow within tumors or polyps, but never with a clot. Sometimes the whole bladder lumen has a hazy, gelatinous mass within it. This is seen with acute intraluminal bleeding (Figure 2-51, D to F; also see Figure 2-46, D, and Figure 2-48, S).

Hernia. The bladder may be displaced in inguinal, ventral, or perineal hernias. In the case of perineal hernia, the bladder may be retroflexed caudally and may be difficult to demonstrate radiographically. The possibility of perineal hernia should be considered if there is absence of the normal bladder shadow on plain radiographs and normal serosal detail in a patient with a history

Figure 2-49 A, In this animal, which had sustained multiple fractures of the pelvis, positive contrast material introduced by a catheter has leaked from the bladder into the peritoneal cavity, indicating rupture of the bladder. B, A 3-year-old male crossbred Collie presented with anorexia, polydipsia, and vomiting. It had been hit by a car 7 days earlier. A fluid wave was palpable in the abdomen. Plain studies showed poor abdominal contrast and pelvic fractures. A double-contrast cystogram illustrates a filling defect at the cranioventral aspect of the bladder. At surgery, a localized thickening of the wall with an associated perforation was found. A diagnosis of transitional cell carcinoma was subsequently confirmed.

Figure 2-50 A diverticulum in the wall of the bladder. The wall is markedly thickened around the defect. Air has entered a ureter and outlines a renal pelvis and diverticula overlying an intestinal gas shadow.
of stranguria. The overlying thigh muscles inhibit visualization of the displaced bladder. Contrast studies, either positive or negative, may be helpful. There may be difficulty in introducing a catheter or contrast medium because of the retroflexion (see Figure 2-6, D and G).

Ultrasoundography. In an inguinal or ventral hernia, part of the bladder may be identified within the peritoneal cavity. It may have an abnormal shape. In a perineal hernia, the urethra will be turned back on itself. The bladder is seen as an anechoic, fluid-filled structure in an abnormal location and, depending on the cause of the hernia, may or may not contain hyperechoic flocules of blood.

Displacement. Any large mass in the caudal abdomen may displace the bladder. The most common cause of cranial displacement is an enlarged prostate gland. An enlarged uterus may displace the bladder ventrally. In advanced pregnancy, the uterus may come to lie below the bladder and displace it dorsally. The bladder may be displaced in cases of perineal, ventral, or inguinal hernias. Midabdominal masses, if large enough, displace the bladder caudally.

Ultrasoundography. The location of the bladder depends on adjacent structures, but its anechoic nature permits differentiation from most organs. A paraprostatic cyst may confuse the image, but the wall separating the structures can usually be found. In some cases the rapid introduction of saline into the bladder permits saline bubbles to be identified and therefore identify the location of the bladder.

A fluid-filled uterus has a tubular or circular shape, with contents generally having an echogenic appearance.

Distention. The bladder may be highly distended in house-trained dogs that have not had an opportunity to void urine before a radiographic examination. Distention may also be seen after pressure on

Figure 2-51 A, A 9-year-old female Scottish Terrier presented with hematuria and dysuria of 2 months’ duration. An intravenous urogram shows an irregular radiolucent filling defect within the bladder lumen. It was a large blood clot. B, A double-contrast cystogram and intravenous urogram in a dog. The bladder has been distended with a large volume of air. A small pool of positive contrast material is present in the dependent portion of the bladder. Within this pool an irregularly shaped radiolucent filling defect is present. The location and the irregular shape of the filling defect are characteristic of a blood clot. C, Double-contrast cystogram in a cat. The urinary bladder is moderately distended with air, and there is a pool of iodinated contrast. A urethral catheter is present with the tip extending into the bladder. Numerous variably sized air bubbles are seen at the periphery of the contrast pool, which is the typical location.
or damage to the spinal cord, such as in cases of disk protrusion. Distention may also result from blockage of the urethra by a calculus or pelvic damage resulting in pressure on the urethra, or it may be associated with neoplasia. Failure of the bladder to distend normally may be the result of cystitis, neoplasia, rupture, ectopic ureters or, rarely, congenital defects. Failure of the bladder to distend can be demonstrated only on contrast studies (Figure 2-52).

Persistent Urachus (Urachal Remnant). On rare occasions, persistent urachus causes dribbling of urine from the umbilicus. A positive contrast study of the bladder will show leakage of the contrast medium into the urachus. In some cases, part of the urachus persists as an outpouching from the cranial pole of the urinary bladder. This may predispose to recurrent cystitis. Positive contrast cystography can be used to demonstrate the lesion.

Ultrasonography. A high-frequency, high-resolution transducer should be used. The urachus may be identified running from the cranioventral aspect of the bladder toward the umbilical region. The appearance is similar with an urachal remnant, which is seen as a blind pouch rather than a tube.

THE URETHRA

Anatomy

The urethra is the canal that carries urine from the bladder to the exterior. In the male it also transports seminal secretions. The proximal portion of the urethra
in the male passes through the prostate gland before curving around the ischium. Distally, it lies along the ventral aspect of the os penis. In the female the urethra is short, extending from the bladder to the urethral orifice, which lies just caudal to the vaginovestibular junction on the floor of the vagina. The penile urethra in the male cat is directed caudally.

Radiography
In the male dog, two studies are made in lateral recumbency, one with the hindlimbs drawn cranially and one with the hindlimbs drawn caudally. These positions enable evaluation of the extrapelvic and prostatic portions of the urethra, respectively. The normal urethra is not seen on plain radiographs. Oblique lateral views of the pelvis are advisable to confirm or exclude the presence of calculi at the level of the tuber ischi.

Urethrography
If this is an elective procedure, a preliminary enema is advisable. Sedation is required and, in some painful cases, general anesthesia. The urethra can be demonstrated by the introduction of water-soluble iodinated contrast medium through a catheter. Lateral views are the most informative.

Aqueous media, diluted as for cystography, give the best results. Negative contrast studies are less satisfactory. Lidocaine hydrochloride without epinephrine, 5 mL of a 2% solution, introduced before the contrast agent reduces spasm and facilitates the study in sedated patients. A male urethral catheter prefilled with positive contrast agent, containing no air bubbles, is introduced through the urethral orifice and advanced a few centimeters along the urethra. A balloon-tipped catheter may be preferred for the procedure because it seals the urethra and prevent antegrade passage of contrast. Undue pressure should not be applied. The dose administered should be the amount necessary to outline the urethra satisfactorily, usually 10 to 15 mL of water-soluble iodinated contrast medium in the dog and 5 to 10 mL in the cat. The study is enhanced if the bladder is full. Indirect urethrography is more commonly performed in the bitch using the retrograde vaginourethrography technique (see p. 144) rather than direct urethrography. This technique outlines the entire urethra, which is an advantage and is technically easier. The urethra fills once the vagina is distended. In the female, direct urethrography is more difficult to carry out.

Normal Appearance
On contrast studies, the urethra is smooth in outline. The prostatic urethra is somewhat wider than the extrapelvic portion. Contrast material does not usually enter the prostatic ducts. The mucosa in the female shows longitudinal striations. Air bubbles introduced with contrast medium should not be mistaken for calculi (Figure 2-53, F).

Ultrasonography
The urethra can usually be imaged caudal to the bladder as it passes to the level of the pubic brim. In the male it passes through the prostate and is occasionally seen as an eccentric hypoechoic, vaguely circular structure on the transverse scan. Longitudinal hyper-echoic linear streaks in the center of the prostate gland on a sagittal scan represent periurethral fibrous tissue. These streaks are called the hilar echo. The urethra may also be identified caudal to the ischial arch. The use of a urethral catheter in the urethral lumen may help localize the ischial and penile urethra.

Abnormalities
Congenital Anomalies. Congenital anomalies of the urethra are rare in dogs and cats. Absence of the urethra has been reported. Abnormal openings of the urethra have been encountered on the ventral aspect of the penis (hypospadias), into the rectum and, in the female, into the vagina and in the perineal region. Demonstration of anomalies requires the use of contrast studies.

Calculi. The common presenting signs of urethral obstruction are frequent attempts at micturition and the passage of small quantities of urine that is often blood stained. If obstruction is complete, no urine is voided and a full bladder can be palpated through the abdominal wall. Signs of uremia may develop. Urethral obstruction caused by calculi is rare in females.

The most common abnormality associated with the urethra is the presence of urethral calculi in the male dog. These are usually phosphate in nature and radiopaque. They are readily seen on plain radiographs and are often irregular in outline. Positive contrast urethrography is required to outline radiolucent calculi. They appear as filling defects within the column of contrast medium. Air bubbles should not be mistaken for calculi. They are round in appearance and they do not distort the urethra. The best view is the lateral recumbent view taken with the animal’s hindlimbs drawn cranially. Some difficulty may be encountered in identifying calculi within the prostatic urethra or in the area of the ischial arch unless there has been adequate penetration of the tissues by the x-ray beam. The most common sites at which calculi are seen are at the proximal extremity of the os penis and at the ischial arch (Figure 2-53).

Whereas feline urolithiasis syndrome affects both male and female cats, calculi may not be demonstrable radiographically. The obstructing material is often sabulous plugs.

Rupture. Severe trauma to the pelvic area may result in rupture of the urethra. Rupture may also occur during the passage of a catheter. A positive contrast retrograde urethrogram will show leakage of contrast medium into the periurethral tissues (Figure 2-54, A to C).

Stenosis. Stenosis of the urethra may be congenital or follow fracture of the os penis, fracture of the pelvis, surgical interference, or inflammation. Positive contrast radiography is required for its demonstration. The urethra may be dilated proximal to the stenosis (Figure 2-54, D and E).
Ultrasonography. The prostatic urethra may be invaded by neoplastic tissue (Figure 2-54, F and G).

Neoplasia. Urethral neoplasia is rare in the male dog. It is occasionally seen in females. On a retrograde urethrogram or vaginourethrogram, tumors may present either as diffuse mucosal irregularities, local or multiple, or as filling defects. In females, granulomatous urethritis should be considered as a differential diagnosis for urethral transitional cell carcinoma. Neoplasms may extend into the urethral lumen. Cranial extension may involve the neck of the bladder.

Figure 2-53 A and B, Urethral and cystic calculi in a dog. A, A lateral radiograph of the caudal abdomen demonstrates numerous mineral opacities within the urinary bladder. These are calculi that are quite variable in size and have an irregular shape. There are also multiple calculi within the lumen of the urethra in the caudal half of the os penis, causing urethral obstruction. An additional radiograph centered on the perineum should be made to assess the entire urethra. B, Urethral calculi in a dog. This lateral radiograph is taken with both hindlimbs drawn cranially, resulting in a skyline projection of the perineum. It demonstrates multiple mineral opacities of variable size within the urethra at the base of the os penis. This patient had an open reduction of a hip luxation, and the orthopedic implants are superimposed on the hip joint. C and D, Cystic and urethral calculi. Small radiopaque calculi are present in the bladder and along the course of the penile urethra. The bladder is distended from urethral obstruction. E, A radiolucent calculus is outlined by positive contrast (arrow). Air bubbles may be mistaken for calculi. A calculus distends the urethra, whereas an air bubble does not. In this case the filling defect in the urethra was demonstrated on several radiographs. The bladder is distended, and the animal had difficulty passing urine for several days.

Continued
Involvement of the periurethral tissues may occasionally cause an intrapelvic mass that elevates the rectum. It may be difficult to differentiate urethritis from neoplasia. Biopsy or cytologic study results are necessary for a definitive diagnosis (see Figure 2-57, V).

**Ultrasonography.** Urethral tumors may be identified, particularly if the bladder neck is situated well cranial to the pubic brim. They are usually encircling lesions within the wall and can involve the bladder neck. Without the use of transrectal transducers, ultrasonography is of limited benefit; positive contrast radiography is superior as a diagnostic aid (Figure 2-54, F and G).

**Fistulas.** Fistulas, congenital or acquired, are rare. Urethrorectal and urethrovaginal fistulas have been described. Positive contrast retrograde urethrography offers the best means of outlining fistulas.
Chapter 2  ■  The Abdomen  173

structure lying dorsal to the testis. The head lies cranially (Figure 2-56, A).

Abnormalities

Enlarged Testis. An enlarged testicle within the scrotum is readily diagnosed on clinical examination without the aid of radiography. Plain radiographs of the caudal pelvis will show an enlarged scrotum. Orchitis may result in swelling of a testis within the scrotum. Seminomas and Sertoli cell tumors cause swelling of the testis within the scrotum.

Neoplasia. The testis may be the seat of three types of neoplasm: seminoma, interstitial cell tumor, and Sertoli cell tumor. Sertoli cell tumor most frequently arises within a retained testicle when it presents as an intraabdominal mass. Clinically, affected animals may show signs of feminization with bilateral symmetrical alopecia, a pendulous prepuce, and prostatitis. Sertoli cell tumors cause generalized enlargement of the affected testicle and atrophy of the contralateral testis. Interstitial cell tumors are usually composed of small focal nodules. They may be bilateral in distribution. Seminomas are large single masses that are unilateral.

Ultrasonography. The echogenicity and echotexture of testicular tumors are varied and not typical for any one tumor type. They are most often hypoechoic but may be hyperechoic and, if large, generate a mixed heterogenic pattern (Figure 2-56, D to I, K to M, and O).
Atrophy. Atrophy of testicular tissue has been described as an ageing feature in a cryptorchid testicle. It may be seen in the opposite testicle to one damaged by tumor, abscess, or hemorrhage. There is a generalized hypoechoic or isoechoic tissue texture compared with the normal testis.

Retained Testis. Cryptorchidism, or retention of one or both testicles within the abdomen, is a relatively common congenital condition in dogs. The retained testis often becomes neoplastic, with a Sertoli cell tumor being the most common development.

Ultrasonography. A cryptorchid testis may not be seen in the abdomen because it is small. It may lie between the caudal pole of the kidney and the inguinal canal. Abdominal testes are hypoechoic and have an elongated ovoid shape. They are distinguished from lymph nodes by the mediastinum testis. A Sertoli cell tumor is identified as an intraabdominal mass with a mixed echotexture.

Torsion. Torsion of the spermatic cord may occur within the abdomen or the scrotum. Torsion within the abdomen occurs in combination with neoplasia and may present as an intraabdominal mass caused by
swelling of the testicle with acute abdominal pain. The condition also occurs in cats (Figure 2-56, B and C).

Scrotal Hernia. See Figure 2-56, N, and p. 37.

Orchitis. On ultrasound examination, an infected testicle has a generalized hypoechoic echotexture. Focal anechoic regions may be identified, with distinct margins containing some flocculation where abscessation has developed (Figure 2-56, J).

THE PROSTATE GLAND

Anatomy
The prostate gland surrounds the neck of the bladder and the proximal part of the urethra. It lies on the pelvic symphysis and is extraperitoneal. Its position changes to some extent with distention of the bladder. When the bladder is full, the prostate lies cranial to the brim of the pubis. When the bladder is empty, the normal prostate is usually intrapelvic or partially intrapelvic in position. The prostate tends to move cranially with increasing age. In chondrodystrophic breeds, it is situated somewhat more cranially. The urethra passes through the prostate gland. Several prostatic ducts enter the urethra as drainage channels for prostatic secretions. In the cat the gland is small and not usually seen on radiographs.

Radiography
The prostate gland can be seen on plain radiographs of the abdomen. It is best studied on a lateral view. Positive retrograde urethrography is sometimes of value in assessing the prostatic urethra. Prostatic reflux is occasionally seen on retrograde positive or negative contrast studies of the bladder or urethra.

Normal Appearance
The prostate gland is seen on the lateral view just cranial to the pubic brim when the bladder is distended with urine. If the bladder is empty, the prostate is intrapelvic or partially intrapelvic, and its visibility depends on the amount of surrounding fat. It may be seen on a ventrodorsal view on the midline, at or behind the pubic brim.

Ultrasonography
Provided the prostate is intraabdominal in location, it can be examined in lateral or dorsal recumbency or in the standing position in large dogs. Hair is clipped lateral to the prepuce and acoustic coupling gel applied. Parasagittal and transverse scans should be made. The transducer is placed parallel to the prepuce, perpendicular to the skin, and the bladder is located. The transducer is moved caudally to the bladder neck. Angulation of the transducer from side to side will image the intrapelvic prostate. The whole gland should be identified by sweeping the transducer cranially and from side to side. The size varies with age, breed, sexual maturity, and disease process. A normal prostate may be intraabdominal, drawn cranially by the bladder. Correlations
of body weight with ultrasonographic prostate size have been found to be reasonably reliable, but prostatic size is probably still best evaluated by radiography because the whole gland can be seen at one time.

The prostate encircles the urethra as it leaves the bladder neck. The rectum lies dorsally and the bladder cranially. The pubic brim lies ventrally, and variable portions of the prostate may extend over the pubic brim. It has a homogeneous, fine, or medium echotexture with a moderate or hyperechoic echogenicity (Figure 2-57, A and B).

On the sagittal (longitudinal) scan, it is seen as a round or oval structure with a smooth margin and a distinct hyperechoic capsule. Only the part of the prostatic capsule that is perpendicular to the ultrasound beam is seen as a bright linear stripe. On the transverse scan the prostate has a bilobed, rounded appearance, with a distinct hyperechoic capsule. The urethra is identified as a central echolucent circular area in the dorsal or ventral portion of the gland. A small midline depression is seen on the dorsal margin. Linear echogenic streaks are seen in the central gland area and are associated with periurethral tissue. The urethra is
not usually seen except in sedated or anesthetized animals or when the bladder is distended. The prostatic urethra may be identified as a hypoechoic area within the gland. The echo texture of the prostate in sexually mature dogs is hyperechoic. In immature or neutered dogs the prostate is small and hypoechoic. The urethra may be centrally or eccentrically located (Figure 2-57, B).

Small linear transrectal transducers are required for examination of the intrapelvic prostate.

Abnormalities

Enlargement (Prostatomegaly). The clinical signs of prostatic enlargement will depend, to some extent, on the cause of the enlargement. They include constipation and tenesmus (straining). In inflammatory conditions, the prostate is painful when palpated. There may be dysuria, stranguria, pyuria, and a discharge from the penis. An acutely inflamed prostate may affect hindlimb gait.

Enlargement of the prostate gland may be caused by hyperplasia, cyst formation, prostatitis, abscess formation, or neoplasia. It may be impossible to differentiate these conditions on radiographic evidence alone. The most common cause of prostatic enlargement is benign prostatic hyperplasia (Figure 2-57, L and P). Retrograde urethrography helps visualize the prostatic urethra. A prostatic neoplasm may spread to the bladder, causing occlusion of one or both ureters. Metastases from prostatic neoplasms are to the medial iliac (sublumbar) lymph nodes, the lungs, the pelvis, the caudal lumbar vertebrae and sacrum, and other bones. More than one disease process may be present in a patient, such as carcinoma and abscess. Prostatic disease is rare in the cat.

Radiologic Signs

1. An enlarged prostate displaces the bladder cranially and ventrally. There may be little enlargement with acute prostatitis. The prostate may be reduced in size with chronic prostatitis.
2. The colon or rectum is displaced dorsally.
3. The enlarged prostate can be identified in the caudal abdomen as a rounded mass caudal to the bladder. Irregularity of outline suggests malignancy (adenocarcinoma).
4. Varying opacities may be evident within the pros
tatic mass, depending on the underlying pathol-
logic condition. Calcification within the gland may
be the result of chronic inflammation or neoplasia.
5. If neoplasia is present, there may be enlargement
of the medial iliac (sublumbar) lymph nodes.
6. Periosteal new bone formation on the caudal lum-
bar vertebrae and sacrum and on the ilia indicates
local metastasis from a tumor.
7. If two masses are seen in the caudal abdomen, it
may not be apparent which mass represents the
bladder and which the prostate. Cystography will
outline the bladder.
8. An evaluation of prostatic size is best made after
evacuation of the bladder.
9. A positive contrast urethrogram may show nar-
rowing of the prostatic urethra, especially with
hyperplasia.
10. In the case of prostatitis, contrast material will
sometimes leak into the prostatic ducts after ret-
rograde urethrocytography. This may help dis-
tinguish inflammatory changes from hypertrophy
or neoplasia, although it is not an infallible sign.
Contrast medium may reach the prostatic ducts in
a normal prostate.

11. Cyst cavities sometimes fill with gas during retro-
grade pneumocystography.
12. Metastatic spread is first to local lymph nodes
and then to the pelvis, caudal lumbar spine, and
sacrum. Distant metastatic spread to the lungs
and long bones occurs late in the disease.
13. Gas shadows within the prostate may be indica-
tive of neoplasia or prostatitis (Figure 2-57, C to E).

Ultrasonography. With benign prostatic hyperpla-
sia, the gland retains its shape, symmetry, and smooth
margin. The echotexture is unchanged, but the echo-
genicity is slightly hyperechoic. Small anechoic areas
may be seen, representing small retention cysts, which
are usually of little clinical significance. If the cysts
become large and are located at the periphery, they
may disrupt the gland outline, in which case acoustic
enhancement will be seen in the far field (Figure 2-57,
F and N).

Cysts
Paraprostatic Cysts. Soft tissue opacity may be seen
lying adjacent to or silhouetting with the bladder.
Cysts may be of varying sizes. Mineralization of the
wall is sometimes seen. Contrast cystography will
define the bladder as a separate entity (Figure 2-57, G and H).

**Ultrasonography.** Paraprostatic cysts are seen as large, usually anechoic, well-marginated, fluid-filled structures in the caudal abdomen. The fluid may contain echogenic material that moves when agitated. The wall may be of variable thickness, and septa may divide the structure. Mineralization of the wall causes acoustic shadowing. Differentiation between the bladder and the cyst can be assisted by emptying the bladder and rapidly introducing saline into the bladder lumen. The saline will be seen swirling in the bladder. The cyst may be attached to the prostate gland by a pedicle (Figure 2-57, I).

**Prostatic Cysts.** Intraprostatic cysts are usually not visible on radiographs unless they deform the outline of the gland. Ultrasonography shows anechoic areas of varying size (Figure 2-57, F, I, O, and P).

**Neoplasia.** Radiography can demonstrate enlargement of the gland but cannot accurately differentiate the various causes of enlargement. Benign prostatic
tumors have not been reported. The most common primary prostatic neoplasm is adenocarcinoma.

Carcinoma of the prostate has been described in the cat. Presenting signs were dysuria and hematuria. Retrograde contrast radiography showed irregularities in the prostatic urethra. The enlarged prostate may or may not be visible on plain radiographs of the abdomen (Figure 2-57, Q and T to V).

Ultrasonography. Prostatic neoplasia has a variable presentation. The lesions cause enlargement that ranges from mild to severe. In males castrated at an early age, carcinomas usually cause only mild prostatic enlargement. The prostate is often asymmetrically enlarged and has an irregular capsular contour. Many have hypoechoic parenchyma with poorly defined hyperechoic foci or small focal mineralizations. Carcinomas that cause severe prostatomegaly usually have a complex, heterogeneous appearance with multiple variably sized cavities. Neoplastic disease causes an irregularly shaped gland with multiple coalescing hyperechoic foci, resulting in a mixed echogenicity and variable echotexture. Areas of hemorrhage and necrosis are seen as focal hypoechoic regions. Cavitation may be a feature. Mineralization, indicated by hyperechoic foci with acoustic shadowing, is also associated with neoplastic disease. The iliac lymph nodes should be examined (Figure 2-57, J, K, M, Q, and T to V).

Infection. The prostate is usually enlarged, and gas shadows may be seen within it. Positive contrast urethrography may cause contrast to reflux into the gland (Figure 2-57, R).

Ultrasoundography. Differentiation between prostatitis and neoplasia can be difficult, and both may be present. Fine-needle aspiration or a catheter prostatic wash is usually required for a definitive diagnosis. Prostatitis may cause focal areas of anechoic or hypoechoic regions representing inflammatory tissue or abscesses. Patchy echogenic foci with a generalized increase in echotexture have also been described. Focal mineralization may also be present. In acute infections
there may be periprostatic fluid. Cavitation containing echogenic fluid may be seen with prostatic abscesses. Abscesses can be drained by using ultrasound guidance. Medial iliac (sublumbar) lymph node enlargement may be identified with prostatic infection or neoplastic disease (Figure 2-57, S).

THE FEMALE GENITAL TRACT
The organs of interest are the ovaries, the uterus, the vagina, and the mammary gland.

THE UTERUS
Anatomy
The uterus consists of a neck, a body, and two horns. The horns are completely within the abdomen, and the body lies partly in the abdomen and partly in the pelvis. The uterus is related dorsally to the descending colon and the ureters. Ventrally it is related to the urinary bladder and the small intestine.

Normal Appearance
The genital tract of the female is not visualized on plain radiographs in the nonpregnant animal unless the uterus or ovaries are enlarged. It can be demonstrated by pneumoperitoneography, but this technique is rarely used. Positive contrast studies of the uterus are unlikely to yield much information of value. With the animal in lateral recumbency, compression of the caudal abdomen with a radiolucent paddle or spoon improves visualization of the uterus by displacing the intestines cranially. It also enhances visualization of serosal borders.

During pregnancy, the uterus gradually enlarges and can be seen on radiographs after approximately the fifth week of pregnancy, occasionally earlier.
Figure 2-57, cont'd I, This caudal abdominal sonogram shows the bladder (B) lying caudally. Cranial to the bladder, an anechoic fluid-filled structure (arrow) is seen. This was a paraprostatic cyst. J, This dog had tenesmus. Sonography of the prostate (arrows) demonstrates that the gland is asymmetrically enlarged. It is variable in echogenicity with multiple hyperechoic foci and hypoechoic areas within a heterogeneous tissue texture. This was a carcinoma. K, This right lobe of the prostate gland (arrows) is grossly enlarged with disruption of the normal echotexture. Focal areas of hyperechoic tissue are seen. Diagnosis: ultrasound-guided fine-needle aspirate revealed prostatic carcinoma. L, This prostate gland is well marginated (arrowheads). A fine-needle aspiration was performed under ultrasound guidance. The echogenic needle tip (arrows) is seen in the gland tissue. Diagnosis: prostatic hyperplasia. M, A 6-year-old male dog presented with pain on defecation. Sagittal sonogram of the prostate (p) shows a large cavitated area (c) within the gland substance. This was aspirated under ultrasound guidance and proved to be an inflammatory exudate. At surgery, an abscess was confirmed. An intraoperative biopsy of suspicious gland tissue proved, however, that the animal had a prostatic carcinoma. N, Sagittal sonogram of the prostate. The gland is enlarged with a variable echotexture. The two parallel echogenic lines (arrow) represent a urinary catheter within the urethra. This was a carcinoma.
This dog had a mass in the caudal abdomen. A transverse sonogram shows an eccentric shaped prostate gland delineated by short arrows. A fluid-filled cavity (long arrow) is seen within the right lobe of the prostate. This was a large prostatic cyst.

Sagittal sonogram of a dog. The prostatic tissue is hyperechoic, and a fluid-filled cavity (long arrow) is seen with the substance of the gland (short arrows). Diagnosis: prostatic cyst and prostatic hyperplasia.

A 10-year-old Scottish Terrier had a recurrent urinary tract infection. The prostate is enlarged and lies within the abdominal cavity. Fine focal areas of mineralization are seen within it. The bladder is displaced cranially, and residual air from a previous pneumocystogram is seen within it. Between the air shadow in the bladder and the enlarged prostate, stippled mineralized opacities are seen. This was a prostatic carcinoma. An incidental finding is that there are only six lumbar vertebrae. The sacrum has four segments because the seventh lumbar vertebra has been sacralized (see Chapter 5) (same case as Figure 2-54, F and G).

This is a 4-year-old Boxer with hematuria and dysuria. An enlarged prostate displaces the bladder cranially and the colon dorsally. The prostate appears as an indistinct soft tissue shadow overlying the bladder neck at the level of L7. An electrocardiogram cable overlies the lumbar spine and pelvis.

Ultrasonography shows a large cavitated mass (AB) within the prostate containing highly echogenic fluid. Large, thick septa are seen in some areas. This was a prostatic abscess.

This is a 6-year-old Labrador with a hindlimb lameness. This lateral radiograph shows that the bladder is displaced cranially by a soft tissue mass with a mineralized rim. This is a prostatic carcinoma.
The only diagnosis that can be made at this time is one of uterine enlargement. Individual fetal swellings are seldom identifiable. At approximately the forty-fifth day of pregnancy, the fetal bones begin to ossify. Ossification occurs a few days earlier in the cat. It may be several days before all the bones have become visible and an estimate can be made of the number of fetuses present. Ossification of fetal skeletons is the best radiographic evidence of pregnancy. Counting fetuses is best done by counting the skulls, because when several fetuses are present overlapping of skeletons has been recognized by individuals difficult. The metacarpal and metatarsal bones are the last to ossify in utero. If these can be seen, the pregnancy is very near term. The pregnant uterus lies on the floor of the abdomen during the last half of pregnancy. After parturition, a noninverted uterus may be seen as a soft tissue opacity in the caudal abdomen (Figure 2-58, A and B). In the absence of pregnancy, any fluid within the uterus is abnormal.

**Ultrasonography**

To evaluate the uterus, a complete examination of the abdominal cavity should be performed from the ventral midline position. Supplemental examination from the lateral aspect of the abdomen helps avoid the possibility of erroneous interpretations resulting from gas in the intestines. The uterus may be imaged with the animal in dorsal or lateral recumbency, but the standing position is most convenient. The skin should be clipped and an acoustic gel applied. A 7.5-MHz transducer is preferred except for very large or giant breeds. The normal nongravid uterus can usually be imaged dorsal to the urinary bladder and ventral to the colon. It is seen as a solid, mainly hypoechoic structure with a slightly hyperchoic lumen and a thin hyperechoic serosal rim. It is differentiated from the intestine by the lack of peristalsis and intraluminal gas. Two uterine wall layers may be identified, an inner hypoechoic area and a hyperechoic periphery. A thin hyperechoic line is seen in the lumen during proestrus. During estrus the uterus enlarges and develops radiating hyperechoic lines. The size will vary depending on the physiologic status and the size of the animal.

Pregnancy is confirmed by the identification of a fetal sac. Conception can occur in the bitch up to 7 days after mating. As a result, marked underestimation of gestational age can be made. Therefore care must be taken when establishing a negative pregnancy diagnosis, particularly if multiple matings have occurred. The fetal sacs may be too small to identify on the initial examination. Reexamination 1 week later is an advisable precaution. Some authors suggest that the ideal time for pregnancy diagnosis is 30 days after the last breeding date. This would mean that the pregnancy cannot be less than 23 to 25 days and is therefore less likely to be overlooked. In the cat the gestational age can be estimated from the last mating date because it is an induced ovulator. Pregnancy can usually be established from the fifteenth day after mating.

Fetal numbers are not accurately assessable because of the inability to image the whole uterus at one time. The presence of several fetuses presents difficulties because overlap and folding of a fetus on itself may make counting inaccurate. Estimations of fetal numbers...
is most accurate between the twenty-eighth and thirty-fifth days. Fetal sacs can usually be imaged at 20 days, but a singleton pregnancy may be overlooked because of the superimposition of overlying gas or noncooperation of the animal during the examination.

The fetal sac is first identified as a vaguely circular anechoic structure, within which is the echoic fetus. As the fetus enlarges it moves away from the uterine wall, and an echoic linear yolk sac may be seen. The fetal heart may be identified as a rapid winking or fluttering anechoic area surrounded by the isoechoic lungs. This finding confirms fetal viability. Fetal movement can be identified at approximately 35 days. As the fetus enlarges, the skeleton can be identified as hyperechoic structures with acoustic shadowing (Figure 2-58, C to H).

The postpartum uterus is enlarged and contains variable quantities of fluid that may have an echogenic texture. The uterus regresses back to normal size within 4 to 6 weeks postpartum. It is not fully involuted until approximately the fifteenth week postpartum.

Abnormalities
Dystocia. Radiography is often used to demonstrate abnormal presentations or relative fetal oversize. The number of fetuses present can also be ascertained. Radiography and ultrasonography are useful in determining whether fetuses remain in the uterus after parturition has apparently been completed (Figure 2-59).

Pyometra (Pyometritis). Pyometra is pus in the uterus. It is evidenced radiographically by the presence of an enlarged uterus. It is seen in the caudal abdomen and midabdomen as a large coiled mass that displaces the small intestine cranially and dorsally. The uterus is usually not seen until its diameter exceeds the diameter of the small bowel, particularly in cases of open pyometra. The mass has a homogeneous, fluid opacity. It is usually not possible to distinguish radiographically between enlargement from pregnancy and enlargement from pyometra unless fetal ossification has commenced. Both conditions may or may not exhibit fusiform swellings (Figure 2-60, A and B). Enlarged uterine horns are often easier
Figure 2-58, cont'd C to H, Fetal development in the bitch. C, This 30-day pregnancy shows a fetal thorax. The heart (H) is surrounded by echogenic (nonaerated) lung (L). The ribs (R) are casting multiple acoustic shadows. Cr, Cranial. D, At 25 days the fetus (between cursors) is surrounded by fluid. The umbilicus is clearly seen in the near field. E, At 34 days the skull of this fetus is clearly recognizable in cross-section (cursors). F, At approximately 50 days. The fetal rib bones cast multiple acoustic shadows (arrows). The heart (star) is seen in the middle of the image. G, At 56 days, as the fetus becomes larger there is relatively less fluid. This fetus is in dorsal recumbency. The heart (star) is visible in the right of the image, and the caudal vena cava (white arrowhead) and aorta (lower black arrow) are seen surrounded by lung tissue (upper black arrow). The fetal rib bones cast multiple acoustic shadows in the far field (black arrowheads). H, This color flow Doppler scan of a 30-day pregnancy shows the fetal heart with the left ventricle in the center and aorta extending to the right. The ribs are seen along the thoracic wall in the near field. (See Color Plate 2-58, H.)
to identify on the ventrodorsal view because they lie just medial to the lateral abdominal wall and lateral to the bowel. In this view, the small intestine is often displaced into the center of the abdomen by the enlarged uterine horns located laterally.

Bitches older than 6 years sometimes develop endometrial cystic hyperplasia, which may be a precursor of pyometra (Figure 2-60, H and I). Metritis is not a radiographic diagnosis.

Ultrasonography. In a closed pyometra the uterus is identified as a convoluted, thin-walled tubular structure in the caudal abdomen. Distended uterine loops are seen adjacent to one another, with flattening
The uterine lumen ranges from anechoic to densely echogenic. In an open pyometra, the uterus is not as enlarged, and it may be mistaken for intestinal loops. However, peristalsis and intraluminal gas are absent. The uterus is identified immediately dorsal to the bladder. In cross-section it is seen as a fluid-filled, circular structure. Fetal sacs are absent (Figure 2-60, C to E). Differentiation between pyometra and other uterine fluid accumulations is not usually possible.

A fluid-filled colon can mimic pyometra, and careful examination is required to avoid error (Figure 2-34, E and F). Fine-needle aspiration is contraindicated because of the friable nature of the uterine wall, which may rupture, allowing the septic contents to escape.

Granuloma. After ovariohysterectomy, a granuloma may develop in the uterine stump or at the site of ligation of an ovarian vessel. The use of nonabsorbable
ligature material predisposes an animal to this condition. Granulomas are mass lesions and may be seen on plain radiographs. There is often an associated localized peritonitis. A granulomatous mass involving the uterine stump may involve the bladder or ureters, causing clinical signs referable to the urinary tract (Figure 2-60, F).

**Ultrasonography.** Differentiation of neoplasia from a uterine stump granuloma is difficult unless a fine-needle biopsy is performed. Granulomata usually have a mixed echotexture and irregular margins. They lie dorsal to the bladder and ventral to the colon. Discrete fluid-filled areas within the tissue may represent abscessation (Figure 2-60, G).

**Fetal Death and Mummification.** After the fetus dies, if no infection is present, resorption of soft tissues results in the bony structures of the fetus becoming more compact and opaque than usual. If infection is present, physometra (gas in the uterus) will be seen. Mummified fetuses have opaque bones, with the skeletons having a compressed appearance and occupying a relatively small area. They appear to be rolled up. Live fetuses have a gentle curve to the spine. It is not possible to tell on radiographic evidence alone, whether fetuses are alive. If death has occurred recently, there may be no radiographic changes. Later signs of fetal death are the presence of gas within the uterus, gas within the fetus, overlapping of the bones of the cranium (Spalding’s sign), and excessive curvature of the spine. The normal fetus is in a relaxed, extended position with little curvature of the spine (Figure 2-61).

**Ultrasonography.** If embryonic death occurs before the twenty-fifth day, the fetus is usually completely resorbed. This resorption is identified as the conceptus...
collapses and there is reduced volume of the gestational sac, reduced size of the embryo, and cessation of heartbeat.

The first signs of abortion may be identified after the thirty-fifth day as an increased echogenicity of fetal fluid and an absence of fetal heartbeats in ill-defined fetal tissue. The fetal fluid may subsequently become speckled. The fetal membranes may be thickened and the volume of fluid is reduced. Fetal abnormalities are not commonly detected because of the multiparous nature of the pregnancy and the small size of the embryos. Signs of fetal death include lack of fetal heartbeat and movement and gas echoes within the fetus. Fetal retention may be diagnosed by the presence of echogenic fetal bones.

**Ectopic Pregnancy.** In ectopic pregnancy the fetuses have a opaque appearance because of the absence of fluid within the tissues. The appearance is often similar to mummification. The fetuses frequently lie in the abdomen distant from the position of the uterus.

**Neoplasia.** Uterine neoplasia is rare. The associated mass may be seen on plain radiographs (Figure 2-62, A and B).

**Ultrasonography.** Uterine neoplasms may be identified as mainly homogeneous mixed echogenic tissue attached to the uterine wall. Necrosis may develop, resulting in a complex mixed echogenicity that cannot be differentiated from a granuloma.
THE OVARIES

Anatomy
The ovaries are located caudal to the kidneys, with the right ovary being more cranially placed than the left. The left ovary lies between the abdominal wall and the descending colon at approximately the level of the third or fourth lumbar vertebrae. The right ovary lies dorsal to the descending duodenum and ventral and caudal to the right kidney. Normal ovaries are not seen on plain radiographs of the abdomen.

Ultrasonography
The ovaries are located adjacent to and just caudal to the kidneys. They are difficult to locate unless enlarged. They are often surrounded by fat and may not be seen in the young bitch. They are approximately 1 cm in length and have an oval, bean shape. The echotexture varies. The echogenicity is homogeneous and isoechoic with the kidney cortex. Follicles may be identified as thin-walled circular anechoic structures. As the follicles enlarge, the ovaries become easier to see. Their identification depends on the resolution of the image, the transducer frequency, and the experience of the operator (Figure 2-62, D to F).

Abnormalities
Ovarian Masses. Ovarian masses may be seen on plain radiographs. They may be cystic or neoplastic in nature. They displace coils of the small intestine in the cranial abdomen and midabdomen. A left ovarian mass may displace the descending colon. Large
masses may stretch the ovarian ligament and lie in the ventral abdomen. Ovarian masses, although rare, should be considered in the differential diagnosis of intraabdominal masses (Figure 2-62, C).

It may be difficult to identify a neoplasm as arising from the ovary. Tumors may be of varying sizes and echotexture. Granulosa cell tumors may be large and anechoic with septa. Differentiation of neoplasia from an ovarian stump granuloma requires fine-needle biopsy (Figure 2-62, I).

Ovarian cysts have thin walls with anechoic contents. Acoustic enhancement is a feature. Luteal cysts may have an increased wall thickness, which may help differentiate them from follicles (Figure 2-62, G and H).

THE VAGINA
Vaginal masses are readily accessible to visual inspection and palpation. Radiology may be of use in determining the cranial limits of a large mass. Retrograde vaginography (see p. 144) with a positive contrast agent may be used to demonstrate vaginal masses, urethral masses, and ectopic ureters. If the mass extends cranially into the abdomen, it will be identified as a caudal abdominal mass. On ultrasonography, differentiation between a vaginal and a uterine mass may not be possible. If the bladder is empty, saline can be introduced to differentiate a vaginal mass from a bladder mass. They have a mixed echogenicity (Figure 2-63).

THE MAMMARY GLAND
The mammary gland is recognized on radiographs as a soft tissue opacity ventral to the abdominal wall. On the ventrodorsal view the teats may be mistaken for intraabdominal or intrathoracic masses. A careful examination of the radiograph will confirm a bilateral, symmetric distribution.

The gland may be increased in size when neoplastic. Calcific opacities are sometimes seen within the substance of the gland. They are likely to be
Figure 2-62, cont’d  D to I, Normal ovaries.  D, This is a close-up sonogram of the dorsal abdomen caudal to the left kidney (long arrow). The circular 4-mm hypoechoic structure caudal to the kidney is the left ovary (small arrows). The ovary contains an anechoic center that is a follicle. Diagnosis: normal ovary.  E, This sonogram shows a mainly hypoechoic ovary (arrowheads) with two small follicles (long arrows) in the cranial pole of the ovary.  F, This ovary is elongated with multiple circular anechoic follicles aligned in a linear pattern.  G, This ovary contains irregular hypoechoic circular structures. Diagnosis: cystic ovary.  H, The outline of the ovary (arrowheads) is irregular and contains multiple cysts (arrows) of variable size. Diagnosis: cystic ovary.  I, A 9-year-old crossbred dog had an abdominal mass. A sonogram shows a 4-cm circular mass (M) caudal to the kidney. This was an ovarian leiomyoma at surgery.  Cr, Cranial.
Figure 2-63  A to C, Rectal displacement by a vaginal mass. A 7-year-old German Shepherd bitch presented with vaginal bleeding 2 months after an ovariohysterectomy. A plain radiograph showed a distended bladder and the rectum displaced dorsally. A, The positive cystogram shows dorsal displacement of the rectum and ventral displacement of the urethra. Spondylosis is an incidental finding. A retrograde vaginourethrogram was subsequently performed. Lateral (B) and ventrodorsal (C) radiographs show radiolucent masses outlined by the positive contrast in the vagina. D, This 11-year-old bitch had a history of vaginal bleeding. The sonogram shows a densely compacted echotexture in a mass that is well marginated (arrows). Diagnosis: leiomyoma. E, This 12-year-old bitch presented with a history of prolonged estrus. The abdominal sonogram shows a mixed echogenic mass (M) lying ventral to the colon (C). At surgery this proved to be a vaginal anaplastic sarcoma. It is unusual for vaginal tumors to lie intraabdominally. The mass could not be palpated per vaginam.
associated with neoplasia. Malignant neoplasms metastasize to the draining lymph nodes and to the lungs, where they may be seen as nodular infiltrates (see Figure 6-1, C).

Ultrasonography

The mammary tissue is echogenic and homogeneous. Mammary tumors have variable echotexture. Malignant tumors may be seen extending into adjacent fascial planes. Acoustic shadowing may be noted. Mastitis causes an increase in size and a reduced echotexture (Figure 2-64).

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**Ultrasonography**


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Some structures, the larynx and the trachea, directly associated with the respiratory tract lie outside or partially outside the thorax.

**THE PHARYNX, LARYNX, AND HYOID APPARATUS**

**Anatomy**

The pharynx is a passage common to the digestive and respiratory tracts. It is divided by the soft palate into the oropharynx, which communicates with the mouth and the esophagus, and the nasopharynx, which communicates with the nasal chambers and the larynx. The soft palate extends caudally as far as the epiglottis. Air within the pharynx provides contrast, enabling soft tissue or other abnormalities within it to be identified. The tip of the epiglottis may lie dorsal or ventral to the soft palate. It may reach the floor of the pharynx.

The larynx is composed of a number of cartilages, namely the epiglottis, the thyroid, the cricoid, and two arytenoids. In addition, there is a small oval sesamoid cartilage cranial to the cricoid lamina between the arytenoid cartilages and a small flat interarytenoid cartilage caudal to the sesamoid. Older animals sometimes show calcification of some or all of the laryngeal cartilages.

The hyoid apparatus is a bony structure that suspends the tongue and the larynx. It is attached to the skull dorsally and to the tongue and the larynx ventrally. It is composed of a single basihyoid bone in the base of the tongue and several other small bones—the paired thyrohyoid, the keratohyoid, the epihyoid, and the stylohyoid.

Several abnormalities have been described associated with the pharynx.

**Normal Appearance**

The pharynx and larynx are readily identifiable on properly exposed lateral views of the neck (Figure 3-1, A and B). On ventrodorsal projections, the larynx overlies the cervical vertebrae, and most of its detail is lost. Good radiographs will show the soft palate, hyoid apparatus, epiglottis, and cricoid cartilage. The diameter of the larynx is somewhat wider than that of the trachea (Figure 3-1, A and B).

**Ultrasonography**

The larynx may be imaged with a 7.5- to 10-MHz high-resolution transducer. The vocal cords are imaged using the ventral aperture between the cricoid and thyroid cartilages. Alternatively, they may be examined by using the thyroid cartilage as an acoustic window. The tongue and floor of the mouth are examined through the intermandibular space. The areas are clipped and prepared in the usual way. Sagittal and transverse scans should be made. Anatomic landmarks are often difficult to interpret.

**Abnormalities**

Abnormalities of the larynx are usually diagnosed by methods other than radiologic. Displacement of the larynx, compression, or calcification may result in visible radiographic changes. Fractures of the hyoid bones occur (Figure 3-1, C). Foreign bodies or mass lesions in the pharynx or larynx are usually visible because of surrounding contrasting air (Figure 3-1, D).

**Pharyngeal Dysphagia and Cricopharyngeal Achalasia.** A number of abnormalities may affect the oropharynx, and they are difficult to distinguish from one another. Both the oropharynx and nasopharynx should be examined. Plain radiographs are seldom diagnostic in cases of dysphagia. These are functional disorders and require fluoroscopy to make a definitive diagnosis.

In pharyngeal dysphagia resulting from structural or neurologic disorders, inefficiency of pharyngeal contractions results in the retention of food material within the pharynx. Affected animals make repeated efforts to swallow food. Coughing may occur. Food material may come down the nose. Aspiration pneumonia is common. With fluoroscopy, a barium examination will show retention of barium in the pharynx despite repeated efforts to swallow it. Barium may enter the trachea, and air is often seen within the esophagus.

Cricopharyngeal achalasia results from failure of the cricopharyngeus muscle to relax during swallowing or from lack of coordination of the mechanisms involved in swallowing. The clinical signs are similar to those seen in pharyngeal dysphagia. A barium
study shows retention of barium in the pharynx and cervical esophagus. On fluoroscopy, pharyngeal contractions are seen to force the barium against the caudal wall of the pharynx, with only a small amount of barium entering the esophagus, where it tends to remain. Barium may come down the nose or enter the larynx or trachea. Failure of the cricopharyngeus muscle to relax can be treated surgically. However, cricopharyngeal myotomy is contraindicated in other disorders of this region. Hence, accurate diagnosis is important.

Pharyngeal dysphagia and cricopharyngeal achalasia should be considered in the differential diagnosis in young animals that have difficulty swallowing.

**Laryngeal Paralysis.** As a result of paralysis of the laryngeal muscles, the laryngeal airway does not open adequately during respiration. Clinically, there is a
Figure 3-1, cont’d  C, This Greyhound was bleeding from the mouth with marked swelling of the tongue and pharyngeal region. On the lateral study of the larynx, the hyoid is fractured through both epiphyoid bones, and there is considerable displacement of the fracture ends. Diagnosis: fractured epiphyoid bones. D, A radiopaque pharyngeal foreign body in a cat. The pharynx is distended with air. The foreign body is in the caudal pharynx and cranial esophagus. Air is seen in the proximal esophagus caudal to the foreign body, which was part of a chicken wishbone. E and F, Brachycephalic airway syndrome. E, This is a young Bulldog. The larynx is at an unusual angle and is lying in an almost vertical position compared with the normal (A). The nasopharynx is occluded by the soft palate. There is mineralization of the laryngeal cartilages. F, This is a young Pug. The larynx is lying in an abnormal caudoventral position that is consistent with severe brachycephalic airway syndrome.
moist cough and, in more severe cases, a loud inspiratory noise.

The condition may be the result of a variety of causes. It may be hereditary, particularly in the larger breeds such as the Dalmatian and the English Bulldog. It is most common in the Labrador and Golden Retriever. It is rare in cats. Other causes include trauma, inflammation, and neoplasia, or it may be the result of a systemic condition such as hypothyroidism. It may be idiopathic.

Radiologic signs may be absent. Obstruction of the upper airway may result in hyperinflation of the lungs. The tracheal lumen may vary in width. There may be aspiration pneumonia. Pulmonary edema may form.

**Brachycephalic Airway Syndrome.** This is seen in brachycephalic dogs as a combination of elongated soft palate and various laryngeal abnormalities such as paralysis. The pharynx is small, and the thyroid apparatus is directed vertically (Figure 3-1, E and F).

**Laryngeal Hypoplasia.** This condition is common in brachycephalic breeds and in the Skye Terrier. The laryngeal cartilages are soft and underdeveloped. This results in partial obstruction of the upper airway. The degree of respiratory distress caused depends on the severity of the abnormality. Clinical and radiologic findings are consistent with obstruction of the upper airway.

**THE TRACHEA**

**Anatomy**

The trachea is a tubular structure that extends from the level of the body of the axis to approximately the fifth thoracic vertebra, where it bifurcates into the principal or mainstem bronchi over the base of the heart. It consists of a series of circular cartilages. In the dog, the cartilaginous rings are incomplete dorsally, the roof of the trachea being formed by the trachealis muscle. The apex of the partition between the openings of the primary (stem) bronchi is called the carina. It is not seen on radiographs.

**Radiography**

Lateral and ventrodorsal views of the neck and thorax are necessary for routine examination of the trachea. Oblique views are helpful in demonstrating the trachea without superimposition of the vertebrae and sternum, as occurs on the ventrodorsal view. Care must be taken that no rotation of the thorax is present on lateral views; this will cause an apparent displacement of the trachea. The neck should be comfortably extended. Overextension results in a pseudonarrowing at the thoracic inlet, whereas flexion of the head or neck or elevation from the table top will cause tracheal deviation in the cranial thorax (Figure 3-2, A and B).

Contrast studies may be carried out as described for bronchography, but the contrast medium is deposited further cranially. Such studies are now rarely performed because endoscopy is more informative.

**Normal Appearance**

The trachea is visualized more clearly on lateral views. The air within it acts as a contrast medium, contrasting with the soft tissue opacity of the neck muscles and structures within the mediastinum. On ventrodorsal or dorsoventral views, the trachea is more difficult to see because of the superimposed vertebrae and sternum. The trachea, in the cranial mediastinum, lies to the right of the midline, becoming centrally placed at its bifurcation. On the lateral view, it forms an acute angle with the line of the thoracic vertebrae. The angle is greater in dogs with a deep, narrow thorax and more acute in dogs with a shallow thorax. A rounded lucency over the base of the heart marks the point of bifurcation. It represents the origin of the right cranial lobe bronchus seen end-on. A second rounded lucency may be seen that represents the origin of the left cranial lobe bronchus. The trachea curves somewhat ventrally toward its bifurcation between the fifth and sixth ribs. Only the primary bronchi near the bifurcation are recognizable on normal radiographs. Smaller bronchi cannot be identified. The diameter of the tracheal lumen varies slightly during inspiration and expiration. It is slightly smaller than the width of the larynx. It has been suggested that the width of the lumen should be three times the width of the proximal third of the third rib. Alternatively, the tracheal diameter can be expressed as a ratio to the thoracic inlet as measured on the lateral view. Normally the trachea is approximately one fifth the depth of the thoracic inlet (Figures 3-2, A, and 3-3, D).

**Ultrasoundography**

Ultrasoundography of the cervical trachea is possible. It lies adjacent to the esophagus and is identified as a hyperechoic, well-defined curvilinear structure. Air is seen to move within the lumen during respiration. The intrathoracic trachea cannot be evaluated.

**Abnormalities**

**Displacement.** The trachea may be displaced by cranial lung lobes, pleural, cervical, or mediastinal masses or by an enlarged heart. Adjacent masses tend to displace rather than compress it. Compression may occur at the thoracic inlet or over the base of the heart. The trachea may be compressed between a mass and the ribs, the spine, the aorta, or the heart, which are all relatively rigid structures.

A distended esophagus may displace the trachea ventrally. An enlarged heart displaces the trachea dorsally. Cranial mediastinal masses usually displace it dorsally and laterally, and they may displace the terminal trachea caudally. Intrathoracic masses may displace the tracheal bifurcation cranially. Enlarged tracheobronchial lymph nodes may depress, elevate, or compress the trachea and separate the mainstem bronchi.

Before making a diagnosis of tracheal displacement, one must be sure that the animal has been positioned correctly. Undue extension may result in the trachea appearing compressed at the thoracic
Figure 3-2  
A, The normal cervical trachea. B, A tangential, or skyline, view of a normal trachea in a chondrodystrophic dog. C, Tracheal foreign body in a cat. This 18-month-old cat had been coughing for 1 year. There is an irregularly shaped, radiopaque foreign body within the lumen of the trachea at the level of the third intercostal space. The airways, lungs, and heart are within normal limits. D, Tracheal foreign body in a dog. The patient was involved in a fight with another dog a few days earlier and presented in respiratory distress. There is moderate, nonuniform narrowing of the trachea. This appears to be a result, at least in part, of thickening of the dorsal tracheal ligament. A fourth premolar tooth is seen within the lumen of the trachea, just ventral to the C6-C7 intervertebral disk space. The tooth was successfully extracted by endoscopy. Air is present in the esophagus.
inlet (Figure 3-3, A). Extreme flexion of the neck during radiography may result in a ventral displacement of the trachea in the cranial thorax (Figure 3-3, B and C). Dorsal displacement may be seen with lateral or ventral flexion of the neck. This results in artifactual displacement of the trachea in the cranial mediastinum, simulating a mass (Figure 3-3, C and D). Rotation of the thorax on the lateral view will cause an apparent elevation. Some deviation of the trachea to the right is often seen in normal dogs in the cranial thorax. It may be more pronounced in brachycephalic breeds (see Figure 3-29, G). A ventrodorsal or dorsoventral view is required to demonstrate deviation in the lateral plane (Figure 3-3, E).

Collapse. Tracheal collapse affects the smaller breeds of dogs in middle to old age. It may be acquired or congenital. The congenital form manifests itself in later life. The clinical signs comprise varying degrees of respiratory distress and a paroxysmal, chronic, dry “goose honk” cough. Because the usual type of collapse is in the dorsoventral plane, lateral radiographs are the most informative. Both inspiratory and expiratory radiographs of the full length of the trachea should be made with the forelimbs at right angles to the spine. A skyline or tangential view of the thoracic inlet with the dog in sternal recumbency and the head and neck extended dorsally is occasionally useful (see Figure 3-2, B). Extreme care should
Figure 3-3, cont’d E, The trachea is displaced to the left by a mass in the neck. This was a thyroid mass. F and G, Tracheal collapse. A 7-year-old Yorkshire Terrier had been coughing in violent spasms for several months. Lateral studies of the trachea in expiration (F) and inspiration (G). The intrathoracic tracheal lumen is markedly narrowed at expiration, and the difference between the two phases of respiration is well demonstrated.

Continued
Figure 3-3, cont’d  H and I, A 9-year-old Boston Terrier was depressed, cyanotic, and tachypneic. H, A lateral radiograph shows severe narrowing of the intrathoracic trachea. There is widespread infiltration of the lungs from hemorrhage. There is some air in the cervical esophagus. This was submucosal hemorrhage in the trachea caused by anticoagulant poisoning. I, Four days later there is almost complete resolution of the condition. (This is the same case as Figure 3-25, I and J.) J, This 1-year-old Pug had a history since birth of repetitive collapse after exercise. The tracheal lumen is grossly narrowed throughout its length. Diagnosis: tracheal hypoplasia.
be taken because such positioning may exacerbate the clinical signs.

Radiologic Signs
1. The lumen of the trachea is seen to be markedly narrowed.
2. The dorsal margin is indistinct in outline because of inversion of the dorsal trachealis muscle.
3. The cervical or the thoracic portion or both may be affected. If collapse is in the cervical trachea, it occurs at inspiration. If collapse is intrathoracic, it occurs at expiration and may involve the mainstem bronchi (Figure 3-3, F and G).
4. Induced coughing, by exerting gentle pressure on the trachea at the thoracic inlet, or by occluding the nares, may help make the collapse more apparent.

Fluoroscopy and/or endoscopy is useful if the clinical signs suggest the diagnosis and may demonstrate collapse even when the inspiratory and expiratory radiographs are negative. Fluoroscopy is particularly useful in diagnosing mainstem bronchial collapse.

Some obese animals may have an apparent narrowing of the trachea because of superimposition of fat or flaccidity of the trachealis muscle, causing it to project into the tracheal lumen. In fat animals, the trachea is less clearly visualized than in thinner ones. The esophagus may overlie the trachea in such a way as to give the appearance of collapse. Careful examination may show the true tracheal outline.

Hepatomegaly has been reported in association with tracheal collapse, as has an enlarged left atrium, causing pressure on the left stem bronchus. Reasonable variations in the position of the neck will not affect the lumen of a normal trachea. Hyperextension may cause a pseudonarrowing. Tracheal collapse must be distinguished from congenital hypoplasia.

Ultrasonography. Ultrasonography of the cervical trachea may show the air column as flattened and the tracheal diameter varying in size between inspiration and expiration.

Hypoplasia. Congenital hypoplasia (congenital stenosis) is seen in some brachycephalic breeds such as the English Bulldog and the Bullmastiff. It is occasionally seen in other breeds such as the German Shepherd, the Labrador Retriever, and the Basset Hound. It is rare in cats. The tracheal lumen size is grossly narrowed, usually throughout its length. The diameter may be less than half that of the larynx or less than the width of the proximal third of the third rib. With hypoplasia, there is no variation in diameter on inspiratory and expiratory radiographs or during fluoroscopy (Figure 3-3, J). Aspiration pneumonia may be a complicating factor. The trachea may be narrowed as a result of intramural hemorrhage (Figure 3-3, H and I).

Neoplasia. Neoplasia of the trachea is rarely seen in dogs and cats. Osteosarcoma, chondroma, adenocarcinoma, and squamous cell carcinoma have been reported. A neoplastic mass projecting into the tracheal lumen can be seen because of the air that surrounds it. The use of contrast medium (bronchography) is sometimes helpful in differentiating between intraluminal and extraluminal masses. However, endoscopy has superseded traditional contrast studies.

Ultrasonography. An intraluminal or intramural mass in the cervical trachea may be identified because it displaces the intraluminal air.

Calcification. Calcification of the tracheal rings is sometimes seen in older dogs, particularly in the chondrodystrophic breeds. It does not appear to have any significance (Figure 3-4, A).

Rupture. If the trachea is punctured, air escapes into the peritracheal tissues, and subcutaneous emphysema can be recognized on radiographs as air opacities beneath the skin. Air may also be seen dissecting along fascial planes in the soft tissues. Pneumomediastinum may result if the rupture is within the thorax, or air may track into the mediastinum from an extrathoracic rupture. Damage to the tracheal rings may result in narrowing of the lumen and ultimately stenosis.

Stenosis. Stenosis, or narrowing of the trachea, may be seen on lateral studies. It may occur in dogs or cats after laceration, direct blunt trauma, or bite wounds (Figure 3-4, B).

Oslerus osleri. Irregularities in the tracheal lumen and soft tissue opacities projecting into it, with increased peribronchial radiopacities in the perihilar area, have been described in association with Oslerus osleri (Filaroides osleri) infestation. Diagnosis is more certainly achieved by demonstrating larvae in fecal samples or tracheal washings or by endoscopy (Figure 3-4, C).

Avulsion. This is a disruption in continuity of the tracheal rings within the thorax. It is seen in cats after trauma. The clinical signs include dyspnea, exercise intolerance, and cyanosis on exercise. At the time of injury there may be no respiratory signs. Radiologically there is loss of continuity of the tracheal lumen and an irregular outline to the tracheal margins. Often there is an air-filled bulge dorsally at the site of disruption. Avulsion of the left or right mainstem bronchus has also been encountered. Surgical repair has been described.

Obstruction. Foreign body obstruction of the trachea is not common. The main clinical finding is sudden bouts of severe coughing. The air-filled trachea provides a good contrast background against which a foreign body can usually be seen (see Figures 3-2, C and D, and 3-5, A and B). If the foreign body is radiolucent, endoscopy may be more informative. Obstruction of the trachea may result in hyperinflated lung fields due to a ball-valve effect, resulting in difficulty in
expelling air. If a foreign body passes into a bronchus, the resulting atelectasis may obscure it. No air bronchograms will be seen in the atelectatic lobe because the presence of fluid obliterates contrast between the bronchi and the lung. Flexion of the neck with an endotracheal tube in place may cause kinking of the tube and obstruction of the airway (Figure 3-5, C).

**Tracheitis.** There are usually no radiographic signs of tracheitis. Intratracheal exudation and mucosal swelling may cause the tracheal lumen to appear less sharp than usual.

### THE THORACIC CAVITY

#### THE SKIN

The skin forms part of the background opacity on radiographs of the thorax. Foreign substances on the skin may cause radiographic opacities within the thoracic shadow, thus simulating abnormalities. The skin should be examined visually and manually in cases of doubt. Prominent skinfolds often cause well-defined lines that traverse the thorax in a craniocaudal direction on ventrodorsal views. These lines may seem to represent lung edges and so lead to a false diagnosis of pneumothorax and collapsed lungs. Such skinfolds can usually be traced out beyond the confines of the thoracic cavity. On the lateral study, they may also be seen on the ventral third of the thorax associated with the forelimbs (see Figure 3-23, I and J). Teat shadows or skin masses superimposed on lung shadows should not be mistaken for intrapulmonary opacities (see Figure 3-6, P to S). Subcutaneous emphysema makes the thoracic cavity appear more radiolucent and can cause linear streaks or a honeycomb effect. The air-filled lungs provide good contrast for the demonstration of intrathoracic structures.

### Radiography

For routine examination at least two views are necessary: a lateral view and a dorsoventral or ventrodorsal view. A comprehensive study should include two opposing lateral views and either a dorsoventral or a ventrodorsal view. Radiographs should be made during the inspiratory pause because when the lungs are filled with air, maximal contrast is achieved between the different structures within the thorax. The beam should be collimated to include the entire thorax from a point 2 cm cranial (just cranial to the manubrium) to the first rib to a point caudal to the first lumbar
Chapter 3  ■  The Thorax

A machine with a capability of at least \( \frac{1}{30} \) or better, \( \frac{1}{60} \) of a second is desirable. Rare-earth screens reduce exposure times. At slower speeds, motion is not effectively excluded unless the animal is anesthetized and artificially ventilated. Motion causes blurring of intrathoracic structures and makes viewing of finer details impossible. Underexposure gives the impression of increased lung opacity. Films of obese patients are relatively underexposed, which may mimic pulmonary change. Overexposure blackens out normal vascular patterns and may mask pathologic changes. The use of a high-kilovoltage combined with low-milliamperage per-second technique gives a wider range of contrast than one of low kilovoltage. A good technique will barely outline the spinous processes of the cranial thoracic vertebrae on the lateral view.

It is essential that a technique be elaborated that will make possible the production of technically repeatable films. Unless radiographs of comparable technical quality can be produced on a day-to-day basis, it will not be possible to monitor progressive changes in pulmonary structures. The use of a technique chart and accurate measurement of the thickness of the thorax with calipers are essential aids to the production of good-quality radiographs.

On films made at expiration, the lung fields appear more opaque, and much of the pulmonary vasculature detail is lost. But expiratory films may be of value in pulmonary emphysema, in which air cannot be expelled from the lungs. In addition, expiratory films are useful for the identification of small volumes of pleural air or fluid and bronchial or tracheal collapse (see Figure 3-3, F).

**Lateral View.** The animal is placed in lateral recumbency. The forelimbs are drawn cranially and

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**Figure 3-5**
A, This 3-month-old Boxer had a chronic cough. A discrete radiopaque foreign body lies in the distal trachea. Some air is present in the esophagus. A piece of gravel was successfully removed during endoscopy. B, A radiopaque foreign body in the trachea. C, The neck is flexed, causing obstruction of the endotracheal tube. (B, Courtesy Dr. Colin Healy.)
positioned parallel to one another. This position prevents superimposition of the triceps muscles on the apical portions of the cranial lung lobes. The sternum should be supported and should be on the same level and parallel to the thoracic vertebrae so that there is no rotation of the thorax relative to the incident x-ray beam. The neck is extended, or at least not flexed. The beam is centered at the fifth intercostal space, usually at the caudal edge of the scapula. There is little difference between radiographs made in left lateral recumbency and those made in right lateral recumbency. Right lateral recumbency may be preferred because in this position the phrenicopericardial ligament restricts movement of the cardiac apex toward the dependent side.

If pathology is suspected in one lung, that lung should be uppermost because the dependent lung does not inflate fully, and contrast in it is therefore diminished. For this reason, two opposing lateral studies are needed to fully evaluate both lungs.

Figure 3-6 Normal thorax. Right lateral recumbent (A) and dorsoventral (B) studies of the thorax. C, Dorsoventral thorax of a brachycephalic dog. In this breed type the mediastinum is wider than usual.
FIGURE 3-6, cont’d D, Lateral radiograph of the thorax of a cat showing that the caudal lung fields do not fill the diaphragmaticolumbar recess (arrows) as do those of the dog. E and F, A 4-year-old Cavalier King Charles Spaniel with extensive intrathoracic fat deposits. E, The cardiac silhouette is displaced away from the sternum by a large fat deposit lying on the sternum. F, On the dorsoventral view the width of the mediastinum is increased because of the presence of fat.

Continued
Figure 3-6, cont'd  

G and H, This 9-year-old German Shepherd had a malignant bone tumor. These are right (G) and left (H) lateral recumbent views of the thorax. G, A soft tissue opacity (arrows) can barely be distinguished overlying the cardiac shadow. H, Two soft tissue opacities superimposed on the cranial half of the cardiac silhouette are clearly shown. This also indicates that the opacities are in the right (uppermost) lung and emphasizes the importance of opposing recumbent views to demonstrate lesions in the chest.

Standing lateral views are occasionally useful if pleural fluid or air is suspected. For this view, the cassette is positioned along the thoracic wall with the animal in the standing position. A horizontal beam is used, centered on the fifth intercostal space. A lateral view, using a horizontal beam and with the animal in sternal recumbency, is an alternative. Dorsal recumbency using a horizontal beam is occasionally used to examine the ventral thoracic region, but this position requires care in animals with compromised respiration.

Dorsoventral and Ventrodorsal Views. The cardiac outline is less distorted on the dorsoventral view, that is, with the animal in sternal recumbency. If the
Figure 3-6, cont’d  I and J, Normal feline thorax. On both projections, the heart has an ovoid or leaflike shape. The normal pulmonary vessels form a fine herringbone pattern in the caudal lung lobes. On the lateral view the caudodorsal lung margin curves away from the thoracic spine and is separated from it by a band of soft tissue.

Continued
cardiac shadow is the main item of interest, the dorsoventral view is preferable. The vessels to the caudal lung lobes are better seen on this view. To obtain a dorsoventral view, the animal is placed in sternal (ventral) recumbency with the elbows abducted and the forelimbs drawn slightly forward. The hindlimbs are flexed, with the hocks resting on the table. The head is positioned between the forelimbs on the midline. The thorax should not be rotated. The thoracic vertebrae should overlie the sternum. The beam is centered over the caudal edge of the scapula.

To obtain a ventrodorsal view, the animal is placed in dorsal recumbency with the forelimbs drawn forward and the beam centered over the caudal edge of the scapula. The sternum should overlie the thoracic vertebrae. When the animal is in dorsal recumbency, for a ventrodorsal view, gravity tends to move the heart away from the sternum. However, positioning is often easier with the animal in dorsal recumbency, and better inspiratory films can be obtained in this position. It is therefore the preferred study for lung evaluation. Placing the animal on its back may increase distress in cases with dyspnea. In such cases, a dorsoventral view should be used.

**Oblique View.** Oblique views are sometimes helpful in demonstrating areas of lung tissue that are obscured by the cardiac silhouette on more conventional views. They may also be useful in studying the trachea and esophagus. Lesion-oriented oblique views may be required to demonstrate masses on the thoracic wall or on the ribs.

**Normal Appearance**

On a satisfactory inspiratory radiograph, there should be good contrast between the pulmonary vessels, cardiac silhouette, and air-filled lungs. On the lateral view, the caudal vena cava is almost parallel to the long axis of the body. Little or no contact exists between the diaphragm and the cardiac shadow, nor should there be any superimposition of one on the other, though whether this is the case depends to some extent on the conformation of the animal. Animals with a deep, narrow thorax tend to have greater separation between the cardiac outline and the diaphragm than do animals with a more rounded thorax. The diaphragmaticolumbar recess is at approximately the level of the twelfth thoracic vertebra, and the diaphragm appears more flattened than rounded in deep-chested dogs. In left lateral recumbency on full inspiration, the ventral cardiac border may be displaced away from the sternum by the tip of the right middle lung lobe. This should not be mistaken for evidence of pneumothorax. It may also be displaced from the sternum in obese animals.

In the cat there is less variation in conformation than in dogs. The cardiac silhouette is somewhat oval in shape, and its long axis lies more obliquely to the sternum. The sternebrae are often not in direct alignment with one another. The diaphragmaticolumbar recess is not occupied by lung tissue. This should not be mistaken for fluid.

On the dorsoventral and ventrodorsal views, the angles between the diaphragm and the heart (cardiophrenic angles) and the diaphragm and the ribs (costophrenic angles) are well opened, and the cranial part of the diaphragm lies at approximately the level of the eighth to the tenth thoracic vertebrae. On the lateral view, projection of the dorsal curvature of the ribs unilaterally beyond the spine indicates that the animal was rotated axially when the radiograph was made. On dorsoventral and ventrodorsal views, the sternebrae and the spine should be superimposed on one another (Figure 3-6).
Figure 3-6, cont’d M, A transverse computed tomographic (CT) image of the cranial thorax, displayed in a lung window, at the level of the fourth rib. The major vessels, including the cranial vena cava and brachycephalic trunk, are visible in the mediastinum ventral to the trachea. The ventral mediastinum is a thin linear structure (arrows) running dorsoventrally between the left and right cranial lung lobes (the right side of the thorax is on the left side of the image). N, A transverse CT image of the thorax of a normal dog just caudal to the level of the tracheal bifurcation, displayed in a lung window. The esophagus and aorta are seen within the dorsal mediastinum, dorsal to the left and the right caudal lobar bronchi. The heart is the slightly irregularly shaped soft tissue structure ventral to the bronchi. In this window, internal cardiac structure is not visible. O, A transverse CT image of the thorax of a normal dog, at the level of the cardiac apex, displayed in a lung window. The cardiac apex is the soft tissue structure visible in the ventral thorax (star). A fold of the mediastinum, the plica vena cava, extends from the cardiac apex dorsally and toward the right and wraps around the caudal vena cava. The accessory lung lobe is positioned within the pocket formed by the caudal mediastinum on the left (arrows) and the plica vena cava and the caudal vena cava on the right. The thoracic aorta is visible just ventral to the thoracic spine within the mediastinum. Immediately ventral to this the esophagus (asterisk) is a fusiform soft tissue structure within the mediastinum. Multiple bronchi and paired pulmonary arteries and veins are seen within the left and right caudal lung lobes and the accessory lung lobe.

Continued
In the cat, the thorax appears more elongated and the cardiac outline is centrally located. In old cats, the aortic arch is often seen protruding cranial to the heart on the left side. The heart tilts more cranially in older cats (see Figure 3-6, D, I to L).

**Ultrasonography**

Routine ultrasonographic examination of the thoracic cavity is restricted in the main to examination of the heart. The ribs and lungs usually prevent imaging of thoracic structures. If the pathology is adjacent to the chest wall or the lungs have been displaced by fluid, then ultrasonographic examination is very useful. The transmission of sound waves is inhibited by the high acoustic impedance between the subcutaneous tissues and bone and between the subcutaneous tissues and the air-filled lung. Therefore acoustic windows must be found that optimize visualization of the heart. The acoustic windows lie on either side of the cranioventral thorax, where the heart is in contact with the ribs and consequently can be imaged directly through the intercostal spaces. The usual location is over the site of apex beat. This imaging location is termed the parasternal position.

The preferred technique for cardiac assessment is imaging the animal in the lateral recumbent position using a cutout table or elevated cutout platform on a table. The transducer is placed on the dependent side of the thorax. Recumbency ensures that the heart is as close as possible to the rib cage, displacing the adjacent lung. This position may also be useful in the general examination of other thoracic structures.

Sometimes an abdominal approach is used, called the **subcostal approach**. The transducer is located just caudal to the xiphisternum and angled cranially to...
locate the heart, using the liver as an acoustic window. This window is used to obtain a better Doppler angle of the aorta. This location is also useful for examining the diaphragm and caudal thorax. Rarely, the thoracic inlet may be used to image the cranial mediastinum and heart base—the suprasternal position.

Dyspneic animals are often more comfortable if they are examined while they are standing or lying in the sternal position. Sedation may be required with intractable dogs and cats. The intercostal space width is a practical limiting factor in small dogs and cats. The acoustic window is on the craniocaudal thorax, where the intercostal spaces become narrow. The transducer footprint must be small enough to be able to be placed on an intercostal space close to the sternum. It must be capable of being angled cranially and caudally around the ribs.

A sector-type transducer is required for ultrasound examination of the heart because the transducers or probes have small footprints that allow examination of the heart through an intercostal space. In small dogs and cats a probe with a frequency range of 7 to 10 MHz is recommended. For medium-sized dogs, a frequency range of 5 to 7 MHz is desirable. Large and giant-breed dogs may require a probe with a frequency range of 2 to 3 MHz.

Linear transducers may be used because they can be placed longitudinally along the intercostal space. However, the information thus gained may be limited because of the inability to manipulate the transducer.

Many ultrasound machines now offer multiple-frequency transducers that can cover a range of frequencies and allow the same probe to be used to evaluate patients of different sizes. Some ultrasound probes may offer the option of using a lower frequency for color and pulsed-wave Doppler interrogation than is used for B-mode imaging. The use of a lower frequency for Doppler interrogation allows the measurement of high-velocity blood flow without the problem of aliasing. Harmonic imaging uses ultrasound waves at frequencies that are multiples of the fundamental frequency of the probe. Harmonic imaging results in improved border delineation and image contrast. It works more effectively at relatively low frequencies. Implementation of harmonic imaging technology varies considerably from one manufacturer to another. In general, it results in significant improvement in image quality in echocardiography when using lower frequencies such as those for medium-sized to large dogs.

Depending on the purpose of the examination, the appropriate area of the thorax should be close clipped, the skin cleaned with surgical spirit if it is greasy or dirty, and acoustic gel applied.

THE BRONCHI
Anatomy
The trachea divides into left and right primary or mainstem bronchi. The left primary bronchus divides into cranial and caudal secondary bronchi. The cranial secondary bronchus divides to supply the cranial (apical) and caudal (cardiac) segments of the cranial lung lobe. The left caudal secondary bronchus supplies the left caudal (diaphragmatic) lung lobe. The right primary bronchus divides into four secondary bronchi, which supply the four lobes of the right lung—the cranial (apical), middle (cardiac), caudal (diaphragmatic), and accessory (intermediate or azygos).

Radiography
Lateral and dorsoventral or ventrodorsal views of the thorax are required for routine examination of the bronchi. In the past, bronchography was sometimes used to outline the bronchi. It is now rarely used because of the associated hazards and the advent of computed tomography and endoscopy.

Normal Appearance
Plain radiographs give little information about normal bronchi. Only the larger bronchi in the hilar region are regularly seen. The walls of the bronchi merge with the outlines of the accompanying pulmonary vessels.

Ultrasonography
Normal bronchi are not amenable to transcutaneous ultrasonography.

Abnormalities
Diseases of the bronchial tree involve intrapulmonary changes (see p. 227).

Bronchitis. Acute bronchitis can be present without radiographic evidence of disease. Chronic bronchitis frequently shows an interstitial pattern. Widespread disease changes associated with the bronchi will be manifested as a decreased lucency of the lung fields, an increase in nonvascular linear markings, and peribronchial infiltration.

In end-on views of individual bronchi, peribronchial infiltration is seen as a ring shadow or as a cuff surrounding the affected bronchus. This has been described as giving the bronchus a “doughnut” appearance. Thick peribronchial cuffs suggest an acute process; thinner cuffs suggest chronicity. Converging, almost parallel, lines of thickened bronchial walls may be seen extending toward the periphery of the lungs. This has been called the “railroad track” or “tramline” effect. If the bronchi are filled with exudate and if there is air in the surrounding lung, they appear as nodular lesions when projected end-on. If the surrounding lung is infiltrated and the bronchi contain exudate, contrast is lost and the bronchi are not seen. Interstitial and bronchial patterns may be seen in older animals as part of the aging process (Figure 3-7).

Radiographic evaluation should be made in conjunction with clinical and other findings. The principal clinical sign of bronchitis is coughing. Chronic bronchitis and sinusitis may be associated with situs inversus.

Bronchiectasis. Bronchiectasis is an uncommon, abnormal, and irreversible dilation of the bronchi. It
is rarely seen in cats. It may be tubular or saccular in nature. It is usually a result of chronic respiratory disease. Bronchial secretions accumulate in the dilated bronchi, predisposing to infection. The radiographic appearance of bronchiectasis is variable. In early cases there may be no radiographic signs. Later changes depend on the course of the disease. Widening and unevenness of the bronchial lumen are probably the first detectable changes. As the bronchi fill with secretions and exudate, they appear as nodular opacities when seen end-on. These may simulate metastatic foci. Peribronchial cuffs or ring shadows are prominent. Thickening of the bronchial walls, interstitial infiltration, and areas of atelectasis or pneumonia may be seen. Dilated bronchi may be seen extending out toward the periphery of the lung fields. Bronchography is useful in making a diagnosis, particularly in early cases (Figure 3-8, C to F).

In young Rottweilers and Newfoundlands, bronchiectasis, usually accompanied by pneumonia, may be caused by an inherited ciliary dyskinesia (immotile cilia syndrome) (Figure 3-8, I to K).

Chronic bronchitis and sinusitis may be associated with situs inversus. The concurrent presence of situs inversus, sinusitis, rhinitis, and bronchiectasis is known as Kartagener’s syndrome.

Displacement. Displacement of bronchi may occur as a result of pathology in adjacent areas. Pulmonary masses, lung lobe torsion, and enlargement of mediastinal structures may all result in displacement (see Figure 3-26, K). Bronchi may appear displaced on rotated views. Bronchi are displaced away from enlargements and masses. With lung lobe torsion, the normal cranial or lateral direction of the bronchus is changed and the bronchus runs in an aberrant direction.

Calcification. Older animals sometimes have calcified bronchi, which in themselves are not significant. The bronchi appear as linear calcific opacities traversing the lung fields. Often there are almost parallel calcific linear shadows outlining the bronchus in that area (railroad track or tramline markings). Calcification may be seen in dogs with hyperadrenocorticism (see Figure 3-8, B).

Allergic Bronchitis (Bronchial Asthma, Feline Asthma). Asthma is a chronic inflammatory disease of the airways affecting the bronchi and bronchioles. The cause or causes remain obscure. The clinical signs are related to a decreased intake of air through narrowed bronchi and bronchioles caused by constriction of these structures as result of spasm, mucus secretion, and edema of the walls. There may be sudden difficulty in breathing, or signs may be more chronic, primarily a persistent cough.

Radiologic signs of bronchial asthma include increased lucency of the lung fields and an increase in their size as a result of hyperinflation. The lung fields may extend beyond the costal arch. There is also some...
Chapter 3  ■  The Thorax

Figure 3-8  A, Bronchogram of the left lung, lateral view.  a, Trachea;  b, left cranial lobe bronchus;  c, left middle lobe bronchus;  d, left caudal lobe bronchus;  e, right caudal lobe bronchus;  f, accessory lobe bronchus.  B, Bronchial mineralization in a dog. The walls of the major bronchi are more prominent than normal and seen as radiopaque converging lines. This change is often seen in older patients. It may also be caused by endocrine disorders such as Cushing's syndrome.  C to  F, Chronic pneumonia and severe bronchiectasis in a dog. This is a 1-year-old Labrador Retriever with an immune deficiency (immunoglobulin M) that caused recurrent episodes of pneumonia.  C and  D, There is severe dilation of multiple bronchi. The bronchi in the hilar and middle zones of the lungs have a tubular appearance with thin walls.  E, There are saclike dilations of the distal bronchi.  F, An alveolar infiltrate is present in the right cranial and right middle lung lobes. There is moderate volume loss in these lobes, with a displacement of the heart cranially and to the right (a mediastinal shift). (A, From Ticer JW (ed):  *Radiographic technique in veterinary practice*, Philadelphia, 1975, WB Saunders.)

Continued
Figure 3-8, cont'd  

G and H, This cat presented with periodic episodes of respiratory distress. The lung fields are hyperlucent, and the diaphragm is lying at an excessive inspiratory excursion. Diagnosis: feline asthma syndrome, pulmonary hyperinflation.

I to K, Bronchopneumonia. This was a 2-year-old Rottweiler with a cough and tachypnea. I, A right lateral view of the thorax shows several radiolucencies (dilated bronchi) superimposed on the cardiac silhouette. A lobar margin is seen (arrow). J, A left lateral recumbent study shows a wide cranial lobe bronchus with thickened walls (arrows). There is an alveolar infiltrate in the ventral portion of the left cranial lobe. K, A dorsoventral view shows a widespread alveolar pattern in the left cranial and caudal lung lobes. L, Bronchial foreign body in a dog. A slightly oblique dorsoventral view of the thorax shows a well-defined spherical foreign body within the right caudal lobar bronchus (arrow). There are patchy alveolar and interstitial infiltrates in both the left and right lungs. There is a slight mediastinal shift to the right as a result of atelectasis of the right caudal lung lobe caused by obstruction of the lobar bronchus. The foreign body was a small rubber ball.
degree of flattening of the diaphragm and unusually clear visibility of bronchovascular markings. Varying degrees of bronchial and interstitial changes may be detected. The radiologic signs are variable, ranging from those of chronic bronchitis with thickening and calcification of bronchial walls to few or no changes. If there is trapping of air in the alveoli, the lungs appear more radiolucent than usual. Conversely, no radiographic changes may be evident. Bronchial asthma is not common in dogs. Cats are much more frequently affected than dogs.

In asthmatic cats, there may be little difference between inspiratory and expiratory films because of increased lung volume as inflammation of small airways causes air trapping (Figure 3-8, G and H, and Figure 3-12, F to H). In cats, stress fracture of a rib or ribs may occur in association with the labored breathing.

**Bronchial Foreign Body.** A radiopaque foreign body will be visible on plain radiographs. It may appear to be in the esophagus. The presence of a radiolucent foreign body may be suspected because of its effects on the affected lung lobe. The caudal bronchi are most commonly affected. Atelectasis followed by bronchopneumonia and consolidation may develop as a result of obstruction of a bronchus. The caudal lung lobes are the most commonly affected. A foreign body may act as a valve, allowing air to enter the lung but preventing it from escaping. This may cause overinflation of the lung and ultimately emphysema. Rupture of a bronchus will result in atelectasis. Complete obstruction of a bronchus will result in consolidation of the lung lobe supplied by that bronchus (Figure 3-8, L).

**THE LUNGS**

**Anatomy**

The left lung has two lobes, a cranial and a caudal. The cranial lobe is divided into cranial (apical) and caudal (cardiac) segments. The caudal lobe was formerly called the *diaphragmatic lobe*. The right lung has four lobes: cranial (apical), middle (cardiac), caudal (diaphragmatic), and accessory (intermediate or azygos). The lobes are separated from one another by interlobar fissures. On inspiration, the left cranial lobe extends beyond the first pair of ribs and projects a little into the right side of the thorax at its cranial extremity. At full inspiration, the right middle lobe may extend underneath the heart, between it and the sternum, particularly in left lateral recumbency (Figure 3-9, H and I). This should not be mistaken for pneumothorax. Dorsally, the lungs extend on either side of the vertebral column to the level of the costo-vertebral junctions. In the cat, the lungs do not extend into the diaphragmaticolumbar recess. This should not be mistaken for displacement of the lung edge by pleural fluid (see Figure 3-6, D).

The hilus is that part of the lung at which the bronchi, pulmonary vessels, bronchial vessels, and nerves enter.

**Normal Appearance**

A radiograph of the lung fields is a composite shadow of many structures, including the pulmonary vasculature, bronchi, bronchioles, alveolar ducts, alveoli, interstitial tissue, lymphatics, pleurae, and thoracic wall. Air in the bronchial tree and alveoli provide a good contrast medium against which the pulmonary vasculature can be seen. The other structures provide the background opacity. Only the larger bronchi near the hilus are seen on normal films. Because the arteries and veins lie alongside the bronchi, the bronchial walls contribute to the vascular outlines seen. The lung lobes are partially separated from one another by interlobar fissures. On normal radiographs, the fissure between the right and left cranial lobes is usually seen on the lateral view. The fissure is seen as a faint linear opacity, cranial to the heart, extending from approximately the second or third sternaebra cranially and dorsally to blend with the ventral border of the cranial mediastinum at the level of the first rib. It represents a mediastinal reflection where the cranial extremity of the left cranial lung lobe crosses to the right side of the thorax to lie cranial to the cranial lobe of the right lung. There is a considerable overlapping of lung lobes in the lateral, ventrodorsal, and dorso-ventral views.

The most prominent features in the thorax are the cardiac silhouette and the pulmonary vasculature, that is, the pulmonary artery with its branches and the pulmonary veins. The bronchial arteries are not seen. The clarity with which the vessels are visualized varies with the degree of inspiration, the age of the animal, the posture of the animal, the presence or absence of a disease process, and the radiographic technique. Films made at expiration show an apparent increase in lung opacity and a decrease in the visibility of blood vessels; this is because the reduced intrathoracic air mass decreases contrast and, furthermore, expiration compresses the lung structure. Radiographs of older animals show poorer contrast than those of young ones because of an increase in interstitial tissue (fibrosis). The pulmonary vasculature may be obscured by other structures on improperly positioned radiographs.

On the lateral view, the vessels of the right and left lungs are superimposed on one another. Cranial to the heart, two pairs of vessels can usually be distinguished. The dorsal pair are the right cranial lobar artery and vein; the ventral pair are the left cranial lobar artery and vein. On lateral views, the cranial lobar arteries lie dorsal to the corresponding veins. Caudal to the heart, the right and left pulmonary arteries branch out toward the periphery of the thorax, the left pulmonary artery being slightly dorsal to the right. Opposing lateral views are necessary for a complete study. This is because in the lateral recumbent position the dependent lung is not fully inflated because of pressure caused by the upper or nondependent lung.

On the dorsoventral or ventrodorsal view, the pulmonary vasculature is best seen in the perihilar and middle areas of the lung fields. At the hilus, vessels...
Figure 3-9 Lateral views of the thorax taken at inspiration (A) and expiration (B). At inspiration the ribs are more widely separated, and the lung fields appear more lucent. Greater vascular detail can be seen at inspiration, especially in the caudal lung lobes, and more of the accessory lung lobe area (arrow) caudal to the heart can be seen. At inspiration, the caudal vena cava is more centrally placed and is almost horizontal. At expiration, it is angled obliquely toward the dorsal third of the thorax and is directed obliquely cranioventrally. The diaphragm does not overlie the cardiac shadow on the inspiratory film. C, Some structures are visible on the right lateral recumbent thoracic radiograph. A, Thoracic aorta; T, trachea; B, origin of the left cranial lung lobe bronchus; C, origin of the right cranial lung lobe bronchus; PA, branches of the pulmonary artery; RD, right diaphragm crus; LD, left diaphragm crus; CVC, caudal vena cava; H, heart; RL, artery and vein for the right cranial lung lobe; LL, artery and vein for the left cranial lung lobe; CM, cranial mediastinum; P, fold of pleura marking the cranial limit of the right cranial lung lobe. Caudal to this fold, the right and left cranial lung lobes are superimposed on one another. LC, Cranial portion of the left cranial lung lobe viewed end-on; LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle. D, Distribution of the pulmonary arteries within the lungs as seen on the lateral view. RV, Right ventricle; PV, pulmonic valve; PT, pulmonary artery trunk; RPA, right pulmonary artery; LPA, left pulmonary artery; DD, diaphragm. E, The larger pulmonary veins are seen on the lateral view. LV, Left ventricle; AV, aortic valve; A, aorta; PV, pulmonary veins entering the left atrium; LA, left atrium; MV, mitral valve; Au, left auricle.
are obscured by the cardiac shadow and, at the periphery, vascular shadows are small and few. On these views, the caudal lobar arteries lie lateral to the corresponding bronchi, and veins lie medial to them. On most ventrodorsal and dorsoventral radiographs of the thorax, a thin, opaque line is seen extending from the apex of the cardiac shadow to the left hemidiaphragm. This line has been erroneously called the phrenicopericardial ligament, the diaphragmaticopericardial ligament, and the cardiophrenic ligament. In fact, it represents the mediastinum and a pleural reflection along the line where the accessory and left caudal lung lobes meet. The cardiophrenic ligament is not visible radiographically.

The pulmonary arteries are much more clearly seen than are the pulmonary veins. Tracing the vascular shadows toward the hilus shows that they originate from the main pulmonary artery cranial to the tracheal bifurcation. They follow the course of the bronchial tree. Veins are much less clearly defined and, when seen, are short and take a direct course toward the left atrium, located caudal to the tracheal bifurcation. On the left lateral view, the cranial lobar arteries and veins should be equal in size and should be no greater in diameter than the width of the proximal third of the fourth rib. In the larger breeds of dog, the veins appear slightly larger than the arteries. On the dorsoventral radiograph, the caudal lobar artery and

Figure 3-9, cont’d F, Angiocardiogram showing the distribution of the pulmonary arteries as seen on the ventrodorsal view. G, The thymus gland (arrow) is sometimes seen in the left thorax on the ventrodorsal or dorsoventral view. Because of its shape, it is sometimes referred to as the thymic sail. Right (H) and left (I) lateral recumbent views of the thorax of the same dog. The left lateral view shows elevation of the cardiac silhouette from the sternum when compared with the right. This is a normal variant with well-inflated lungs and the dog lying in left lateral recumbency.
vein should be similar in size and equal to or less than the diameter of the ninth rib where the vessels cross these ribs.

The thoracic aorta can be seen in the dorsal thorax through the pulmonary shadow on lateral views. On well-penetrated ventrodorsal and dorsoventral views, the aorta can be seen through the cardiac shadow. The great vessels in the cranial thorax form part of the mediastinal shadow. The caudal vena cava is seen on lateral and ventrodorsal and dorsoventral views. On dorsoventral and ventrodorsal views, it is seen in the right hemithorax, lateral to the cardiophrenic angle (the angle between the diaphragm and the cardiac shadow; see Figure 3-9).

Ultrasonography

The air-filled lung tissue does not transmit sound waves because of the difference in acoustic impedance between soft tissue and air. Therefore the normal ultrasonographic image of the lungs is of a hyperechoic smooth line that represents the pleura/lung interface. This interface can be seen moving to and fro. Because of the reflection of the ultrasound beam, reverberation artifacts are seen as a series of parallel hyperechoic lines throughout the image (see Figure 1-11).

Abnormalities

Many difficulties are encountered in distinguishing pathologic changes within the lungs and in classifying them satisfactorily. The pulmonary vasculature in normal lungs is seen with a considerable degree of clarity because of the background contrast provided by the air-filled lungs. Hence, anything that causes a reduction in the amount of alveolar air will make the vascular pattern less distinct. The vasculature will also be obscured by changes that cause an increase in opacity of the interstitial tissues. Disease processes affecting the vessels themselves may reduce their visibility or distort their normal pattern. Abnormalities of the bronchial tree may be reflected on thoracic radiographs and may affect the visibility of the pulmonary vessels because of loss of contrast between the vessels and the bronchi. Pleural effusions mask lung shadows. Pulmonary disease may manifest itself in a variety of ways.

Because different disease conditions may produce similar radiographic changes in the lung fields, it is important to evaluate the distribution of changes within the lungs. Other thoracic structures must be carefully examined. Hence, it is more useful to classify pathologic changes into basic lung patterns according to the structures primarily involved, namely alveoli, interstitial components, bronchi, and blood vessels. Once a change in the normal pattern has been identified as affecting one or more of these structures, a list of differential diagnoses can be elaborated that might explain the changes seen. The different possibilities thus presented can be further arranged in order of probability by taking into consideration evidence available from other sources, such as the history of the case, the clinical examination, and the results provided by laboratory or other tests.

Abnormal Lung Patterns

Table 3-1 summarizes the different pulmonary patterns. The significance of the changes seen within the lungs may often be difficult to evaluate. Clinical findings and the results of other diagnostic procedures must be taken into account in arriving at a diagnosis. High-quality radiographs are essential for the proper evaluation of the lung fields. Overexposure will obliterate and underexposure will unduly emphasize lung features and lead to misdiagnosis. Inspiratory radiographs are essential for proper contrast and the recognition of abnormalities. Lung detail is often indistinct in obese animals. An advantage of the pattern approach to abnormal thoracic radiographs is that it directs attention to the underlying processes producing the radiographic changes. This makes it easier to suggest logical reasons for the changes seen. There is a tendency to overread thoracic radiographs, attaching pathologic significance to normal variations. The recognition of a particular pattern of change, however, will limit the possible range of diagnoses and facilitate a correlation between the changes seen and basic pathologic processes. Serial studies are often helpful, because lung patterns, particularly the alveolar pattern, are subject to rapid change. In addition to observing the pattern type, the distribution of the pattern in the lungs is helpful because some conditions tend to localize in a typical lobe or location within a lobe.

Few clinical cases present showing one pattern only. This is because of the proximity of the various structures to one another and because of the varying stages of the disease process visible at the time of examination.

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<th>Table 3-1 Pulmonary Patterns</th>
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<td><strong>Alveolar</strong></td>
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<td>Fluffy opacities</td>
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<td>Areas of increased opacity</td>
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<td>tend to merge Interlobar f fissures become visible</td>
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<td>Air bronchograms</td>
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Alveolar Pattern. An alveolar pattern results when alveoli become filled with fluid, cellular debris, or neoplastic infiltration, or when they collapse. The alveolar ducts and terminal bronchioles may also become affected. The fluid or debris displaces air in the alveoli, and their contribution to overall contrast is thus lost.

Radiologic Signs
1. “Fluffy” lung opacities. Ill-defined fluffy opacities gradually fade into the adjacent, more normal lung tissue. These opacities have been likened to a “cotton candy” or “cotton wool” appearance. The areas of increased opacity tend to merge with one another.
2. Air bronchograms. Bronchi that contain air become visible as radiolucent tubular or branching structures that contrast with the more opaque infiltrated lung tissue. These are referred to as air bronchograms. End-on, they appear as discrete circular lucencies. The spaces between the cranial lobar arteries and veins should not be mistaken for air bronchograms. Fluid-filled bronchi are not seen. If there is widespread filling of bronchi, the affected area of lung will have a consolidated or homogeneous appearance.
3. Lobar distribution. The area of increased opacity affects a lobe or portion of a lobe. As a result, lobar borders, not normally seen, become visible; that is, the position of the interlobar fissures can be recognized.
4. Air alveolograms. Dispersed among the infiltrated alveoli are often groups of alveoli that contain air. These radiolucent air-filled groups of alveoli are referred to as air alveolograms. They give the lung field in this area a mottled appearance. Ill-defined nodular opacities are sometimes seen. These opacities result when air is replaced by fluid or debris in a group of alveoli supplied by a terminal bronchiole. They are called acinar nodules.
5. Rapid change. The alveolar pattern often undergoes rapid change. It appears soon after the onset of clinical signs and tends to disappear rapidly after successful therapy has been instituted.
6. Vessels within the affected lobe or segment are completely obscured.
7. Where the affected part of lung is in contact with the heart or diaphragm, the border of the soft tissue structure is obscured or blends with the lung.

All these signs are not necessarily seen in any one case. Conditions that show an alveolar pattern include pulmonary edema, intrapulmonary hemorrhage, pneumonia, granulomatous lesions, obstruction of a bronchus, infarcts, allergies, atelectasis, and chronic alveolar disease. Neoplasia rarely causes an alveolar type of pattern, but it may (Figure 3-10).

Atelectasis indicates incomplete expansion or collapse of a lung or part of a lung. It may result from obstruction of an airway, compression (as in pneumothorax), pleural effusion, inhalation anesthesia, prolonged recumbency, or lung lobe torsion (see Figure 3-23). Many infiltrative diseases such as pneumonia have an atelectatic component. It may involve one lobe or several lobes, and it may be partial or complete. The reduced lung volume causes a mediastinal shift toward the affected side. The atelectatic lobe shows an increased opacity as a result of loss of air, and associated interlobar fissures are displaced. This feature is often best seen on the ventrodorsal or dorsoventral view. With lobar atelectasis, adjacent lung lobes expand to fill the deficit. Air bronchograms may be seen in severe cases. It can be difficult to differentiate atelectasis from pneumonia with an alveolar pattern. In dogs and cats the lobe that is most often affected by atelectasis is the right middle lobe. In cats this is especially associated with bronchial asthma.

Consolidation is a pathophysiologic concept, not a pulmonary pattern. It implies the replacement of alveolar air by fluid or cellular material. There is no loss of volume of the affected lung or lobe and consequently no mediastinal shift. Air bronchograms are seen. Consolidation is commonly seen with pneumonia, hemorrhage, and neoplastic infiltrates. If either the ventral or dorsal portion of a lobe is affected, both ventrodorsal and dorsoventral views may be required to demonstrate the full extent of the lesion (see Figure 3-15, J and K).

Interstitial Pattern. The interstitium of the lung is the supporting structure and includes the walls of the alveoli and alveolar ducts, the interlobular septa, the capillaries, and the tissues that support the lymphatics, bronchioles, and pulmonary vasculature.

Radiologic Signs
1. There is a general loss of contrast in the lung fields because of an increase in opacity of the interstitial tissues.
2. The outlines of pulmonary vessels become less sharp, although they may still be readily identified.
3. A structured pattern is usually associated with nodular opacities. Such a pattern may show the following:
   (a) Nodules of varying size.
   (b) Cavitary lesions.
   (c) Single or multiple lesions may be distributed throughout the lung fields. Small multiple nodules are often referred to as miliary.
   (d) The nodular opacities are larger than the adjacent blood vessels.
   (e) Nodules may vary in size and distribution but are usually more numerous in the periphery.
4. An unstructured interstitial pattern shows a general lack of contrast and blurring of the pulmonary vasculature.
   (a) Nonvascular linear markings are seen within the lungs.
   (b) The walls of the bronchioles and bronchi may appear thickened because of an increase in their interstitial component.
   (c) A reticulated, or “honeycomb,” appearance is sometimes seen, particularly in the lungs of older dogs. This represents chronic changes in the interstitium (Figure 3-11).
Figure 3-10 A and B show the fluffy type of infiltration characteristic of an alveolar pattern. The infiltrates are irregular in outline and frequently coalesce. Air bronchograms (black arrows) and areas showing air alveolograms (some indicated by open arrows) are seen. These changes represent pulmonary edema secondary to heart failure. C, Principle of the air bronchogram. In A, a represents air-filled groups of alveoli, b is a bronchus, and v is a pulmonary vessel. Air in the alveoli and bronchus provides a contrast for the soft tissue opacity (fluid opacity) of the vessel, so the vessel can be seen on a radiograph. The bronchus is not seen because it has the same radiographic opacity as the alveoli. In B, the alveoli have been infiltrated. They now have the same opacity as the vessel. Contrast is lost, and the vessel can no longer be seen. However, the bronchus now becomes visible because it contrasts with the fluid opacity in the alveoli and blood vessel. D, Principle of the air alveologram. A represents groups of air-filled alveoli. They all have the same degree of radiolucency and will be seen as a dark area on the radiograph. B, If some groups of alveoli become infiltrated while others retain air, a mottled effect is produced on the radiograph. The fluid opacity in some alveoli contrasts with the air opacity in others.
Conditions that may show a structured or nodular pattern include neoplasms, granulomata, parasitic infestations, mycoses, abscesses, cysts, and eosinophilia. Conditions that may show an unstructured pattern include early pulmonary edema, hemorrhage, pneumonia, parasitic infestations, pulmonary embolism, lung collapse, bronchial foreign body, pulmonary fibrosis, early blastomycosis, and neoplastic cellular infiltration, such as is seen in lymphoma. The interstitium provides the main background opacity in radiographs of the lungs. Interstitial disease is often more difficult to evaluate than alveolar disease. Indeed, interstitial disease may have progressed to the stage of alveolar involvement before it becomes detectable on radiographs. Abnormalities of the interstitial tissues do not involve the air space within the lung directly; the total air volume, however, may be reduced in such conditions by compression of the air space. The interstitium may be infiltrated by fibrous tissue, neoplasia, cells, or fluid. Fluid cannot be distinguished from other manifestations of interstitial disease.

Nodular opacities must not be confused with the circular opacities exhibited by blood vessels seen end-on. Blood vessel opacities are not usually numerous, and they are larger toward the hilus. Blood vessels seen end-on are circular and have the same diameter as the width of adjacent blood vessels seen in profile. Nodular infiltrates are of varying sizes and are scattered indiscriminately throughout the lungs. Skin nodules vary in shape and size, are usually distinct in outline, and are generally few in number. Other soft tissue opacities occasionally seen are engorged ticks and prominent teats (see Figures 3-6, P to S, and 3-11, A). Costochondral mineralization should not be mistaken for intrapulmonary masses.

Heterotopic bone formation in the form of discrete, small, nodular, mineralized opacities may be present—pulmonary osteomas (osteomata). They are opaque, 1 to 2 mm in diameter, and scattered throughout the lung tissue. They are of no clinical significance and should not be mistaken for pulmonary metastases (see Figure 3-18, M).

Line markings not associated with blood vessels are seen. They are usually short, do not follow the course of vessels, and frequently fade out after a short distance. The interstitial pattern resulting from disease changes must be distinguished from changes resulting from aging. The case history is of value in making the distinction. It should also be remembered that interstitial changes may precede alveolar changes or follow them during resolution. For example, in pulmonary edema, there may be fluid infiltration of the interstitial tissues before fluid appears in the alveoli. Interstitial changes are often seen in urban dogs at a relatively early age.

**Bronchial Pattern.** Whether bronchi can be seen depends on their relative opacity when contrasted with the air-filled lung tissue. Except for the larger bronchi near the hilus, the bronchial tree cannot be recognized under normal conditions. Some smaller bronchi may be recognized when seen end-on. The branches of the pulmonary artery follow the bronchial tree. Aging and inflammatory changes cause thickening of the bronchial walls, which then become visible.
Radiologic Signs
1. In inflammatory conditions, an irregular infiltrate may surround the bronchi—peribronchial infiltration. This can be clearly seen in end-on views as a soft tissue cuff around the affected bronchus, giving it a “doughnut” appearance. Affected bronchi appear as ringlike structures. The accompanying artery is often seen end-on beside the bronchus, giving an appearance that has been compared to a signet ring. Thick cuffs suggest an acute condition; thin cuffs suggest chronicity. In longitudinal profile, thickened bronchial walls appear as converging linear opacities surrounding a radiolucent lumen.

2. Infiltration of the peribronchial tissues causes a loss of sharpness in the vascular outlines.

3. Fluid within a bronchus causes loss of the normal air opacity in that bronchus. This may appear radiographically as a nodular opacity within the lung when seen end-on or as a thickened linear opacity that rapidly fades out.

4. Calcification of the bronchial cartilage gives rise to a linear pattern within the lung fields. This can be seen, at least in places, to follow the outline of the bronchial tree. Branching pairs of converging lines may be seen extending toward the periphery of the lungs. They have been likened to a railroad track or tramlines. Calcification of bronchi is sometimes seen in old dogs.

5. If infection spreads through the wall of a bronchus to the surrounding alveoli, the bronchiole will be outlined by the surrounding infiltrate.

Diseases that show a bronchial pattern include chronic bronchitis and bronchiectasis (see p. 217). Acute bronchitis may be present despite the absence of visible radiographic changes (Figure 3-12).

Vascular Pattern. The vascular pattern represents a change in the appearance of blood vessels as a result of changes within the vessels themselves. Abnormalities may affect the pulmonary vessels in a number of ways (Figure 3-13).

Hypovascular. A hypovascular pattern may affect all or part of a single lobe, multiple lobes, or the entire lung. The affected portion of lung appears hyperlucent, that is, darker than the normal lung. The pulmonary vessels appear smaller and less numerous than normal. The pulmonary arteries to the cranial lung lobes should not be significantly narrower than the proximal third of the fourth rib. There may be a complete absence of normal vessels in the affected segment. Possible causes for a segmental or lobar hypovascular pattern include pulmonary thromboembolism and lobar emphysema. In a generalized hypovascular pattern, both the arteries and veins are reduced in size and number and the lungs appear dark. It may be very difficult to identify vascular structures in the peripheral zone of the lungs. This appearance must be distinguished from overexposure, which will render the lung fields relatively dark. In the case of overexposure, evaluation of the lungs with a bright light will reveal normal vascular markings in the peripheral zone, and
Figure 3-12 Two examples of a chronic bronchial pattern. A and B, Numerous bronchi are seen end-on with peribronchial infiltration, and there is widespread calcification of bronchial walls. There is a considerable interstitial component with nonvascular linear markings and obliteration of normal vascular shadows. C and D, Pulmonary interstitial fibrosis. This was a 14-year-old West Highland White Terrier with coughing. Lateral and dorsoventral radiographs show widespread peribronchial cuffing and interstitial infiltration. There is cardiomegaly. The tracheal lumen varies in diameter. The lung edges protrude between the ribs. E, Hyperadrenocorticism. The lateral thorax shows a fine, diffuse increase in opacity throughout the lung fields. Bronchial calcification and hepatomegaly are also present.

Continued
the vessels within the hilar and midzone of the lungs appear normal in size. Reduced pulmonary vasculature may result in a compensatory hyperinflation, in which case vessels are more clearly seen than usual and peripheral branches are clearly seen. A generalized hypovascular pattern is usually the result of a reduction in the circulating blood volume from causes such as severe dehydration, hemorrhagic shock, Addison’s disease, anemia, or pulmonic stenosis (see Figures 3-32, C, and 3-33).

**Hypervascular.** Hypervascularization may result from any condition that causes an increase in right heart output, such as left-to-right cardiac shunts. Hypervascularization is also seen in the early stages of inflammatory conditions. Enlargement of the pulmonary veins suggests incompetence of the left side of the heart or a right-to-left shunt. Arteries, veins, or both may be affected.

Pulmonary venous congestion occurs as a result of congenital or acquired left-sided cardiac disease. It is the earliest indication of left-sided congestive heart failure. The pulmonary veins appear larger than the corresponding arteries. The veins may exceed the width of the fourth rib (cranial lobar veins) or the ninth rib (caudal lobar veins) where they cross these structures. There is an increase in the number and size of peripheral pulmonary veins (see Figures 3-31, C, and 3-41, A and B).

The most common cause of pulmonary arterial enlargement is infestation with heartworms (*Dirofilaria immitis*). The parasites provoke proliferation of the intimal layer of the pulmonary arteries, resulting in increased vascular resistance and pulmonary hypertension. The pulmonary arteries are irregularly enlarged and have a tortuous or convoluted shape. End-on projections of abnormal vessels may appear as nodules or even masses (see Figures 3-13 A and B, and 3-43).
Enlargement of both the pulmonary arteries and veins occurs as a result of a right-to-left shunt. Possible etiologies include patent ductus arteriosus, atrial or ventricular septal defects, and arteriovenous fistulas. Shunting of blood from the left side of the heart to the right results in increased right-sided cardiac output and pulmonary venous congestion, causing enlargement of both arteries and veins. There is an increase in both the size and number of small peripheral vascular structures.

Pulmonary hypoplasia or agenesis may cause distortion of the normal vascular pattern in the opposite, unaffected lung (see Figure 3-13, C to G).

**Mixed Pattern.** In many conditions, the pattern seen will be a mixed one because of the close relations among the various structures within the lungs. Thus, for example, interstitial infiltration may precede alveolar infiltration. Hence, at the time of radiography some areas may show predominantly interstitial changes, and other areas may show predominantly alveolar changes. Disease processes in one structure may affect surrounding tissues. Congestive heart failure, associated with a vascular pattern, may also produce an alveolar pattern if alveolar edema develops (see Figure 3-40).

Ultrasonography. Pulmonary tissue changes that are distributed throughout the lung cannot be assessed because of interference from air in the lungs. However, if pathology is present close to or adjacent to an intercostal space and the lung is either displaced or replaced by abnormal tissue, then ultrasonography is useful for assessing the type of lesion. Cavitated masses such as abscesses or cysts that contain fluid and that transmit sound waves can be differentiated from solid masses. Ultrasound-guided fine-needle aspiration or drainage is possible. If there are areas of consolidation, pneumonia, atelectasis, or hemorrhage, the lung tissue echogenicity is mixed and heterogenous. Areas of air-filled lung pockets are seen as hyperechoic edges or flecks interspersed with hypoechoic patches of affected lung. If the bronchi contain fluid, they may be identified as anechoic linear or circular structures. Complete consolidation often gives the appearance of hepatic tissue within which linear hyperechoic shadows representing air-filled bronchi can be identified. This pattern is seen with pneumonia, atelectasis, lung lobe torsion, or intrapulmonary hemorrhage. The presence of pleural fluid will act as an acoustic window (see Figure 3-15, N).

**Hyperlucent Lungs.** The term hyperlucency is used to describe lungs that appear to contain more air than usual. The increased lucency enhances contrast, and so the heart and the aorta are more clearly defined. Generalized hyperlucency in seen in feline asthma (see p. 218) and emphysema. A localized hyperlucency is seen with blebs or bullae or pulmonary thromboembolism. An apparent hyperlucency may be caused by
Figure 3-13, cont'd C to G, An 8-month-old Siamese cat had respiratory difficulty when stressed. There was poor weight gain. C, A lateral radiograph shows the heart in an unusual caudodorsal position. Pulmonary vessels are seen, but their distribution is abnormal. D, A ventrodorsal radiograph shows the heart on the left side of the thorax. Enlarged pulmonary arteries and veins can be seen in the right caudal lung lobes. No vessels are seen in the cranial lung lobe. E and F, A nonselective angiogram through a jugular vein shows an abnormal distribution of the pulmonary arteries. On the lateral view, the contrast medium seems to “stain” the caudal lung lobe area through a mass of fine capillaries. On the dorsoventral view, no left pulmonary artery is seen. There is some reflux into the caudal vena cava. G, A bronchogram shows an abnormal bronchial distribution. At autopsy, the diagnosis was hypoplasia of the left lung, which was virtually entirely absent.
overexposure of the radiograph or by overinflation of the lungs if radiographs are being made during anesthesia. A similar appearance may be seen in cachexic patients (see Figure 3-8, G and H).

**Blebs and Bullae.** A bleb occurs on the surface of the lung, and a bulla occurs within the substance of the lung. They are collections of air arising as a result of alveolar disruption. They may be seen associated with chronic pulmonary disease such as emphysema or neoplasia. A pneumatocele is a bulla that forms after pulmonary trauma. Such bullae are thin walled, circular, and radiolucent. Some may fill with blood and become pulmonary hematomas. They are spheroid to fusiform with soft tissue opacity. If both blood and air are present, the center may appear lucent. They are differentiated from cavitated abscesses, which have thick walls and variable amounts of soft tissue or fluid opacities within them. Spontaneous pneumothorax may occur if they rupture (see Figure 3-15, X and Y).

**Emphysema.** Emphysema is rare in dogs and cats. It is a complex condition in which there is dilatation of the air spaces distal to the terminal bronchioli and destruction of alveolar walls. It can be seen as a sequel to chronic bronchitis, as in bronchial asthma. In some breeds, notably the Jack Russell Terrier and the Shih Tzu, it may be congenital. Radiologically, pulmonary hyperlucency affects one or more lobes with mediastinal shift away from the affected side. The diaphragm is flattened and displaced caudally. The size of the cardiac silhouette is reduced. Positional radiography may be helpful in arriving at a diagnosis. The dog is positioned in lateral recumbency with the affected part of the lungs in contact with the heart. Radiographs must, of course, be adequately penetrated (Figure 3-14).

**Nonspecific Changes**

**Aging.** The lungs of old animals frequently differ in appearance from those of younger ones. The changes associated with advancing age are referable to an increased interstitial component—a loss of sharpness in the outlines of blood vessels and an increase in linear markings within the lungs. Changes associated with age include a prominent interstitial lung pattern; pleural thickening; calcification of the larynx, trachea, and bronchial walls; calcification of costal cartilages and costochondral junctions; new bone formation on the sternum; and spondylosis. The costal cartilages have a stippled appearance with interruptions in their continuity. In aging cats, the cardiac silhouette on the lateral view is more oblique and appears elongated. On the dorsoventral view, the aortic arch is prominent (see Figure 3-6, K and L).

**Obesity.** In obese dogs, the lateral view reveals elevation of the cardiac shadow from the sternum. On the dorsoventral view, the trachea is displaced to the right and the cranial mediastinum is widened. On both views, there is separation of lung margins from the ribs with prominence of the pleural reflections or fissures. Obesity may limit the excursion of the chest wall during respiration (see Figure 3-6, E and F).

**Breed Variation.** In chondrodystrophic and brachycephalic breeds, there are varying degrees of calcification of the larynx, trachea, bronchi, and costochondral junctions. The mediastinum is widened as a result of fat accumulation. The trachea is elevated on the lateral view and displaced laterally on the dorsoventral view (see Figure 3-6, C).

**Border Effacement (Silhouette Sign).** A radiopaque lesion within the thorax that touches the heart, aorta, or diaphragm will cause obliteration of the border it touches in the area of contact. This is known as border effacement or the silhouette sign. A radiopaque lesion within the thorax that overlies but does not touch these structures will not obliterate their borders. This finding is based on the fact that air-filled lung tissue between a lesion and a structure or between structures acts as contrast, outlining both. The cardiac silhouette, for example, is clearly seen because of the touching air-filled lung. If a portion of lung in contact with the heart loses its air, contrast is lost and the cardiac border is obliterated in that area. The aorta can be seen through the cardiac shadow on dorsoventral or ventrodorsal views because of the lung tissue interposed between it and the heart. Radiographs must, of course, be adequately penetrated (Figure 3-14).

**Pneumonia.** The typical radiologic patterns of pneumonia are the alveolar and the interstitial. In acute pneumonia, radiologic changes become evident soon after the onset of clinical signs. Pneumonic infiltrates are usually patchy in distribution, with irregular, indistinct borders. Radiographs should be made in right and left lateral recumbency and in the dorsoventral and/or ventrodorsal positions (Figures 3-15, 3-7, I to K, and 3-14, C to E).

**Bronchopneumonia.** This disease commonly affects the dependent parts of the lungs in the middle and cranial lobes. Various lobes may be affected in different phases of the disease. Serial radiographs, made over a number of days, show changes in the pattern, either progressive or regressive, depending on the response to treatment. Chronic pneumonia often produces a mixed pattern (alveolar, interstitial, and bronchial). There is frequently pleural effusion with nocardiosis (Figure 3-15).

**Bacterial Pneumonia.** Acute bacterial pneumonias produce an alveolar pattern with fluffy infiltrates. The exudative process results in the expulsion of air from groups of alveoli and alveolar ducts. In the early stages, it tends to involve one or two lung lobes. It can be secondary to viral disease or foreign body inhalation. Tuberculosis may cause chronic pneumonia and have a nodular interstitial pattern.

**Foreign Body Pneumonia.** Aspiration pneumonia is the result of fluids or large particles entering the
lungs. The right middle, right cranial, and left cranial lobes are most commonly affected if aspiration occurs as a result of regurgitation or vomiting by a conscious patient. The dependent peripheral portion of the lung is affected first. In the early stage, the infiltrate may appear to surround the bronchus. If the patient aspirates while unconscious, under anesthesia or while recumbent, the aspirated material will be deposited in the dependent lung. Thus any lobe may be affected, and distribution of lesions in such cases can be quite random. The patterns usually seen are alveolar or mixed. A diffuse pneumonia may develop.

Inhalation pneumonia is caused by material such as plant awns settling in the caudal lobes, more commonly the right. Foreign bodies may result in bronchopneumonia, bronchiectasis, lung abscess, atelectasis, or a granulomatous pneumonia. Frequent radiographic examination to monitor progress is advisable.

**Interstitial Pneumonia.** This disease is characterized by loss of clarity of the vascular pattern and an overall hazy increase in lung opacity. This is because the interstitial structures become more opaque, the overall

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**Figure 3-14**

A. The caudal cardiac and dorsal diaphragmatic outlines have been lost because of infiltration of the adjacent lung from pulmonary edema (border effacement). B. The caudal cardiac border and diaphragm can be clearly seen through a superimposed intrathoracic mass. This indicates that the mass is not in contact with the heart or diaphragm. C and D, Chronic pneumonia in the right middle lung lobe of a Bulldog. C, On the left lateral view, the abnormal lung does not have a distinct margin. Air bronchograms are present within the affected lobe, superimposed on the caudal half of the cardiac silhouette. D, On the ventrodorsal view, there is uniform soft tissue opacity within the right middle lung lobe, which blends with the outline of the heart-border effacement. The other lung fields appear normal. The cranial mediastinum is wider than the thoracic spine on the ventrodorsal view. This is a normal feature in this breed because of mediastinal fat accumulation. Evaluation of the lungs on lateral thoracic radiographs in Bulldogs is difficult, and abnormalities may be more obvious on dorsoventral projections.
air volume is reduced, and contrast with the vessels is diminished. Small nodular opacities, peribronchial cuffs, and nonvascular linear markings are seen. Because air is present in the alveoli, the fluffy opacities seen in the alveolar pattern are not apparent in interstitial pneumonia. Interstitial pneumonia usually has a widespread distribution within the lungs. Acute interstitial disease may show some features of the alveolar pattern as a result of early alveolar infiltration.

Viral Pneumonia. Viral pneumonia usually causes little visible radiographic change unless accompanied by secondary bacterial infection that produces exudation or atelectasis. Radiographically, the changes seen are not specific. An interstitial pattern is frequently observed, with reduced contrast between the pulmonary vasculature and the lung parenchyma. There may be peribronchial infiltration. If secondary bacterial pneumonia supervenes, an alveolar pattern will become evident. Conditions such as canine distemper may show these changes.

Fungal Pneumonias. These pneumonias are most commonly seen in the southwestern United States (Coccidioides spp.) and the Midwest (Blastomyces spp.). Cryptococcus is seen sporadically in cats throughout North America and may affect the nasal cavity, lungs, and abdominal viscera. They produce mainly an interstitial pattern. Nodular opacities of varying sizes are usual. The picture may simulate metastatic lung disease. Hilar lymphadenopathy is a common feature. Coccidioidomycosis may be present without any visible pulmonary changes, or a perihilar interstitial pattern may be observed. The history and origin of the patient are helpful in the differential diagnosis (Figure 3-15, D).

Parasitic Pneumonias. Pneumonia may develop secondarily to parasitic infestation such as Dirofilaria immitis. The signs will be associated with the pulmonary structures involved—alveolar, interstitial, or bronchial. Consolidations around the bronchi and a bronchial pattern are common (see Figures 3-43 and 3-44).

Toxoplasmosis. In dogs, the radiographic pattern seen with toxoplasmosis may be interstitial and/or alveolar, frequently with some degree of pleural effusion. In cats an interstitial pattern is seen, particularly in the caudal lung lobes. Numerous ill-defined consolidations around the bronchi and a bronchial pattern are common.

Aelurostrongylosis. The Aelurostrongylus abstrusus worm lives in the bronchioles of affected cats. Small nodular opacities are seen, widely distributed throughout the lung fields. The caudal lung lobes are more severely affected. Bronchial markings become
prominent, and small pleural effusions and pleural thickening have been reported (Figure 3-15, L).

**Paragonimiasis.** Lung fluke worms (*Paragonimus kellicotti*) in dogs are common in some parts of the United States, most commonly around the area of the Great Lakes, and in eastern Asia. Radiographic findings comprise nodular opacities resulting from granulomatous lesions, linear and peribronchial infiltrates, and intrapulmonary cystic lesions. The tracheobronchial lymph nodes may be enlarged. Pneumothorax may occur. It also occurs in cats. **Filaroides Hirthi.** This metastrongyloid parasite invades the lungs, provoking a granulomatous reaction around the nematodes. The radiologic features consist of interstitial miliary nodules and linear or reticular opacities, with an increased bronchial pattern that is most severe in the caudal lobes. It is a rare condition.
Acute Respiratory Distress Syndrome. Severe trauma to the thorax, major surgery, endotoxemia, severe uremia, and other illnesses such as acute pancreatitis and disseminated intravascular coagulation may result in a deficiency of pulmonary surfactant in the lungs. ARDS may also occur in cases of smoke inhalation, aspiration pneumonia, oxygen toxicity, and Paraquat poisoning. The efficiency of the alveolar/capillary exchange mechanism is compromised, and severe respiratory distress and hypoxia ensue. There are varying degrees of consolidation of the lungs. It is a form of noncardiogenic pulmonary edema (see p. 245). The condition may be acute in onset, appearing suddenly, or may be chronic, developing over the course of several days. Radiologic signs, which are not specific, include an interstitial lung pattern in the early stages progressing through an alveolar type of pattern with eventually consolidation of the lung. A diagnosis of the condition is not possible on radiographic evidence alone. A similar lack of pulmonary surfactant has been described in puppies, which results in neonatal respiratory distress syndrome—a condition similar to ARDS.

Pulmonary Fibrosis. Cryptogenic or idiopathic pulmonary fibrosis has been described in West Highland White Terriers. Dogs affected were between 4½ and 13 years of age. Clinically, animals present with... **Continued**
Figure 3-15, cont’d  D4 and D5, Feline pulmonary cryptococcal infection. 

D4, On the right lateral view, there are two small, poorly defined soft tissue nodules in the caudal lung lobes (arrows). 

D5, On the dorsoventral view, nodules (arrows) are present in the periphery of the right caudal lung lobe. Metastatic pulmonary neoplasia is the major differential for these lesions. 

D6 to D8, Feline pulmonary Histoplasma infection. 

D6 and D7, Right and left lateral thoracic radiographs. There is a diffuse increase in soft tissue opacity in the lungs. There is a generalized unstructured interstitial pattern. Numerous poorly defined soft tissue nodules are also present, some of which coalesce (arrows) to form irregularly shaped mass lesions. 

D8, On the dorsoventral view, a mass lesion in the right cranial lung lobe outlines the interlobar division with the right middle lobe (long arrows). A large mass is present in the periphery of the left caudal lobe (short arrows).
Figure 3-15, cont’d  
E and F, Bacterial bronchopneumonia in a cat. A tracheostomy tube is in place. Air is seen in the fascial planes along the left side and dorsal aspect of the thorax from the tracheostomy tube. Lateral (E) and close-up lateral (E1) projections. The trachea is widened. Multiple thin, branching, linear radiolucent structures are seen within the lung, superimposed on the heart. These are air bronchograms. The increased opacity of the lung obscures the outline of the heart and the cupola of the diaphragm. These features are characteristic of an alveolar pattern. Air bronchograms are formed when fluid of some type fills the lung parenchyma surrounding the airways or when all the air within the lung is removed or displaced, as in complete atelectasis. There is a blotchy, nonhomogeneous increased opacity within the lung at the junction between the alveolar pattern and the more normal lung. This is an interstitial pattern that is common in the transition zone between an alveolar pattern of whatever cause and adjacent normal lung. F, On the dorsoventral view, it is evident that the changes are widespread and affect both right and left lung fields. G, This dog developed respiratory distress after surgery for the removal of a cystic calculus. It died 36 hours later. The right lung is completely infiltrated, and air bronchograms are seen. There is also some infiltration of the left caudal lung lobe. Part of the opacity in the left cranial lung lobe area is caused by overlying of the scapula. Diagnosis: *Klebsiella pneumonia*. 

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Figure 3-15, cont’d H and I, Pneumonia. A widespread patchy infiltration associated with pneumonia. There are fluffy infiltrates and air bronchograms. Peribronchial infiltrates (arrows) can also be seen. This was an 8-year-old German Shepherd that presented with a cough. Although the lateral view might be considered suggestive of pulmonary edema, the ventrodorsal view shows the patchy distribution of the infiltrate indicative of pneumonia. J and K, Bronchopneumonia in a dog. J, Arrows point to the right cranial lung lobe bronchus and several of its branches. K, Arrows point to linear and cross-sectional air bronchograms in the left and right caudal lung lobes. The air-filled bronchi are visible because they are surrounded by lung that is more opaque than air. The air-filled bronchi are referred to as air bronchograms. Because the lungs have become consolidated, the contrast between them and the heart is lost and the cardiac silhouette is not visible. (J and K courtesy Dr. W. H. Rhodes.)
Figure 3-15, cont’d L, This radiograph of a young stray cat shows a widespread interstitial and bronchial type of pulmonary infiltration. The cause was *Aelurostrongylus abstrusus* infestation. M, This cat presented with abnormal respiration. There is a diffuse bronchial and interstitial infiltrate with a miliary nodular component throughout the lungs. Diagnosis: tuberculosis. N, Pulmonary consolidation in a dog. This is a transverse plane image of the right cranial lung lobe. Dorsal is to the right of the image. A segment of consolidated lung appears as an hypoechoic, almost anechoic irregularly marginated lesion in the center of the image (asterisk). This section of lung contains multiple hyperechoic speckles. The lung dorsal to the affected segment has a ragged pleural surface (short arrows), with a ringdown-type artifact (long arrow) deep to it. This appearance suggests partial consolidation of this region of lung.

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Figure 3-15, cont'd  O and P, Tuberculosis. A 3½-year-old Wire Fox Terrier had a cough and dyspnea. There is a widespread alveolar infiltration affecting the left lung and the right middle lung lobe. Air bronchograms and interlobar fissures are seen. Q and R, This was a 4-year-old dog with a chronic cough. Lateral and ventrodorsal views show widespread and severe bronchial and interstitial patterns throughout the lung fields. A bronchoalveolar lavage confirmed pulmonary infiltration with eosinophils.
Figure 3-15, cont’d. S to W. Pulmonary infiltrates with eosinophilia and their progression in a 7-year-old Whippet. Right lateral (S) left lateral (T), and close-up (U) radiographs on initial presentation. There is a severe diffuse bronchial pattern. The bronchial walls are severely thickened. These are visible as thick, converging nonvascular linear markings (short arrows). These extend into the periphery of the lung. Multiple end-on bronchi are visible as ringlike markings or ring “doughnuts” (long arrows). On the left lateral view (T) there is an indistinct mass lesion present within the lung (short arrows), just cranial to the diaphragm and dorsal to the caudal vena cava. Pulmonary infiltrates with eosinophilia more commonly present as an interstitial, bronchial, or mixed interstitial and bronchial pattern. Nodules or mass lesions are occasionally found. V. After treatment for 1 week, the appearance of the thorax is improved with some reduction in severity of the bronchial pattern. However, a moderate to severe diffuse bronchial pattern persists. W. After 2 weeks of immunosuppressive treatment, the appearance of the lungs is almost normal.

Continued
Figure 3-15, cont'd X and Y, Pulmonary bullae. This was an 11-year-old crossbred Collie recently hit by a car. Lateral (X) and dorsoventral (Y) views of the thorax show that pleural fluid separates the lung margins from the ribs. Multiple, circular, well-defined shadows of varying sizes are seen within the lungs. Some are radiolucent (bullae), and some have a soft tissue opacity (hematomas). Focal areas of mineralization are present in the midthoracic area at the level of the fourth to sixth ribs. The trachea is elevated. Costochondral mineralization (black arrows) is seen ventrally and laterally as an incidental finding. Z1 and Z2, Bacterial bronchopneumonia in a cat. Z1, On the ventrodorsal view, there is a patchy increased opacity in the left cranial lung lobe. This obscures the outline of the heart. Air bronchograms are not evident, but the pulmonary vessels are completely obscured. These findings are consistent with an alveolar pattern. Z2, On the lateral view, the pulmonary change appears as a patchy increased opacity superimposed on the heart.
a persistent cough and exercise intolerance. Thoracic radiographs show a widespread interstitial infiltration throughout the lung fields with increased bronchial markings. There is often right heart enlargement secondary to pulmonary hypertension (see Figure 3-12, C and D).

Pulmonary Infiltrates with Eosinophils (PIE, Eosinophilic Pneumonia, Eosinophilic Pneumonitis, Eosinophilic Pneumopathy, Allergic Lung Disease). The etiology of this condition, in which eosinophils infiltrate the lungs, often remains obscure. The changes seen on radiographs are not characteristic. Interstitial, alveolar, bronchial, and mixed patterns are seen. The lung fields may appear hyperlucent, and the diaphragm may be flattened. The changes seen may simulate bronchopneumonia (Figure 3-15, Q to W).

In areas where *Dirofilaria immitis* infestation is endemic, it should be considered the most likely cause of pulmonary infiltrates with eosinophilia. With moderate or large parasitic burdens, there may be right-sided cardiomegaly and large, tortuous pulmonary arteries. However, it is now more common to see patients with a small parasite burden and have no appreciable radiographic changes in the heart or pulmonary arteries.

Ultrasonography. The pnemonic lung, if in contact with the ribs, is seen as a partial hyperechoic margin with a variable echotexture indicating infiltrated areas. Branching hyperechoic areas are aerated bronchi (Figure 3-15, N).

Pulmonary Edema. Pulmonary edema is an abnormal accumulation of fluid in the interstitium and alveoli of the lungs. It therefore may be interstitial or alveolar or both. Alveolar edema is often preceded by interstitial edema. Pulmonary edema may be cardiogenic or noncardiogenic in origin. Cardiogenic pulmonary edema is a result of heart failure from a range of cardiac diseases such as mitral valve disease, cardiomyopathy, and left-to-right shunting. Noncardiogenic edema may be caused by obstruction of blood flow by hilar masses, inhalation of noxious gases or smoke, seizures or status epilepticus, head trauma, near drowning, near strangulation, severe upper airway obstruction, allergies, electrocution, hypoalbuminemia, hyponatremia, congestive, advanced uremia, and ARDS.

Radiologic Signs

Cardiogenic. Pulmonary edema caused by cardiac incompetence is associated with the following signs:

1. The radiologic pattern will be interstitial or alveolar, depending on the type and stage of edema present. Often the pattern is mixed. Alveolar opacities mask interstitial changes.
2. With mitral valve endocardiosis, diffuse changes are seen in the perihilar region, which, in the dog, spread out symmetrically into the lung fields on either side (“butterfly” pattern). The periphery of the lung fields may appear to be unaffected.
3. In cases of canine dilated cardiomyopathy in heart failure, the distribution of pulmonary edema may be similar to that seen with endocardiosis but is often random, patchy, lobar, or even peripheral.
4. In cats, the changes are inconsistent and may be similar to edema from mitral valve endocardiosis in dogs, or there may be random, patchy segmental infiltrates.
5. Pulmonary venous congestion usually precedes pulmonary edema. When edema is present, the congested veins may be obscured by the increased pulmonary opacity. In peracute failure, such as with rupture of the chordae tendineae, there may not be venous congestion. Aggressive diuresis of patients in cardiac failure may cause the pulmonary veins to appear small even while edema persists.
6. The blood vessels, in general, become indistinct.
7. Early cases may show a finely granular or nodular pattern as a result of small groups of alveoli being filled with fluid.
8. Interlobar fissures become visible.
9. The cardiac silhouette is usually—but not always—enlarged; the type of enlargement depends on the underlying abnormality.
10. The pattern is subject to rapid change, depending on the resolution (or otherwise) of the condition.
11. As the condition progresses, areas of lung consolidation become evident.
12. The response to appropriate medical therapy is dramatic, with significant improvement in most cases within 12 to 24 hours.
13. Cardiogenic edema secondary to valvular cardiac disease is usually symmetrical, affecting both left and right caudal lung lobes. However, in some patients the distribution may not be symmetric, affecting either the right or left caudal lung lobes more severely (Figure 3-16, C and D; also see Figure 3-40).

Noncardiogenic. Pulmonary edema from other causes is associated with the following signs, which may resolve very slowly.

1. The radiologic pattern is primarily alveolar.
2. Multiple nodular opacities may be seen if less severe or if the condition is in the transition phase before the alveolar infiltrate becomes uniform. These have been termed acinograms.
3. The caudal lung lobes are commonly affected; the changes affect the midzone and extend first to the periphery and then to the hilus if the edema is severe.
4. Interlobar fissures become visible.
5. The cardiac silhouette is normal in outline.
6. The pattern is subject to rapid change while developing but resolves more slowly than cardiogenic edema.
7. The pattern may be asymmetric (see Figure 3-16, E). Animals that have been in prolonged recumbency or under general anesthesia for a relatively short time often show pulmonary edema resulting from hypostatic congestion on the dependent side (see Figure 3-18, T and U).
Figure 3-16  A and B, Left cranial lung lobe torsion in a dog. A, The lateral projection shows a fine, mildly increased soft tissue opacity throughout the left cranial lung lobe. The pattern has numerous small alternating areas of gas and soft tissue opacities. These represent pulmonary acini, some of which are flooded and some of which contain air. B, The dorsoventral view shows that the margin of the lung lobe is retracted slightly from the thoracic wall. It is separated from the thoracic wall by fluid opacity. This indicates the presence of a moderate volume of pleural fluid that obscures the heart and diaphragm. C and D, Pulmonary edema. This evenly distributed, mainly reticular type of pattern suggests interstitial, rather than alveolar, edema. E, Neurogenic pulmonary edema in a dog with head trauma. Neurogenic pulmonary edema classically appears as edema of the caudal lung fields and is generally limited to the middle third of these lobes. (Courtesy Dr. W. H. Rhodes.)
Pitfalls in Cardiac Disease Diagnosis. The radiologic diagnosis of cardiac disease and cardiac failure can be challenging. There is considerable variation in the size and shape of the cardiac silhouette in different breeds of dog. Experience and familiarity with the normal is the only means to overcome this problem. Exposure of the radiograph at expiration will make the heart appear relatively large. This error also results in a diffusely increased pulmonary opacity that can mimic interstitial pulmonary edema. Relative underexposure of a thoracic radiograph may result in the same appearance. Poor positioning on the lateral or dorsoventral/ventrodorsal radiograph will result in displacement and distortion of the cardiac silhouette that can be misinterpreted as cardiac enlargement. Feline patients present a special diagnostic problem because significant cardiac disease may be present in the absence of any radiographic changes.

Torsion of a Lung Lobe. Torsion of lung lobes has been reported in both dogs and cats. It is not common. The right middle lobe is the most commonly affected. More than one lobe may be involved. The bronchi to the affected lobes or lobe are directed abnormally (“pig-tail bronchi”) or occluded. The principal radiologic sign is pleural effusion, with the fluid trapped about the rotated lobe. This finding can be confirmed by changing the posture of the animal and making further radiographs. It will be seen that the position of the fluid does not change. After the removal of the fluid, air bronchograms may be seen (see Figure 3-16, A and B). These may show that the bronchi are directed abnormally. The tored lobe fails to inflate even when the animal is placed in lateral recumbency with the affected lobe uppermost. This feature may help distinguish torsion from atelectasis. Induced pneumothorax has been suggested as a diagnostic aid.

Ultrasonography. On ultrasonographic examination, the affected portion of lung is surrounded by fluid. The echotexture is granular and hypoechoic, resembling hepatic tissue. Bronchi are seen as hyperechoic linear structures.

Pulmonary Hemorrhage. Pulmonary hemorrhage is usually the result of trauma, although it may occur in coagulopathies and in cases of poisoning with anticoagulant agents. The radiologic pattern is commonly alveolar or mixed, but occasionally an interstitial pattern may be evident. The infiltration is patchy in distribution, and concomitant injuries, such as fractured ribs, are often seen. There is usually a rapid resolution of the radiographic changes over a period of days in recovering patients. Discrete opacities that remain as the general lung pattern clears represent hematomas (Figure 3-17).

Pulmonary Neoplasia. Primary lung neoplasms are occasionally seen in the dog and cat and may be an incidental finding. Pulmonary neoplasia may be broadly divided into primary, metastatic, and multicentric or systemic. Metastatic lung disease is common in dogs, less common in cats.

Both left and right lateral recumbent views should be made because small lesions are best seen in the lung that is uppermost. The reason is that in lateral recumbency, the dependent lung lobe does not inflate well, so contrast within it is diminished. As a result, lesions, particularly small ones, may not be demonstrated. Negative radiographic findings do not exclude the possibility that lung metastases are present. Widespread metastatic disease may be present although thoracic radiographs appear normal. This is because the lesions are smaller than the size at which they cast a visible shadow; they are probably less than 5 mm in diameter. Radiographs should be made with the animal in both right and left lateral recumbency if metastases are suspected.

Secondary infection may superimpose an alveolar or bronchial pattern on an underlying interstitial pattern. The chances of seeing small nodules are enhanced by making left and right lateral recumbent views. Superimposed opacities such as nipples or blood vessels seen end-on should not be mistaken for tumor masses (see Figures 3-6, P to S, and 3-11, A).

Radiologic Signs

Primary Pulmonary Neoplasia
1. Usually only one lobe is affected. All or part of the lobe may be involved. Lesions most commonly present as masses, which may be well or poorly defined. The peripheral part of the caudal lung lobes is the most common site in cats. Feline primary lung tumors are often cavitated.
2. A diffuse interstitial pattern is seen with some primary lung tumors, such as bronchiolar cell carcinoma.
3. A single, large pulmonary mass and multiple small nodules is suggestive of a primary lung neoplasm and intrapulmonary metastasis.

Metastatic Pulmonary Neoplasia
1. The signs of metastatic lung disease are mainly those of an interstitial pattern. Multiple, sharply defined soft tissue nodules are the most common manifestation of metastatic lung disease. Metastases of osteosarcoma often show large spherical opacities (“cannonball” configurations). Metastases from adenocarcinoma of the mammary gland show small, multiple, sharply defined, widely distributed nodules.
2. Superimposition of masses on one another, when they are very numerous, may give the impression that their margins are discrete. Lesions should be examined toward the edges of the areas of greatest infiltration or at the lung periphery. The absence of air bronchograms helps exclude the presence of an alveolar pattern.
3. The lesions are usually widely distributed throughout the lungs.
4. The size and opacity of individual lesions vary considerably. They may be calcified, although this is rare. Usually lesions of several different sizes are seen in a lung.
5. A diffuse interstitial pattern is seen with some primary lung tumors such as bronchiolar cell carcinoma and urinary tract carcinomas.

Pulmonary osteomata should not be mistaken for metastases (see p. 227).

Multicentric lymphosarcoma may show a reticulonodular pattern with hilar lymph node enlargement and enlarged sternal or mediastinal lymph nodes or both (Figure 3-18).

Other conditions may cause solitary nodular opacities, such as lung abscess, cyst, infarction, hematoma, or granuloma.

Ultrasoundography. Depending on the location of a mass and its proximity to the rib cage, it may be possible to image it through an intercostal space. Neoplastic tissue often has a mixed echogenicity with an uneven echotexture. Hyperechoic streaks representing air-filled bronchi can be seen. If a tumor is cavitated, anechoic areas surrounded by a thick hyperechoic capsule or wall may be seen within the lesion. Cavitation of tumors creates some difficulty in differentiating them from abscesses or cysts. Fine-needle aspiration or biopsy is a useful technique to confirm the diagnosis (Figure 3-18, P to S) (see Chapter 6, p. 561).

Figure 3-17 Pulmonary hemorrhage. A and B, A 6-year-old female Shetland Sheepdog was hit by an automobile. There is widespread patchy infiltration of the right and left lungs. Air bronchograms are superimposed on the cardiac silhouette (the ventrodorsal view is rotated). C and D, On the lateral radiograph, the trachea does not contrast as well as usual with the mediastinum because there is air in the mediastinum (pneum mediastinum). The mediastinal air outlines the aorta and the dorsal and ventral walls of the trachea. A large amount of gas (air) is present between the skin (arrows) and the body wall. Patchy, fluffy opacities resulting from pulmonary hemorrhage are seen in both lungs.
THE DIAPHRAGM

Anatomy
The diaphragm is a musculotendinous sheath that separates the abdominal and thoracic cavities. It projects into the thorax like a dome. It consists of a central, ventrally located tendinous cupola and muscular right and left crura (singular, crus) that are sometimes referred to as hemidiaphragms. Between the crura there is an intercrural cleft. The right crus is larger than the left. The crura arise from the third and fourth lumbar vertebrae and have attachments to the ribs from the eighth to the thirteenth on either side. Ventrally, the diaphragm attaches to the xiphoid cartilage of the sternum and the eighth costal cartilage. The aorta penetrates the diaphragm between the left and right crura at the aortic hiatus together with the azygos and hemiazygos veins. The esophagus penetrates it at the esophageal hiatus, and the caudal vena cava enters the thorax through the right crus. Cranially, the diaphragm is covered by the pleura, and caudally, it is covered by the peritoneum.

Normal Appearance
The appearance of the diaphragm varies, depending on several factors: posture of the animal, phase of the respiratory cycle, conformation, obesity, age, filling of the stomach, and position and direction of the x-ray beam. The diaphragm itself is not visualized radiographically unless there is free gas in the abdominal cavity, but its position can be determined because of the contrast provided by the radiolucency of the lungs cranial to it and the radiopacity of the liver caudal to it. Fat in the falciform ligament may help define its position ventrally.

In lateral recumbency, the crus on the dependent side appears cranial to the uppermost crus. In right lateral recumbency, the crura appear more or less parallel to one another, whereas in left lateral recumbency, they appear to intersect at approximately the level of the caudal vena cava. The vena cava penetrates the right side of the diaphragm and in right lateral recumbency can be traced only as far as the most cranially placed crus, that is, the right one. In left lateral recumbency, the vena cava can be seen to pass over the shadow of the left crus, which is cranially placed, to reach the right crus caudally. Gas in the fundus of the stomach may outline the left crus dorsally. On lateral views, the diaphragm forms an acute angle with the lumbar vertebrae. This angle is known as the dorsal, phrenicolumbar, or diaphragmaticolumbar recess (Figure 3-19, A and B).

On the ventrodorsal view, deep-chested animals clearly show left and right crura and the centrally located cupula, whereas animals with a shallow thorax frequently show a single diaphragmatic line. The right crus often lies marginally cranial to the left. The cupula may be indented at its point of contact with the heart. On dorsoventral views, the individual crural shadows are not usually seen when the x-ray beam is centered at the level of the caudal edge of the scapula. The angles formed between the cardiac and diaphragmatic shadows are referred to as the cardiophrenic angles. The angles formed between the diaphragm and the ribs are known as the costophrenic angles.
Figure 3-18 Pulmonary neoplasia. A and B, A 7-year-old female Doberman demonstrated weight loss for a month. She was emaciated and uncoordinated and had a small, movable lump on the left chest wall. There was nonproductive retching for 5 weeks. The right cranial hemithorax is occupied by a homogeneous soft tissue mass displacing the heart caudally. The visible lungs show marked interstitial infiltration. At autopsy, the right cranial lobe was filled with a large mass that contained purulent and necrotic tissue. The diagnosis was primary bronchogenic carcinoma. C1 and C2, Pulmonary metastases from a splenic hemangiosarcoma. There is a diffuse increase in soft tissue opacity in all lung lobes. This is from the presence of numerous small, irregularly shaped soft tissue nodules. This is a miliary, nodular pattern. Individual nodules are best appreciated by evaluating a relatively thin part of the lung, such as in the craniodorsal thorax overlying the trachea or caudal thorax, overlying the liver.
Figure 3-18, cont'd D1 and D2, A 12-year-old Brittany Spaniel had labored breathing and depression. D1, The lateral radiograph shows a large mass in the caudal thorax. D2, On the ventrodorsal view, the mass can be seen in the right caudal lung lobe partly overshadowing the heart. The lung lobe was resected. It contained a large hematocyst surrounded by a granulomatous reaction with local areas of bronchogenic carcinoma. Part of the diaphragm is displaced caudally by the mass, giving a double diaphragmatic outline on the right side. E and F, Metastatic disease. Multiple metastases are seen in both lungs. Although individual lesions have sharply demarcated edges, superimposition of numerous lesions may give an overall fluffy appearance. Lesions should be examined at the periphery of the lung, where detail may be more readily appreciated. Miliary lesions of this nature may indicate lymphatic spread of a tumor.

Continued
The thorax

Chapter 3

The pulmonary vasculature can often be seen caudal to the diaphragmatic shadow, superimposed on the liver shadow on lateral and ventrodorsal or dorsoventral views. On the lateral view at inspiration, the position of the diaphragm may vary by approximately the length of two vertebral bodies from its position at expiration. The cranial crus crosses the ventral edge of the vertebral column between the eleventh and the thirteenth thoracic vertebrae. It may, however, be as far cranial as the ninth thoracic vertebra and as far caudal as the first lumbar vertebra. At rest, the diaphragmatic excursion may be the length of one vertebra or less. Animals with abdominal masses or liver enlargement have reduced excursion.

In pregnant or fat animals, those with a full stomach, or old animals in which the diaphragmatic tone has been lost, the diaphragm may be located farther cranially in the thorax than usual. The cat does not usually show individual crural shadows and the lungs do not fill the phrenicolumbar recess on the lateral view—a phenomenon that should not be mistaken for pleural effusion (Figure 3-6, D and I). Inaccurate centering of the x-ray beam may result in a confusing variety of diaphragmatic shadows (Figure 3-19, C).

Ultrasonography

The diaphragm can be imaged from the cranioventral abdomen at the level of the xiphoid using the liver as an acoustic window. It may be necessary to use an intercostal approach, particularly in deep-chested dogs. The diaphragm is not specifically identified unless pleural or abdominal fluid is present. However, in the normal dog or cat it is located at the interface between the lung and the diaphragm. This interface
Figure 3-18, cont’d K and L, This 12-year-old cat was anorexic and coughing for 2 weeks. Lateral and dorsoventral views show multiple nodular opacities scattered throughout the lung fields. Diagnosis: anaplastic carcinoma. M, Multiple small discrete mineralized opacities are scattered throughout the pulmonary tissue. They are all of similar size. Diagnosis: pulmonary osteomata. N and O, A mass is seen in the right lung field. On the lateral study (N) it lies just caudal to the heart and its center is relatively radiolucent, whereas it has a soft tissue opacity on the dorsoventral (O) view. This cavitated lesion was an abscess.

Continued
Figure 3-18, cont’d  P, A parasternal sonogram of the right lung with a mass demonstrated through an intercostal window. The affected lung is adjacent to the pleural surface (short arrows), allowing the tissue texture to be assessed. The mass (long arrow) has mixed echogenicity. The margins are ill defined where the tumor extends irregularly into the adjacent hyperechoic (bright) lung tissue in the far field. The normal lung is not visualized because of the marked difference in acoustic impedance between air-filled lung and the neoplastic mass. Diagnosis: carcinoma. Q and R, These are right-sided, parasternal short-axis sonograms at the level of the ventricles (Q) and the aorta (R). An irregular, margined, mainly hypoechoic mass (long arrows) is seen within the lung tissue. The lung is immediately adjacent to the heart. The normal air-filled lung (short arrows) is displaced peripherally. RV, Right ventricle; LV, left ventricle. Diagnosis after ultrasound-guided fine-needle aspiration was bronchogenic adenocarcinoma. S, This dog had an abdominal sonogram. During the examination a small pulmonary mass (short arrows) was seen within the thoracic cavity immediately adjacent to the diaphragm (medium arrows). The liver (long arrow) is acting as an acoustic window. This was a metastasis from a splenic tumor.

has a high acoustic impedance, and the diaphragmatic outline is identified as a curved, smooth, hyperechoic, linear structure lying cranial to the liver. It moves cranially and caudally with respiratory motion. The caudal vena cava is identified traversing it as an anechoic linear structure in the dorsal midthoracic region. The aorta is similarly identified in a more dorsally located position.

Mirror-image artifacts must be recognized and not mistaken for diaphragmatic rupture, particularly if the abdominal approach is used (see Figure 1-12).

Abnormalities

Diaphragmatic Hernia and Rupture. A diaphragmatic hernia is a protrusion of any of the abdominal contents into the thorax through an opening in the diaphragm. The hernia may be congenital, which is uncommon, particularly in dogs, or it may be acquired as the result of trauma. Most acquired diaphragmatic hernias are more accurately described as ruptures because they have no hernial sacs, and protrusion is through an abnormal rather than a physiologic opening. There is usually a history of trauma. The clinical signs include impaired respiratory capability and are related to the presence of abdominal contents, and possibly fluid, within the thorax. Auscultation of the thorax may reveal bowel sounds or absence of normal pulmonary sounds. The abdomen appears tucked up and diminished in size. Rarely, clinical signs are absent.

Radiologic Signs

Primary Signs

1. Portions of the gastrointestinal tract, stomach, small bowel, or colon may be displaced cranially into the thorax. Displaced gastrointestinal structures are easily recognized if they are filled with gas.
2. There is increased opacity within the thorax.
3. The outline of the diaphragm is obscured. Depending on the location of the diaphragmatic rupture, the outline of only one crus may be visible.
4. Herniation of the liver will result in a mass effect in the caudal thorax with displacement of the lung.
Figure 3-18, cont’d T and U, A 9-year-old Jack Russell Terrier had been coughing for 6 weeks. T, Dorsoventral view of the thorax made under general anesthesia. The dog had been lying on its right side. The film is slightly rotated. There is an alveolar type of infiltration in the right lung with minimal aeration. U, The study was repeated some days later under sedation. The right lung is aerated, and a circular soft tissue mass is seen in the right caudal lung lobe. The lesion was masked on the study made under general anesthesia. V and W, Lateral (V) and dorsoventral (W) views of the thorax of a 4-year-old Rottweiler with jaundice and a palpable abdominal mass. The lungs show widespread, asymmetrical alveolar infiltration with air bronchograms and a lobar border. At autopsy, this was lymphosarcoma.
Chapter 3  ■  The Thorax

Figure 3-19 The diaphragm. A, In right lateral recumbency, the right hemidiaphragm lies cranial to the left. The caudal vena cava can be seen to emerge through it. Left and right crura lie parallel to one another. B, In left lateral recumbency, the left hemidiaphragm lies cranial to the right. The caudal vena cava (arrows) can be seen crossing it. Gas in the stomach lies behind the left crus. The right and left crura intersect at the intercrural cleft. C, More than one diaphragm outline may be seen if the tube is not accurately positioned over the thorax. The crura and the cupola are seen on this dorsoventral view.

On the lateral radiograph, this obscures the outline of the diaphragm and may obscure the outline of the cardiac silhouette. On a ventrodorsal or dorsoventral projection, the mass effect may extend across the thorax or be located on the midline or to the right or left of the midline, depending on the location of the rupture.

5. The stomach may be displaced cranially if part or all of the liver is herniated into the thorax. The pylorus will be directed cranioventrally.

6. The spleen may be herniated into the thorax. The outline of the spleen may be visible depending on the quantity of pleural fluid and the quantity of omental fat herniated with the spleen.

7. Acute diaphragmatic ruptures may result in pleural fluid accumulation as a result of hemorrhage. In many chronic diaphragmatic hernias, there is a moderate or large volume of pleural fluid due to incarceration of herniated viscera that causes venous congestion and then pleural effusion.

8. If the herniated viscera are contained within the left or right hemithorax only, there may be a mediastinal shift away from the affected side.

Secondary Signs

1. The normal fat present in the falciform ligament may be absent or obscured.

2. Normal abdominal viscera such as the stomach or spleen may be absent from the abdomen.
3. There may be fractures of multiple ribs, either acute or healed, depending on the chronicity of the hernia.
4. Pulmonary contusions and pneumothorax may be present in cases of acute, traumatic rupture.
5. The cardiophrenic angle is obliterated on ventrodorsal and dorsoventral views.
6. On lateral views, the angle at the diaphragmatic–lumbar recess is decreased.
7. A diaphragmatic rupture may be suspected if abdominal organs are displaced cranially.
8. The lung on the affected side may be compressed or collapsed with absence of the normal vascular markings.

**Rare Signs**

1. If most of the abdominal viscera are herniated, the abdomen may appear small or empty.
2. Herniation of the stomach may be complicated by gastric dilation. The herniated stomach gives a hyperlucent appearance to the left hemithorax with a moderate to severe mediastinal shift to the right. This is a life-threatening situation.
3. Herniation of a small portion of liver may escape detection.
   - If a moderate or large volume of pleural fluid is present, repeating radiographs after thoracocentesis is often helpful.

**Additional Diagnostic Studies**

If herniation of part of the gastrointestinal tract is suspected, a limited upper gastrointestinal contrast examination may help confirm a diagnosis of diaphragmatic hernia. Approximately 2 to 5 mL/kg of barium sulfate suspension is administered by stomach tube. Lateral and ventrodorsal radiographs are obtained immediately. Radiographs should be repeated until the contrast reaches the middle jejunum.

Positive contrast peritoneography may also be used to confirm or exclude a diagnosis of diaphragmatic rupture. The skin is clipped and aseptically prepared just to the right of the umbilicus. Approximately 1 to 2 mL/kg of a water-soluble iodinated contrast agent is injected into the peritoneal cavity. The patient is rotated gently to ensure uniform distribution of the contrast. Lateral and ventrodorsal radiographs are then made. The presence of contrast material within the pleural cavity confirms a diaphragmatic rupture. False-negative results may be obtained if displaced organs are incarcerated in the diaphragmatic tear, effectively sealing the connection with the pleural cavity (Figure 3-20). Congenital defects in the diaphragm have been reported (see Chapter 2, pp. 13 and 27).

**Ultrasonography.** Ultrasound may also be helpful in confirming diaphragmatic rupture, especially if there is a moderate or large volume of pleural fluid present. An intercostal or subcostal window can be used. The diagnosis is confirmed by identifying liver, spleen, or part of the gastrointestinal tract within the pleural cavity. Care should be taken not to interpret a mirror image–type artifact as evidence of herniation of the liver. A mirror image artifact is not seen in the presence of pleural fluid.

**Peritoneopericardial Hernia.** Abdominal organs may reach the pericardial sac through a congenital anomalous communication between the pericardial sac and the peritoneal cavity. The cardiac silhouette appears increased in size on radiographs, and it is confluent with the diaphragm. Enlargement of the cardiac silhouette may be severe, and the shape is often bizarre, depending on the hernia contents. Intestinal gas shadows may be seen within the cardiac shadow (see Figure 2-6, E). Diagnosis can be difficult, particularly if the pericardial sac contains only liver or omentum. A barium study may aid diagnosis. The condition is always congenital. It is often an incidental finding and rarely causes clinical signs. Incarceration of herniated bowel may cause obstruction and acute onset of gastrointestinal signs. Some patients have a history of intermittent gastrointestinal upsets that may be due to transient herniation of the stomach and bowel.

**Ultrasoundography.** Ultrasoundography can help differentiate a grossly enlarged cardiac silhouette from a peritoneopericardial hernia that contains liver or spleen. Intestinal gas shadows are usually identified on a radiograph, but the identification of other soft tissue structures is often important for surgical assessment.

In the absence of pleural fluid, differentiation between a congenital peritoneopericardial hernia and a traumatic rupture can be difficult. One way they can be differentiated is if abdominal contents are identified within the pericardial sac, which is identified as a curved, linear, echogenic structure encircling the heart and abdominal viscera.

**Loss of Outline.** Fluid within the pleural cavity, masses or consolidation in the caudal lung lobes, caudal mediastinal masses, or extrapleural masses may cause partial or complete loss of the diaphragmatic outline. Small amounts of fluid cause blurring of the costophrenic angles (Figure 3-20).

**Ultrasonography.** An intrathoracic mass associated with the diaphragm can be differentiated from one involving the pleura. A diaphragmatic mass moves with the diaphragm.

**Displacement.** Pneumothorax, pleural effusions, intrathoracic masses, and hyperinflation may all cause displacement of the diaphragm. Cranial displacement may be caused by obesity, hepatomegaly, pregnancy, intraabdominal masses, ascites, distention of the stomach, paralysis of the diaphragm, or pneumonectomy. Cranial displacement on one side may result from any condition that unilaterally decreases intrathoracic volume or increases intraabdominal volume. Caudal displacement results from increased intrathoracic pressure, such as pleural effusion or pneumothorax.

**THE PLEURAE**

**Anatomy**

The pleurae are membranes that cover the lungs and line the thoracic cavity. They form two sacs within the thorax, one covering each lung. The sacs are known as
Figure 3-20 Diaphragmatic hernia. A, The outline of the diaphragm has been lost. Numerous coils of intestine, containing gas, are seen within the thorax. The long axis of the stomach is directed cranially, indicating displacement of the liver. B, The ventrodorsal view shows an intact diaphragm on the right side and coils of intestine in the left hemithorax. There is a little pleural fluid on the right side. C and D, This 4-year-old Great Dane had a history of weakness. There was difficulty in auscultating the heart on the left side. Lateral and dorsoventral thoracic views show intestinal loops in the left hemithorax. Barium outlines the stomach and intestine in the thorax. Diagnosis: diaphragmatic hernia. E, A 1-year-old cat had been hit by a car 3 days previously. It was dyspneic, and muffled sounds were heard on the left side of the thorax. The stomach is seen occupying the caudodorsal thorax. It is distended with gas. This is a life-threatening situation. Diagnosis: diaphragmatic hernia.
the pleural cavities or pleural space. The pulmonary or visceral pleura adheres to the surfaces of the lungs and lines the interlobar fissures. The parietal pleura lines the thoracic cavity. Each pleural cavity has a capillary film of fluid. Except for this fluid film, the visceral and parietal pleurae are in contact with one another, and the pleural cavity is a potential cavity. Opinion is divided as to whether a communication exists between the right and left pleural cavities. Each pleural sac projects cranially through the thoracic inlet. The projection is called the cupola of the pleura. The left cupola is larger than the right and extends farther cranially. The mediastinum lies between the two pleural sacs.

**Normal Appearance**

Under normal circumstances the pleurae are not seen on radiographs, but occasionally the pleura in an interlobar fissure is seen as a thin radiopaque line.

**Ultrasonography**

The normal pleural cavity is not identifiable. The pleura/lung interface is identified as a bright hyperechoic line that represents the interface where the lung slides cranially and caudally across the pleura with each respiratory movement. Reverberation artifacts are seen. Fat in the pleural cavity is relatively hypoechogenic.

**Abnormalities**

**Pleural Fluid.** Pleural fluid (effusion) refers to fluid within the pleural space. Pleural fluid may be of several kinds.

1. Transudates or modified transudates—for example, in cardiac failure, hypoproteinemia, lung lobe torsion, and incarcerated diaphragmatic hernia, particularly if the hernia includes liver.
2. Hemorrhage (hemothorax)—which may result from trauma, neoplasia, coagulopathy, or anticoagulant poisoning.
3. Lymph (chylothorax)—after rupture of the thoracic duct or its branches or neoplastic disease.
4. Exudates (pyothorax)—exudative pleuritis may be a primary condition, or it may be the result of spread of infection from the lungs or mediastinum. It may also be caused by a penetrating wound of the thoracic wall. Sterile suppurrative effusions may be caused by necrotic neoplasms in contact with the pleural membrane.
The term hydrothorax is used by some authors to describe transudates only, whereas others use it to include fluids such as hemothorax, chylothorax, and pyothorax. They all have a fluid opacity, irrespective of origin. It is not possible radiographically to differentiate among them. Free fluid within the thorax distributes itself according to the laws of gravity.

The radiographic appearance of pleural effusion is different on ventrodorsal and dorsoventral projections of the thorax. In patients with pleural effusion, it is generally safer to make a dorsoventral radiograph first to assess the volume of fluid present; placing the patient in dorsal recumbency may result in severe respiratory compromise and death. When the patient is placed in sternal recumbency, the pleural fluid will collect in the ventral thorax. On a dorsoventral radiograph, this causes the outline of the cardiac silhouette and the cupola of the diaphragm to be obscured. Unfortunately, this also renders it difficult or impossible to assess the heart on this view. When the patient is placed in dorsal recumbency and a ventrodorsal radiograph is made, the pleural fluid will tend to drain to the dorsal thorax and pool left or right of midline. Because the heart is surrounded by air-filled lungs, if these are normal, it is more easily evaluated. The pleural fluid causes an indistinct increased opacity in the left and right caudal hemithorax, which should not be mistaken for pathology in the left and right caudal lung lobes. The dorsoventral view is more sensitive in detecting small volumes of pleural fluid. This sensitivity can be increased further by making the exposure during expiration. During expiration, the pleural fluid is forced into the interlobar fissures, and pleural fissure lines are more easily seen.

Radiologic Signs. There is a diffuse increase in soft tissue opacity in the thorax, the degree of which depends on the volume of fluid present.

1. On the lateral view, there is a homogeneous opacity in the ventral thorax. Often this opacity has a scalloped appearance as a result of fluid outlining the lung borders.
2. The interlobar fissures become visible as curvilinear, soft tissue opacity bands between the lung lobes. They are wide at the periphery and narrow toward the hilus. They are seen only when the x-ray beam strikes them end-on.
3. On the lateral view, fluid is seen in the diaphragmaticolumbar recess separating the lung edge from the ventral aspect of the vertebrae. In cats, the lungs do not normally fill this recess.
4. There is partial or complete obliteration of the cardiac shadow.

Figure 3-21 A and B, This 3-year-old female Labrador was referred to the clinic with a diagnosis of pneumonia. The animal was emaciated and very depressed. A, The leaflike, or scalloped, appearance of fluid within the pleural cavity is seen on this lateral radiograph. The leaflike appearance results from the presence of fluid in the interlobar fissures. The fluid obliterates the cardiac and diaphragmatic outlines. The apparent elevation of the trachea on this study is at least partially caused by rotation of the thorax. B, The ventrodorsal view shows fluid obliterating the cardiac shadow and the diaphragmatic outline. Some pulmonary vessels are seen, and the lungs appear to be hypervascularized. There is fluid in the costophrenic angles. At autopsy, there was a granulomatous mass in the thorax with hyperplasia of the tracheobronchial lymph nodes and focal atelectasis. The diagnosis was granulomatous pneumonia and pyothorax from actinomycosis.
5. In severe cases, the trachea may be displaced dorsally as the lungs float in the fluid. The diaphragmatic shadow may be obscured. Fluid may accumulate between the diaphragm and the lung edges, giving a pseudodiaphragmatic outline.
6. There is loss of the normal sharp angles at the costophrenic junctions on the dorsoventral and ventrodorsal views.
7. The diaphragmatic shadow may be obscured.
8. On the dorsoventral or ventrodorsal view, a fluid opacity can be seen between the thoracic wall and the lung edges. The fluid opacity may be seen to extend into the interlobar fissures.
9. Small volumes of fluid are best demonstrated on a ventrodorsal view and are best seen on expiratory films.
10. Fluid may accumulate in the pleural reflection between the accessory lobe and the caudal lung lobe in the left caudal thorax, giving it a thickened appearance.
11. Atypical or asymmetrical distribution of fluid may indicate the presence of a mass lesion. Fluid tends to collect around the affected lobe in diseases such as lung lobe torsion or tumor, or around the lesion in diaphragmatic ruptures or chest wall tumors.
12. Pleural fluid may be unilateral in distribution, particularly in pyothorax in the cat. Unilateral fluid accumulation usually indicates an inflammatory process. Tumors of the lung and chest wall or chylothorax may also cause unilateral pleural fluid. Asymmetric distribution may also be seen with diaphragmatic rupture or with pleural or thoracic wall disease (Figures 3-21 and 3-22).

Positional radiographs can be used to demonstrate mobility of the fluid or to confirm or exclude the presence of a mass lesion. Small amounts of fluid may not be apparent on conventional radiographs. A standing lateral view, using a horizontal beam, will show an increased opacity in the ventral thorax. No air-fluid interface will be seen unless there is a concomitant pneumothorax. The heart may be visible on a ventrodorsal view and obscured on the dorsoventral.

Pleural fluid will cause border effacement with any intrathoracic structure with which it is in contact. A ventrodorsal view can be made with the animal supported on its hindlimbs and using a horizontal beam. In that case, fluid should be looked for in the costophrenic angles. Pleural fluid may be encapsulated in a particular region, in which case it will not move with changes in position of the animal. Pleural fluid masks underlying thoracic pathology. Drainage of the fluid and immediate radiography of the thorax after drainage are often informative (Figure 3-22, O to R).

Ultrasonography. The pleural fluid may be anechoic to quite echogenic and outlines and dissects between the hyperechoic lung margin and parietal pleura. It

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Figure 3-22 A, On the lateral view, fluid has obliterated the cardiac shadow, though some lung detail can be seen in the caudal thorax. B, On the ventrodorsal view, which is rotated, fluid can be seen separating the lung edges from the thoracic wall, particularly on the left side (arrows). Fluid obscures the costophrenic angles. This was a 3-year-old Siamese with dyspnea.

Continued
Figure 3-22, cont’d  

C and D, A 3-year-old domestic cat presented with labored breathing and depression. The radiologic diagnosis is fluid in the thorax. The cardiac shadow is obscured, and the diaphragm outline is lost. Fluid is seen between the dorsal edges of the caudal lung lobes and the vertebral column. On the ventrodorsal view, fluid can be seen between the lung edges and the thoracic wall and in the interlobar fissures. There is fluid in the left cranial thorax. At autopsy, there was a pleuritis resulting from *Pasteurella multocida*. 

E, A standing lateral view of a cat’s thorax. Fluid has collected in the ventral and middle thorax, and a fluid line is seen. A fluid line is seen only when there is both free gas and fluid in the pleural space (pneumohydrothorax). 

F, Diagram of the positions of the interlobar fissures as seen on the ventrodorsal (dorsoventral) view. 1-1, Fissure between the right cranial and middle lobes. 2-2, Fissure between the right middle and caudal lobes. 3-3, Fissure between the cranial and caudal portions of the left cranial lung lobe. 4-4, Fissure between the caudal portion of the left cranial lung lobe and the left caudal lobe. 

C, The fissure between accessory and left caudal lobes; D, the diaphragm. 

G, This is a left-sided, parasternal view of the left hemithorax. Pleural fluid (Pl EFF) is seen surrounding the heart. 

H, A 3-year-old German Shepherd presented with respiratory distress and pyrexia of 4 days’ duration. Thoracic radiographs demonstrated a pleural effusion. Sonography of the thorax shows that the pleural fluid (f) is echogenic, and fibrin tags (arrow) are evident on the surface of the lung (l). Thoracocentesis provided a sample that was an exudate. Diagnosis: nocardiosis. The dog made a complete recovery after intensive medical therapy.
Figure 3-22, cont’d I and J. An 8-year-old cat with anechoic fluid (f) surrounding the lungs (l). I, The lung margins (l) are clearly discernible, indicating that they are not air filled. J, The hyperechoic branching structure in the lung lobe (arrow) is an air-filled bronchus in a nonaerated lung lobe. Diagnosis: pleural fluid and lung consolidation. K to N, This was a 4-year-old cat with sudden onset of dyspnea and tachypnea. K and L, Lateral and dorsoventral views show fluid in the right hemithorax. M and N, Right-sided, parasternal long-axis (M), and short-axis (N) views through the thorax and heart. Echogenic swirling fluid (F) in the pleural cavity surrounds the heart (H) and outlines the pericardium (arrowhead) and the thoracic wall (arrows). A collapsed lung (L) margin is seen as a hyperechoic edge. This was a bilateral pyothorax, which was treated successfully. Cr, Cranial.

Continued
This German Shepherd presented in a collapsed state, with muffled heart sounds and an increased respiratory rate. Lateral (O) and dorsoventral (P) radiographs indicate the presence of a large volume of pleural fluid. The cardiac silhouette and diaphragm are obscured. The lung margins are separated from the ribs. Three liters of fluid was drained from the thoracic cavity. Repeat lateral (Q) and dorsoventral (R) radiographs were obtained. The lungs have reinflated, and there is only a small volume of pleural fluid remaining. There is a soft tissue opacity (short arrow) visible in the cranioventral thorax, displacing the cranial lung lobes (long arrow) caudally. Ultrasonography was performed, and severe enlargement of the sternal lymph node and a mediastinal mass were found. Diagnosis: Fine-needle aspiration of the mass confirmed lymphoma.
outlines the lung, which, if aerated, is identified as a hyperechoic triangular structure floating in the fluid. If the lungs are consolidated, then the affected lung is usually hypoechoic. Small volumes may be identified in the ventral or dependent portions of the chest cavity. Pleural fluid may be detected during an abdominal ultrasound examination when scanning the liver. It is seen on the thoracic side of the diaphragm in the caudodorsal thorax.

If the fluid is inflammatory, hyperechoic fibrin tags may be seen within it. Chronic cases sometimes develop bands of fibrin attached to the pericardial and pleural surfaces. Fluid may be confined by septa. If the fluid contains cellular material, a swirling, speckled appearance with small echogenic flocules is seen. Bright hyperechoic focal specks in the fluid may be gas or air bubbles.

Pleural reflections and the pericardiophrenic ligament should not be mistaken for fibrin tags. The pericardiophrenic ligament runs from the apex of the heart caudally to the diaphragm and is a continuous, wavy, linear structure (Figure 3-22, G to J).

**Pleural Thickening.** Pleural thickening denotes a condition in which the pleurae become visible but without any significant amount of pleural fluid being present. Interlobar fissures are seen as thin radiopaque lines extending from the hilus to the thoracic wall. Pleural thickening may be a sequel to pleuritis, hemorrhage, or pyothorax. On the dorsoventral or ventrodorsal view, it is characterized by a thin opacity separating the lung edges from the thoracic wall (see Figure 3-27, M and N). In old animals, it may be caused by calcification or fibrosis. A normal prominent pleural fissure is seen at the junction of the left caudal and accessory lung lobes.

Ultrasonographic examination may show a hypoechoic rim along the internal margins of the ribs. It has to be differentiated from fat in the pleural cavity.

**Pneumothorax.** Pneumothorax is the presence of free air (gas) within the pleural cavity. It may be closed or open, in which there is a communication with the exterior. As a result of loss of the capillary pressure or force that is normally present between the parietal and the visceral pleurae, the lungs partly or completely collapse. Pneumothorax is usually the result of trauma, although spontaneous pneumothorax can occur in dogs and cats, usually as a result of rupture of a bulla. Pneumothorax may occur as a sequel to pneumomediastinum, but the reverse does not occur. Rupture of the esophagus, trachea, or bronchi results in pneumomediastinum and may progress to pneumothorax if there is a concurrent or subsequent rupture of the mediastinum. The primary presenting clinical signs are dyspnea and reduced exercise tolerance. A tension pneumothorax occurs when a wound in the thoracic wall or rupture of a bronchus allows air to be forced into the pleural space at inspiration that cannot escape at expiration. Pressure builds up in the pleural cavity, and the lung is compressed. This may be bilateral or unilateral. This condition is life-threatening unless prompt relief measures are instituted (Figure 3-23).

**Radiologic Signs**

1. On the lateral view, the cardiac silhouette is moved away from the sternum because it is no longer held in position by the inflated lungs. The area ventral to it is hyperlucent.
2. The edges of the lung lobes are retracted from the sternum, diaphragm, and diaphragmaticolumbar recess, and air opacity outlines the lung edges.
3. The lungs have an increased opacity resulting from atelectasis or partial atelectasis.
4. There is lack of normal pulmonary markings at the periphery of the thorax beyond the lung edges.
5. Air is sometimes seen in interlobar fissures.
6. The film may appear to be overexposed as a result of the increased amount of air within the thoracic cavity.
7. Small amounts of air are more readily seen on expiratory radiographs. A ventrodorsal view, with the animal in lateral recumbency and using a horizontal beam, will show an accumulation of air in the uppermost part of the thorax. A horizontal beam lateral view, with the patient in sternal recumbency, is preferred if the patient is dyspneic. Pleural air is seen in the caudodorsal thorax, where it outlines the dorsal border of the caudal lung lobes.
8. A tension pneumothorax, when severe, will cause flattening, caudal displacement or even inversion of the diaphragmatic shadow, which may show tenting. Tenting is when the attachments of the diaphragmatic muscle to the ribs become visible as soft tissue triangular protrusions, with the apices pointing toward the heart (Figure 3-23, K). If the condition is unilateral, which is rare, there is a mediastinal shift away from the affected side (see Figure 3-23, E).

In the normal dog, especially those with a deep chest-type conformation, at full inspiration the middle lobe of the right lung may extend ventral to the heart, separating it a little from the sternum, particularly in left lateral recumbency. This should not be misinterpreted as a sign of pneumothorax (see Figure 3-9, H and I).

Unilateral pneumothorax is not common in dogs and cats because air apparently can cross the mediastinum from one hemithorax to the other. Skinfolds frequently cast marked linear shadows along the thorax on either side on the ventrodorsal view. These shadows may be mistaken for lung edges, giving an appearance of pneumothorax. Linear opacities associated with skinfolds can usually be traced cranially or caudally beyond the limits of the thorax (Figure 3-23, J and F).

Pneumothorax may follow thoracocentesis and fine-needle lung aspiration or biopsy of pulmonary lesions. If there is fluid within the thorax, a fluid/air interface can be seen on standing lateral views (see Figure 3-22, E).

Ultrasonography. Free gas in the pleural cavity is difficult to differentiate from an air-filled lung, and radiographs are the preferred diagnostic technique. Normal air-filled lung slides during inspiration and
Figure 3-23 Pneumothorax. A, The heart is displaced from the sternum. There is increased radiolucency of the thorax at the periphery. A lung edge (arrows) can be seen separated from the vertebral column and from the diaphragm. The caudal lung lobe area is increased in opacity because of partial collapse. B, On the dorsoventral view, the partially collapsed lungs are seen on both sides (arrows). The costophrenic angles are deep. This case illustrates the classic appearance of pneumothorax. C and D, On the lateral view, air is seen in the interlobar fissure between the right caudal and middle lung lobes and between the caudal lung lobes and the diaphragm. On the dorsoventral view, air is seen between the heart and the right lung border, suggesting the possibility of rupture of a bronchus. There are patchy pulmonary infiltrates visible in the right cranial and left caudal lung lobes.
**Figure 3-23, cont'd**

**E,** Tension pneumothorax. A large amount of air is present within the thorax. The diaphragm is displaced caudally and flattened and shows a reverse dome. The heart retains its sternal contact. Because of the large amount of air present, the film appears overexposed, and no lung detail can be seen. This is a life-threatening condition.

**F,** Bilateral lung collapse from pneumothorax. The lung edges are clearly seen, and there is an absence of bronchovascular markings at the periphery of the thorax.

**G and H,** Severe pneumothorax in a cat. The heart is displaced from the sternum. A collapsed lung lobe is seen dorsocaudal to the heart. The diaphragm is flattened, indicating that the intrathoracic air is under some pressure. Subcutaneous emphysema is evident.

*Continued*
Expiration, and this motion can be appreciated with ultrasound. Pleural air will not show this characteristic sliding motion.

**Extrapleural Masses.** Masses arising in the thoracic wall, diaphragm, or mediastinum may project into the thorax, pushing the pleura ahead of them. Masses may be the result of inflammatory processes, loculated fluid, or neoplasia and may affect the neighboring soft tissues or the bony structures. Such masses can be difficult to distinguish from pulmonary masses. Extrapleural masses show a sharply defined convex edge as they project into the thorax. They may compress the lung. They have a broad base with concave cranial and caudal edges, blending with the pleura lining the thoracic wall. The widest part of the mass is opposite the center of its attachment to the thoracic wall. There may be an associated accumulation of pleural fluid.

The ribs, sternum, and spine should be examined for signs of periosteal reaction or bone destruction. Clinically, a small neoplastic swelling on a rib or ribs usually represents only a fraction of the total tumor mass lying within the thorax. This is sometimes called the “iceberg phenomenon.” Extrapleural masses associated with the diaphragm, such as abscesses or tumors, are rare. A diaphragmatic rupture, unless it is a true hernia, involves a breach of the pleura and is therefore not an extrapleural mass lesion. Large costochondral junctions or healed rib fractures may simulate extrapleural masses (Figure 3-24, A to C, and Figures 3-27 and 3-28).

**Ultrasonography.** The mass is usually adjacent to the chest wall and displaces the lung tissue. It is recognized as extrapleural because it does not move with respiration. Fine-needle aspiration is a useful diagnostic technique (Figure 3-24, D and E).
Figure 3-24 A and B, Chondrosarcoma of a rib. This was a 6-year-old Boxer with exercise intolerance and a mass on a rib. A, The lateral view shows a soft tissue mass overlying the cranial mediastinum. This is an extrapleural mass. There is erosion of the distal half of a fourth rib. Pleural fissures run from the hilus cranioventrodorsally and caudoventrally. Diaphragmatic outlines are obscured by pleural fluid. B, This lesion-oriented view profiles a destructive and productive lesion on the right fourth rib. There is soft tissue swelling laterally (straight arrow). The lung is displaced medially, forming a concave extrapleural sign (curved arrow). C, A large extrapleural mass associated with neoplasia of a rib displaces the lung edge (arrows) away from the thoracic wall. D and E, This English Setter presented with dyspnea. Pleural fluid was found on radiography. Thoracocentesis was unrewarding. D, Ultrasonography shows an oval hypoechoic mass (arrows) on the floor of the thoracic cavity just above the xiphisternum. E, Freehand ultrasound-guided fine-needle aspiration was performed with the animal under general anesthesia. The needle tip (large arrow) is visible in the mass (small arrows). Diagnosis: carcinoma.
Pleural Neoplasia. Primary neoplasms of the pleura are rare in dogs and cats. They are called mesotheliomas and are not readily seen on radiographs. There may be associated pleural fluid. Secondary tumors have been reported in association with lung tumors. They are difficult to demonstrate radiographically. Pleural tumors must be distinguished from extrapleural masses, which project into the thorax. The latter are well marginated, with a broad base.

Ultrasonography. Pleural masses may be seen and are usually outlined by fluid that may be echogenic. Mesotheliomas may cause diffuse tumor seeding of the pleural surfaces, with numerous small nodules and effusion. These may not be visible with ultrasound, and diagnosis may require a surgical exploration and biopsy. Ultrasound-guided fine-needle aspiration or biopsy is useful. Extrapleural tumors associated with the chest wall have a variable echogenicity depending on the degree of bone destruction or proliferation (Figure 3-24, D and E).

THE MEDIASTINUM
Anatomy
The mediastinum is the space between the two pleural sacs. It has a number of complicated recesses and folds. It reaches the spine dorsally and the sternum ventrally. It is in communication with the deep fascial planes of the neck cranially, and it is in communication caudally with the retroperitoneal space through the hiatus of the aorta. It is not therefore a closed space. It also communicates with the interstitium of the lung through the sheaths of the bronchi and pulmonary vessels.

The mediastinum may be divided into three areas for descriptive purposes: (1) the cranial (precardiac), (2) the middle (pericardiac), and (3) the caudal (postcardiac). It may also be divided into dorsal and ventral areas by an imaginary line drawn through the hilus of the lungs. The dorsal mediastinum contains the trachea, esophagus, and vessels and nerves that enter and leave the heart. The heart lies in the middle, ventral mediastinum. Caudoventrally, the walls of the mediastinum are separated from each other by a thin layer of connective tissue. The mediastinum also contains the thymus gland cranial to the heart, the thoracic duct, azygos vein, lymph nodes, nerves, and fat. The caudal vena cava is within a separate pleural fold (see Figure 3-6, M, N, and O).

The lymph nodes in the thorax lie in the cranial mediastinum and around the tracheal bifurcation (tracheobronchial nodes). The paired sternal lymph nodes lie dorsal to the first or second sternebrae. The sternal lymph nodes drain the peritoneal side of the diaphragm.

Normal Appearance
The mediastinum can be visualized because of the structures within it. Apart from the trachea, the heart, and some of the great vessels, the structures within the mediastinum cannot be distinguished from one another on normal radiographs because they all have the same fluid or soft tissue opacity and are outside the pleura. Use of the lateral view yields the most information. On dorsoventral and ventrodorsal views, the spine and the sternebrae are superimposed on the mediastinum. On the lateral view, the cranial mediastinum—containing the cranial vena cava, the brachiocephalic trunk, the left subclavian artery, the lymphatics, and the nerves—is seen as a soft tissue opacity just ventral to the trachea. Above the trachea it merges with the longus colli muscles. Its ventral edge is formed by the cranial vena cava. Cranial to the heart, a mediastinal fold is seen to course from the second sternebra to the end of the first rib. Cranial to this fold is the portion of the left cranial lung lobe that lies to the right of the midline. The fold marks the cranial limit of the right lung.

On the ventrodorsal or dorsoventral view, the left border of the cranial mediastinum is formed by the left subclavian artery cranially and the aorta caudally. The right border is formed by the cranial vena cava and the edge of the esophagus. On these views, the thymus gland is sometimes seen as a soft tissue opacity projecting beyond the mediastinal edge in the left cranial thorax. Its long axis is directed caudolaterally. Its shape is often an elongated triangle said to resemble a spinnaker sail; hence it is sometimes referred to as the thymic sail (see Figure 3-9, G). Caudally, to the left, the edge of the mediastinum marks the accessory lobe of the right lung where it crosses the midline.

Fat may cause some displacement of the trachea. Fat in the mediastinum may simulate a mass lesion in old, obese dogs (see Figure 3-6, E and F). However, its opacity is less than that of the heart. It may separate the heart from the sternum. Brachycephalic dogs have a widened mediastinum on the dorsoventral or ventrodorsal view because they have a tendency to accumulate mediastinal fat (see Figures 3-6, C, and 3-29, G5). The large volume of cranial mediastinal fat, large shoulder musculature, and difficulty extending the forelimbs cranially in these breeds contribute to increased opacity in the cranial thorax on a lateral view. This increased opacity may partly or completely obscure the cranial cardiac border. Breakdown of the separation between the two pleural cavities occurs readily, allowing communication between the left and right sides of the thorax. As a result, air or fluid on one side can pass to the other.

Ultrasonography
Fat in the mediastinum has a granular echotexture with scattered hypoechoic foci. The normal thymus may be seen in very young animals as an echogenic, granular structure with an even echotexture cranial and lateral to the heart on the left side.

Normal lymph nodes are usually hypoechoic, with an even echotexture. The sternal lymph node, if enlarged, may be imaged just dorsal to the sternum. The mediastinal and perihilar lymph nodes are not
usually seen unless surrounded by fluid. The heart occasionally can be used as an acoustic window to the heart base and the enlarged lymph nodes. Fine-needle aspiration in this area is somewhat hazardous.

Abnormalities

Pneumomediastinum. Pneumomediastinum denotes the presence of air (gas) within the mediastinum. It may result from puncture of the esophagus, trachea, bronchi, or bronchioles or from alveolar rupture. In alveolar rupture, air tracks along the bronchial and vascular sheaths into the mediastinum. Air may also reach the mediastinum from deep puncture wounds in the mouth, neck, or thorax. Extension of air from the abdomen is unusual. Pneumomediastinum can occur spontaneously. The clinical signs include varying degrees of dyspnea and a diminution of normal heart and lung sounds. The head may swell, as may the neck and trunk, because of the presence of air in the subcutaneous tissues. Crepitation can be felt when the skin is palpated. Many animals seem little inconvenienced by the condition, although it may give them a grotesque appearance. Pneumothorax may ensue, but this is not common. In some cases of Paraquat (weed killer) poisoning, pneumomediastinum may develop (see p. 237).

Radiologic Signs
1. Mediastinal structures not normally seen become clearly visible, contrasting with the air. Thus the esophagus, cranial vena cava, brachiocephalic trunk, left subclavian artery, azygos vein, and the ventral border of the longus colli muscles can be seen in the cranial mediastinum.
2. The dorsal and ventral walls of the trachea are outlined. The trachea itself appears less usual because contrast between it and the mediastinal structures is reduced by the surrounding air.
3. The thoracic aorta can be clearly traced caudally as far as the diaphragm or beyond.
4. Air shadows are seen in the soft tissues of the neck. The air may track cranially as far as the head and caudally over the trunk (subcutaneous emphysema).
5. Air may track caudally through the aortic hiatus into the retroperitoneal space and outline the kidneys and abdominal aorta.
6. The mediastinum has an overall abnormal lucency that makes the thorax appear more radiolucent than usual. Use of the lateral view gives the most information in cases of pneumomediastinum.

An esophagus that is dilated with air will provide an air opacity in the mediastinum that will show many of the signs of the presence of free air in the mediastinum. For example, the aorta will be unusually well outlined, and tracheal contrast will be diminished. There will, of course, be no associated air in the soft tissues (Figure 3-25, A to F).

Displacement (Mediastinal Shift). Displacement of the mediastinum is usually indicative of an abnormality in one side of the thorax. A decrease in lung volume causes a shift toward the affected side. It may be caused by collapse of, or removal of, a lung or lung lobe or unilateral pneumothorax. It may also occur with pleural effusion or obstruction of bronchi or as a result of pleural adhesions. An increase in lung volume from emphysema or intrapulmonary masses will cause a mediastinal shift away from the affected side. Diaphragmatic hernia or other pleural masses will cause a shift away from the side of the mass (Figure 3-25, G and H). Properly positioned radiographs are essential because rotation may give the impression of mediastinal shift. Lateral recumbency of even a few minutes’ duration, may result in a mediastinal shift toward the dependent side. Under general anesthesia atelectasis and mediastinal shift can occur quite quickly.

Mediastinal Fluid. Mediastinal fluid may be the result of ruptured esophagus, mediastinitis, congestive heart failure, mediastinal masses, or feline infectious peritonitis. In early cases, there is an indistinct increased soft tissue opacity in the affected part of the mediastinum (Figure 3-25, I and J). If there is a moderate or large volume of fluid or the disease is more chronic, there may be a widened mediastinum and fluid in the interlobar fissures. The fluid originates in the mediastinum and spreads peripherally. It often outlines the fissures from the midline laterally—the reverse of pleural fluid—and forms “reverse fissures.” These fissures are wide centrally and taper toward the periphery.

Ultrasoundography. The mediastinal fluid dissects between the mediastinal structures. It may have a mixed echogenicity, with loculated fluid interspersed between and surrounding the structures.

Mediastinal Masses. Conditions that may produce masses in the cranial mediastinum include mediastinitis, abscess, granuloma, hemorrhage, enlarged thymus gland, edema, esophageal abnormalities, lymphadenopathy, neoplasia, and cysts. Masses in the vertebrae or adjacent muscles may invade the mediastinum. Less commonly, ectopic thyroid tissue, branchial cysts, or chemodectomas are seen. Cardiovascular abnormalities may also cause masses in the mediastinum, such as enlarged right atriun or dilation of the pulmonary artery or aorta. At least two opposing lateral views of the cranial thorax and a ventrodorsal or dorsoventral view may be necessary to differentiate between cranial lobar consolidation and a mediastinal mass. Even with all these views, a diagnosis may be impossible and computed tomographic imaging may be necessary.

Perihilar masses in the middle mediastinum may be caused by mediastinitis, abscess, lymphadenopathy, esophageal foreign bodies, or neoplasms such as chemodectoma or lymphosarcoma. Chemodectomas are sometimes accompanied by fluid in the thorax or pericardial sac. Enlarged pulmonary arteries or veins and enlarged left or right atria cast masslike shadows in the perihilar region.

Caudal mediastinal masses may be a result of esophageal abnormalities, hiatal hernia, abscess, granuloma, or neoplasia. Masses in the caudal mediastinum
may be difficult to distinguish from intrapulmonary masses, particularly those arising in the accessory lung lobe.

The clinical signs associated with mediastinal masses are variable and depend on the nature and location of the mass. Dyspnea, vomiting, coughing, and edema of the head, neck, and forelimbs may be noted, particularly if the cranial vena cava is compressed.

Megaesophagus may cause a masslike lesion throughout the mediastinum. Some older dogs have a considerable amount of fat in the mediastinum, which may result in a widened appearance. In puppies and young cats, the thymus gland may obscure the cranial cardiac border.

Transesophageal ultrasound examination, where available, is useful in assessing the location and extent of mediastinal masses.
Radiologic Signs

1. Masses in the cranioventral mediastinum cause an increase in opacity in that area so that lung lucency in the cranial thorax is lost. Such masses displace the trachea dorsally and may produce a border effacement (silhouette) sign with the cranial border of the heart. An enlarged sternal lymph node produces a soft tissue opacity above the second sternebra (Figure 3-26, N).

Enlargement of the cranial mediastinal nodes results in a convex bulge from the ventral border of the craniodorsal mediastinum.

Figure 3-25, cont’d D and E, Paraquat poisoning. Pneumomediastinum is evident in this dog that presented with severe dyspnea and cyanosis. An interstitial pulmonary infiltrate is clearly seen. F, This cat had been anesthetized for surgery. It was noticed during surgery that it appeared to be getting bigger and subcutaneous air could be felt. A lateral radiograph shows pneumomediastinum, subcutaneous air, and retroperitoneal air. This was the result of blockage of a valve in the anesthetic machine. The animal survived.
Figure 3-25, cont’d  G and H, Mediastinal shift: A 5-year-old short-haired domestic cat was being treated for a fractured left humerus. A preanesthetic check of the thorax shows marked displacement of the cardiac silhouette dorsally and to the right by a large mass, which has a fat opacity. There were no clinical signs referable to the mass during the follow-up period. This was a lipoma. I and J, Pulmonary and mediastinal hemorrhage. I, A widened mediastinum and pulmonary infiltration caused by hemorrhage. J, The same animal 4 days later, showing a reduction in size of the cranial mediastinum and a resolution of the pulmonary changes. (This is the same case as Figure 3-3, H and I.)
Figure 3-26 Intrathoracic masses. A specific diagnosis of the cause of a solitary mass lesion in the thorax is usually not possible on plain radiographs. A, A 12-year-old mixed-breed dog had been coughing for a month. A circumscribed opacity is seen in the caudal thorax. The left caudal lung lobe, containing the mass, was removed surgically. An impression smear revealed inflammatory cells but no bacteria. B to D, This was a 19-month-old Rottweiler with regurgitation and dyspnea. B, A soft tissue mass depresses the trachea. Air is seen in the cervical esophagus. C, A ventrodorsal view shows widening of the cranial mediastinum. This was a connective tissue tumor in the cranial mediastinum. D, The right-sided sonogram shows a hypoechoic mass (M) with blood vessels (arrows) running through it. This was a lymphosarcoma. Cr, Cranial. E, The right scapula and right and left humeri are involved in a destructive process extending from a cranial mediastinal mass. This was a fibrosarcoma.
2. Craniodorsal masses tend to displace the trachea ventrally and to the right.
3. Masses in the hilar area cause an increase in opacity around the tracheal bifurcation and may displace or compress the stem bronchi, or both. Enlarged tracheobronchial lymph nodes displace the terminal trachea ventrally and separate the mainstem bronchi on the dorsoventral projection. The esophagus is displaced dorsally.
4. Masses in the caudal mediastinum produce well-defined opacities superimposed on the caudal lung lobes and may produce a silhouette sign with the diaphragm. The esophagus and caudal vena cava may be displaced.

Fluid within the pleural cavities, which may accompany mediastinal masses, can mask the mediastinal lesion, particularly in the caudal thorax. Fluid can simulate a cranial mediastinal mass from the compression...
Figure 3-26, cont’d J and K, This was a 5-year-old German Shepherd that presented with abdominal pain and distention. The heart sounds were muffled. Abdominal radiographs showed an intraabdominal mass. J, The lateral view shows a homogeneous appearance ventral to the trachea. Caudal to the carina there is an indistinct soft tissue opacity caused by hilar lymphadenopathy. The trachea is elevated but maintains its terminal bend. K, On the ventrodorsal view, there is severe widening of the cranial mediastinum, and the mainstem bronchi are markedly separated and narrowed because of a mass in the caudal hilar region. This sign is sometimes termed a "bowlegged" appearance. These findings suggest a mass in the hilar region. In this case the cause was hilar lymphadenopathy. L, A radiopaque mass is seen dorsal to the base of the heart. This is the result of enlargement of lymph nodes. The terminal trachea is narrowed and depressed. (Left atrial enlargement elevates the trachea. Enlarged lymph nodes dorsal and caudal to the trachea depress it.) The cranial mediastinum is widened as a result of lymphadenopathy, which narrows the trachea by extrinsic pressure. This was mycotic lymphadenitis in a 1-year-old mixed-breed dog. The most common causes of hilar lymphadenopathy are lymphosarcoma and mycotic diseases.

Continued
of the cranial lung lobes and artifactual displacement of the trachea as a result of buoyancy, especially in cats. If the amount of fluid present is small, a standing lateral radiograph with a horizontal beam is often useful. In the erect position the fluid moves ventrally, which may allow the mediastinal lesion to be seen. A positive-contrast study outlining the esophagus may be helpful. Thoracocentesis or diuresis can be used to improve visualization (Figure 3-22, Q).

Ultrasonography. Mediastinal masses are identified cranial and dorsal to the heart as they displace normal aerated lung tissue. A mass may encroach on the heart base, and the great vessels may be identified passing through it. Thymic lymphosarcomas generally are hypoechoic and even in texture. Some neoplasms have a mixed echogenicity, and cavitations may be seen as anechoic areas representing necrosis or hemorrhage. Cranial mediastinal cysts occur in cats. They appear as anechoic, well-circumscribed, thin-walled masses. They are often incidental findings.

The heart can be used as an acoustic window to examine the heart base. Heart base tumors are usually well defined, with an echogenic, even echotexture. They can encircle the heart base and be seen adjacent to the atria. Local invasion of the heart is sometimes a feature. Pericardial and pleural fluid may be present. If a mediastinal mass has extended to make contact with the thoracic wall, this contact site can be used as an acoustic window (Figure 3-26).

**Thymic Lymphosarcoma (Lymphoma).** Clinically affected cats show respiratory distress, and Horner’s syndrome may be present. In dogs with lymphosarcoma, the lymph glands, rather than the thymus, are more commonly involved. In dogs, clinical signs include a generalized lymphadenopathy, but respiratory distress is not usually a feature. Swallowing difficulties and regurgitation may be seen. Thymic lymphosarcoma in cats produces a mass lesion in the cranial mediastinum. It is frequently accompanied by pleural effusion and elevation of the trachea and esophagus. It may be necessary to perform a thoracocentesis before the mass can be identified radiologically. A dorsoventral or ventrodorsal view, with the animal supported on its hindlimbs and the use of a horizontal beam, allows the fluid to gravitate to the caudal thorax and demonstrates the mass in the cranial thorax. There may be sternal and perihilar lymphadenopathy (Figure 3-26, F and G).

**The Thoracic Wall**

The thorax is bounded dorsally by the vertebrae, laterally by the ribs, and ventrally by the sternum. The skin and muscle covering are also important radiographically. Abnormalities or anomalies of any of these structures may affect thoracic function and the appearance of thoracic radiographs. Examination of all these structures should be part of the routine examination of thoracic radiographs.
THE SPINE
Abnormalities of the spine that may affect the thorax may be congenital or acquired. Hemivertebrae, scoliosis, kyphosis, and anomalous vertebrae are encountered, and they may be associated with an abnormal shape of the thoracic cavity. Acquired lesions include fractures, dislocations, infections, and neoplasms. Distortions caused by such abnormalities may affect the function of intrathoracic structures.

THE RIBS
Anatomy
There are 13 pairs of ribs in both the dog and the cat. Each rib has a dorsal bony part and a ventral cartilaginous part—the costal cartilage. The cartilages of the tenth, eleventh, and twelfth ribs form the costal arch on each side. The cartilages of the thirteenth pair of ribs are free of attachments, and are sometimes called floating ribs.

The ribs of the Bassett Hound, the Dachshund, and other chondrodystrophic breeds have an unusual shape. They curve outward and inward at the costochondral junction, and they curve again outward and inward at their sternal attachments. This anatomic feature causes an extra opacity to be superimposed on the lung field in that area. Such opacities may be mistaken for lung pathology.

Abnormalities
Mineralization. Calcification of the costal cartilages begins at an early age and may result in irregular shapes and distributions that are of no clinical significance. Ossification, or calcification, of the costochondral cartilages is common and of no significance. The signs are those of an extrapleural mass. They should be distinguished from pulmonary disease.

Fracture. Fracture of a rib or ribs is a common sequela of road traffic accidents. A rib fracture may easily be missed radiographically if displacement of the fractured ends is slight. If rib damage is suspected, ventrodorsal and lateral views of the thorax should be made, and each rib should be carefully examined for alteration in the normal rib line and variations in opacity. Recent rib fractures usually have associated soft tissue damage. Rib fractures are often associated with other abnormalities such as pleural or intrapulmonary hemorrhage, chylothorax, pneumothorax, or subcutaneous emphysema. In cats, stress fracture of a rib or ribs may occur associated with labored breathing, such as in feline asthma or chronic chylothorax (Figure 3-27, A to N).

Neoplasia. Neoplasia of the ribs is not common but is occasionally encountered. Often the majority of the rib tumor is within the thoracic cavity and only a small part of the neoplasm extends from the outer surface of the ribs. Chondrosarcoma is more common than osteosarcoma. Fibrosarcoma is also seen. Pleural fluid is often present. Expansion of the rib and bone destruction are features (Figure 3-27, P to S). The ribs may be involved in an extension of an adjacent soft tissue tumor, or they may be the site of metastatic lesions. Pathological fractures may occur with rib metastases. The ribs may be affected in cases of multiple myeloma, showing numerous well-defined, small lytic lesions. Multiple cartilaginous exostoses are occasionally seen (Figure 3-27, T). Infection of the ribs can be difficult to differentiate from neoplastic disease (Figure 3-27, O).

Lesion-oriented views are frequently required to demonstrate rib abnormalities. Left and right lateral views should be made.

Ultrasonography
The outer surface of the rib is identified as a smooth hyperechoic line with a marked acoustic shadow distally. When a transcostal imaging plane is used, the ribs are sometimes seen as hyperechoic edges encroaching on the sonographic image and casting echolucent acoustic shadows. Rib masses or masses involving the thoracic wall may be assessed for the amount of tissue involvement and the degree of extension into the thoracic cavity. They have a mixed echogenicity and echotexture, and sometimes cavitation is evident. Acoustic shadowing will be seen associated with hyperechoic mineralized foci (see Figure 3-27, U and V).

THE STERNUM
The sternum is composed of a series of eight bones that form the floor of the thorax. The individual sternebrae are joined by intersternebral cartilages. The cranial sternebra is called the manubrium and the caudal sternebra the xiphoid process. The xiphoid cartilage prolongs the xiphoid process caudally. The first nine ribs articulate with the sternum through the costal cartilages. The first rib articulates with the manubrium and the others with the intersternebral cartilages. As previously mentioned, ribs that have no sternal attachment are sometimes called floating ribs. Calculations between or bridging the sternebrae appear to be of no clinical significance (Figure 3-28, J).

Congenital anomalies are sometimes seen, including fusion and malalignment of sternebrae. The sternum is seen on lateral and dorsoventral or ventrodorsal views. It is best seen on a lateral view; on the dorsoventral or ventrodorsal position, it overlies the vertebrae. It can be demonstrated on oblique views.

Pectus Excavatum (Chondrosternal Depression).
Pectus excavatum may be congenital or acquired. It is a chondrosternal depression, or dorsal displacement of the caudal portion of the sternum and the associated costal cartilages. The sternum at that point projects into the thorax, reducing the dorsoventral diameter of the thoracic cavity. It is best seen on lateral radiographs and may be an incidental finding. Varying degrees of deformity are encountered in the cartilage beds and adjacent ribs. The heart may be displaced. This condition may cause no clinical signs,
or it may be associated with reduced exercise tolerance and recurrent bouts of respiratory disease. It is more common in cats than in dogs. It may occur in combination with a congenital peritoneopericardial hernia in cats. In cats it may be acquired associated with traumatic avulsion of the mainstem bronchus or trachea (Figure 3-28, A to H).

**Fracture.** Fracture of the sternum may result from a traffic accident or other blunt trauma. Such fractures usually heal well, although sometimes with residual deformity. The intersternbral spaces may be narrowed. There will be extrapleural soft tissue swelling and a variable amount of external soft tissue swelling. With chronicity, the margins of the bones become

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**Figure 3-27** The ribs. A to D, Thoracic trauma in a dog from a dog bite. A, On this lateral radiograph multiple, variably sized, irregularly shaped gas lucencies are seen within the ventral subcutaneous tissues of the thoracic wall. The right caudal lung lobe appears as a leaf-like structure in the caudal thorax on the lateral view. The apex of the heart is displaced slightly from the sternum. B, This ventrodorsal view shows that there is subcutaneous emphysema along both the left and right thoracic walls. There are multiple segmental fractures of the right sixth, seventh, and eighth ribs. The fractured rib segments are displaced medially. The right lung is severely atelectatic and has a homogeneous soft tissue appearance. No normal pulmonary vascular markings are seen in the peripheral part of the right hemithorax. The heart is displaced to the left (mediastinal shift). These signs indicate a pneumothorax. C and D, Two weeks later. The subcutaneous emphysema has resolved. The alignment of the rib fractures is slightly improved. The fracture ends are somewhat indistinct and slightly rounded. The pneumothorax has also resolved. The heart is now in its normal position.
Figure 3-27, cont’d  
E and F, Lateral (E) and ventrodorsal (F) images of a Chihuahua attacked by an Akita. There is bandage material wrapped around the thorax. A large pocket of subcutaneous gas is present overlying the left shoulder, left axilla, and left cranial thoracic wall. There are fractures of the left fifth, sixth, seventh, and eighth ribs. The left fifth intercostal space is severely widened. There is moderate widening of the left sixth intercostal space. A mottled, patchy increased soft tissue opacity is present within the left caudal and cranial lung lobes. The abnormal lung blends with the cardiac silhouette where they are in contact. These findings are consistent with an alveolar pattern caused by pulmonary hemorrhage or contusion.  
G, Healed and nonunion rib fractures in a dog. Lateral radiograph showing multiple rib fractures. Most of these have healed with a moderate quantity of well-defined, well-mineralized callus. The callus causes smooth, well-defined bulges of the distal segments of the ribs. There are nonunion rib fractures superimposed on the caudal lobes (short arrows) and a second nonunion fracture (long arrows) superimposed on the liver. The fracture lines are distinctly visible and are widened, smooth, and well defined. This appearance is consistent with a moderately hypertrophic nonunion.  
H, Healed rib fractures in a dog. There is a healed fracture of a cranial rib. Moderate cranial angulation of the distal fracture segment is present. There is a small amount of well-defined, well-mineralized callus. Smooth, well-defined callus is also present on the medial border of the rib caudal to the malunion fracture.

Continued
sclerotic, and bridging new bone may form dorsally and ventrally. Intersternebral subluxations or luxations are more commonly the result of trauma.

Infection of the sternebrae may follow trauma or occur as a result of foreign bodies. The signs are those associated with osteomyelitis, bone erosion, proliferative new bone formation, and soft tissue swelling. An extrapleural mass may be seen (Figure 3-28, K and L). Infection of the intersternebral joints may be seen, frequently with concurrent discospondylitis, in patients with systemic aspergillosis. Neoplasia of the sternum is rare (Figure 3-28, M and N).

THE CARDIOVASCULAR SYSTEM
Anatomy

The Heart. The normal heart is cone shaped and lies within the mediastinum. It is obliquely placed within the thorax, with its base, or hilus, facing dorsocranially and its apex caudoventrally. A transversely curved, longitudinal, obliquely placed septum divides the heart into cranioventral and caudodorsal parts. The cranioventral part is commonly referred to as the right heart and the caudodorsal part as the left heart.

The right heart is composed of the right atrium and the right ventricle. In addition to its main chamber, the atrium has a blind pouch that projects cranioventrally called the auricle. The cranial and caudal venae cavae and the coronary sinus open into the right atrium. The azygos vein usually empties into the cranial vena cava, but it may empty directly into the right atrium. The right atrium drains into the right ventricle through the atrioventricular opening. Backflow of blood is prevented by the right atrioventricular, or tricuspid, valve. The right ventricle, having received blood from the atrium, pumps it into the pulmonary circulation through the pulmonary artery trunk. The pulmonic valve prevents regurgitation of blood from the pulmonary artery into the right ventricle. The part of the ventricle that leads into the pulmonary artery trunk is called the conus arteriosus or infundibulum.

The left heart is composed of the left atrium and the left ventricle. The left atrium forms the dorsocaudal part of the base of the heart. It also has a blind pouch, or auricle, in addition to its main chamber. The left atrium receives blood from the pulmonary veins: three veins from the right lung and two or three veins from the left lung, although this arrangement varies. The pulmonary artery trunk separates the left and right auricles. The interatrial septum separates the left and right atria.

The left atrium empties into the left ventricle. Regurgitation of blood from the ventricle into the atrium is prevented by the atrioventricular, or mitral, valve, complex. The ventricle pumps blood to most parts of the body through the aorta. Regurgitation of blood from the aorta into the ventricle is prevented by the aortic valve. The left ventricle is cone shaped, and its apex forms the apex of the heart. The wall of the left ventricle is several times the thickness of the right ventricular wall. The interventricular septum separates the left and right ventricles.

Normal Cardiac Physiology. The systemic veins return blood to the right atrium from the body. A number of mechanisms contribute to venous return to the right heart. The valves within the veins in the appendages prevent reverse flow of venous blood. The negative pressure within the thorax during inspiration causes blood to flow to the right heart. The returning blood fills the right atrium. During diastole, the right atrioventricular (tricuspid) valve opens, and blood flows into the right ventricle. Most diastolic filling of the right ventricle occurs as a result of relaxation of the myocardium and a small contribution from right atrial contraction at the end of diastole. At the
Figure 3-27, cont’d K1 and K2, These are normal thoracic (K1) and inverted dorsoventral thoracic (K2) images of a case of thoracic trauma from a dog fight. Numerous irregularly shaped gas bubbles are present within the subcutaneous tissues of the right thoracic wall. There are complete fractures of the midportions of the seventh and eighth ribs. There is mild medial indentation (arrow) of the parietal pleura at the level of the fractures. L, Several ribs are fractured on the left side. The fracture ends are displaced. Air is seen in the subcutaneous soft tissues.

Continued
Figure 3-27, cont'd  

M and N, Severe restrictive pleural disease resulting from chronic, chylous pleural effusion. These thoracic radiographs were obtained after therapeutic thoracocentesis. Some fluid remains within the pleural space. There is also a moderate volume of air within the pleural space. The caudal lung lobes are small and have an abnormal shape, appearing quite round. The chronic chylous effusion causes fibrosis and scarring of the pleura that changes the shape of the lung lobes and prevents reinflation. There are healing fractures of the left ninth and tenth ribs with well-defined, well-mineralized callus (arrows). These are chronic stress fractures rather than traumatic fractures. The stress fractures occur as a result of loss of compliance of the lung and chronic dyspnea. There are several small gas pockets within the soft tissues of the left thoracic wall as a result of the therapeutic thoracocentesis. O, Coccidioidomycotic infection in a rib (arrows). P and Q, Malignant histiocytic sarcoma causing a rib mass in a dog. This dog presented with muscle weakness of the right forelimb. P, On the lateral view of the thorax, there is a well-defined, hemispherical, homogeneous soft tissue mass in the cranial dorsal thorax. The proximal part of the second rib is absent (black arrows). Q, The ventrodorsal view shows this is located in the right cranial thorax. There is complete destruction of the proximal two thirds of the right second rib, with lateral displacement of the distal part (long arrow). The third rib is displaced caudally. The trachea is displaced to the left (short arrows). This was an extrapleural mass. Diagnosis: malignant histiocytic sarcoma.
Figure 3-27, cont’d R. Extrapleural sign caused by osteosarcoma of the rib in a dog. There is a well-defined soft tissue mass in the right cranial thorax. The mass is roughly hemispherical in shape, with its base adjacent to the thoracic wall. The edges of the mass taper into the thoracic wall. There is medial displacement of the lung. This is an extrapleural sign, indicating that the mass lesion originates within the thoracic wall and not the pleural space or lung. There is also almost complete destruction of the right fourth rib. S. Primary pulmonary neoplasm with a rib metastasis. There is a poorly defined, soft tissue mass lesion within the right middle lung lobe. Just caudal to the mass, there is lysis of a segment of one rib. There is complete destruction of the bone. The ends of the rib appear quite ragged. There is a small mass effect with medial displacement of the right caudal lung lobe. T, Cartilaginous exostosis on the rib cage (arrows). Continued
beginning of right ventricular systole, rising pressure within the right ventricle causes the tricuspid valve to close. Once pressure within the right ventricle exceeds that within the pulmonary artery, the pulmonic valve opens and ejection of blood into the pulmonary arterial circulation commences. The wall of the right ventricle is thin because resistance within the pulmonary circulation is low and pressure within the pulmonary circulation is also low. Blood flows through the pulmonary arteries, to the pulmonary capillary bed, and then to the pulmonary veins. The volume of blood returning to the left atrium from the pulmonary veins is referred to as preload and represents the work that will be performed by the left ventricle. Left atrial filling occurs as a result of slightly negative pressure within the left atrium as a result of displacement of the atrioventricular valve ring toward the cardiac apex during left ventricular systole. At end systole, the mitral valve opens and left ventricular filling commences. As in the right ventricle, this is largely a passive process because of myocardial relaxation. There is a small contribution from left atrial contraction in late diastole. At the beginning of left ventricular systole, increasing left ventricular pressure causes closure of the mitral valve to prevent reverse blood flow into the left atrium. Initially there is isometric contraction of the myocardium until left ventricular pressure exceeds that in the aorta, at which point the aortic valve opens. There is ejection of blood into the aorta until left ventricular pressure falls and the aortic valve closes. The term afterload is used to describe the resistance within the systemic arterial circulation. This depends on the degree of dilation or constriction within the systemic arteries and arterioles. Afterload determines how hard the left ventricle must work to pump blood into the systemic arterial system.

An increase in preload, that is, an increase in the volume of blood presented to the heart, will cause dilation of the affected chamber. The increased volume of blood and the increased workload on the heart will also cause eccentric hypertrophy of the affected ventricle. An increase in afterload will cause the affected ventricle to undergo concentric hypertrophy as a result of the increased pressure required to eject blood from the ventricle.

**Pulmonary Arteries.** The pulmonary artery trunk arises at the conus arteriosus of the right ventricle. After a short course to the left of the midline, it divides into right and left pulmonary arteries. The right pulmonary artery travels obliquely across the base of the heart to reach the right side of the thorax. Its first branch enters the cranial lobe of the right lung. Just distal to the first branch, it divides into several branches that supply the cranial (apical), middle (cardiac), caudal (diaphragmatic), and accessory (intermediate orazygos) lung lobes. The left pulmonary artery is shorter than the right, and it divides into two branches, the smaller of which supplies the cranial (apical) part of the cranial lung lobe. The larger branch divides to supply the caudal (cardiac) part of the cranial lung lobe and the caudal (diaphragmatic) lobe. The pulmonary veins from each lung empty separately into the left atrium, although variations in this arrangement are common.

**The Aorta.** The aorta leaves the left ventricle near its center. The initial part lies within the pericardium and is called the ascending aorta. It then makes a U-turn dorsocaudally and to the left. This part is called the aortic arch. The remainder of the aorta, from its arch to its terminal branches, is called the descending aorta.

The thoracic aorta is the portion of the aorta that lies within the thorax; the abdominal aorta is the part that lies within the abdomen. The aortic valve lies at the origin of the aorta and prevents backflow of blood from the aorta into the left ventricle. The aortic sinus,
or bulb of the aorta (sinus of Valsalva), is a dilation of the aorta at its origin, from which the coronary arteries arise. The aorta gives off two large branches in the cranial mediastinum: the brachiocephalic trunk and the left subclavian artery.

The Caudal Vena Cava. The normal caudal vena cava is seen in the caudal thorax between the cardiac shadow and the diaphragm. It joins the cardiac shadow in the area of the left atrium. On inspiratory films it lies almost parallel to the long axis of

Figure 3-28 Pectus excavatum (chondrosternal depression). A, On the lateral view of a dog’s thorax, there is moderate dorsal deviation of the caudal half of the sternum. This causes dorsal displacement of the heart. This is a congenital anomaly. B, On the dorsoventral projection of the thorax, there is displacement of the cardiac apex to the left. The caudal part of the thorax is slightly tilted, and the caudal sternum can be seen just to the left of the spine. Many cases have no associated clinical signs. If the deformity is severe, the reduced intrathoracic volume may result in exercise intolerance or dyspnea. This defect may be associated with other defects of midline closure such as peritoneopericardial hernias and umbilical hernias. C and D, Pectus excavatum in a kitten. C, On the lateral view, there is severe dorsal displacement of the caudal half of the sternum. There is severe reduction in the normal dorsoventral height of the thoracic cavity. This results in an hourglass-type appearance. D, On the dorsoventral view, the thorax appears wider than normal. The entire heart is displaced into the left hemithorax. This is a congenital anomaly. In cases of this severity, there may be clinical signs such as dyspnea or exercise intolerance. E, On this lateral projection, there is moderate dorsal displacement of the caudal half of the sternum. The xiphoid is displaced ventrally. The concave deformity of the sternum results in dorsal displacement of the heart.

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Figure 3-28, cont’d. F, Pectus excavatum in an adult cat. The caudal half of the sternum is displaced dorsally and overlies the cardiac silhouette. The cupola of the diaphragm is displaced cranially. Fat can be seen between the tip of the cardiac apex and the cranial border of the liver. This may represent a congenital diaphragmatic hernia or possibly a small peritoneopericardial hernia. G and H, Intermittent sternal deformity. G, The first lateral radiograph in this cat was obtained during a forced inspiratory effort against a closed upper airway caused by laryngeal paralysis. The thoracic wall in this species is quite flexible, which allows severe dorsal displacement of the sternum. H, The second lateral radiograph was obtained while the patient was breathing normally and shows no deformity of the thoracic wall. I, A longstanding traumatic deformity of the third and fourth sternebrae. This was of no current clinical significance. J, A 12-year-old Spaniel had bridging and fusion of the first two sternebrae.

Radiography

Routine lateral and dorsoventral (or ventrodorsal) views of the thorax give much information about the status of the heart and great vessels. The dorsoventral view is preferred to the ventrodorsal. There may be some distortion of the cardiac outline when the radiograph is made with the animal in dorsal recumbency as a result of the ability of the cardiac apex to move to one side or other of the thorax when the animal is in this position. The entire thorax should be on the film, and symmetric positioning is essential. Accurate positioning is of prime importance because sequential studies are often required, and they must be comparable. On both views, the x-ray beam should be centered
Figure 3-28, cont’d K, Systemic aspergillosis in a German Shepherd. There is a moth-eaten to permeative destruction of three of the sternebrae. The margins of the remaining bone are ragged and poorly defined. There is minimal evidence of new bone formation. Soft tissue swelling is present dorsal to the sternum, causing dorsal displacement of the lung lobe margins. The presence of osteomyelitis centered at the intersternebral joints and discospondylitis is strongly suggestive of systemic aspergillosis, especially in German Shepherds (cranial is to the right of the image). L, Chronic infection of the sternum with erosion of the caudal aspect of the third sternebra and the cranial aspect of the fourth sternebra (cranial is to the right of the image). M, A 10-year-old West Highland White Terrier had a lump on the ventral aspect of the thorax. A lateral radiograph shows a dorsal displacement and involvement of the xiphisternum by a mottled, ill-defined, lacy, mineralized mass. An extrapleural mass is seen within the thorax. This was a chondrosarcoma. N, Sternal metastasis from rib osteosarcoma. There is near-complete destruction of the fourth sternebra. A thin, ill-defined rim of cortex is present ventrally. The bone is foreshortened. There is mild soft tissue swelling dorsal to the sternum, visible as a small convex structure protruding into the lung.

at the level of the caudal edge of the scapula—usually at approximately the fifth intercostal space. Rotation may cause significant changes in the appearance of the heart and related structures. On the dorsoventral (ventrodorsal) view, the vertebrae should be superimposed on the sternum; on the lateral view, the arch of the ribs should not project above the level of the vertebrae.

Variations in the appearance of the cardiac silhouette may be caused by several factors, including the stage of respiration, breed variation, conformation, the stage of contraction of the heart, centering of the x-ray beam, and the position of the animal. Radiographs should be made at the end of inspiration. Standardization of technique is very important (Figure 3-29, A to G).

More detailed studies of the heart and great vessels can be made by using angiocardiography. However, this technique has been largely superseded by the use of echocardiography. Contrast medium is introduced into the heart, either directly or indirectly, and rapid serial radiographs are made to demonstrate its
Figure 3-29 The normal heart. A and B, Right lateral recumbent views. A was taken with the heart in systole and B with the heart in diastole. In systole, the cardiac shadow appears smaller, the left heart border is straighter, and the general outline is sharper. The vena cava is narrower. Unless fast exposure times are used (0.05 seconds or less), the heart usually appears in diastole because the largest shadow cast during the exposure determines the outline. C and D, Dorsoventral (C) and ventrodorsal (D) views of the same heart. In the dorsoventral view, the heart appears shorter. The dorsoventral view, although more difficult to position accurately, is preferred to the ventrodorsal for study of the heart. Displacement of the heart within the thorax in the ventrodorsal position makes it difficult to produce comparable repeat studies.
passage through the heart, vessels, and lungs. Iodinated contrast media are used. The maximum contrast for the complete examination should not exceed a total of 1200 mg iodine/kg—less in small dogs.

Selective angiocardiography refers to the introduction of contrast medium through a catheter, the tip of which is placed in a preselected position within either a chamber of the heart or a blood vessel. Studies are conducted with the animal in right lateral recumbency. Fluoroscopy is desirable to facilitate accurate placement of the catheter and to determine its exact location before an injection is made. Catheters with side openings are preferred to those with end openings only because the latter tend to recoil when the injection is made and because they may lead to intramyocardial injection. The contrast medium must be injected rapidly as a bolus; otherwise it will be rapidly diluted by the circulating blood, and the structures under examination will be poorly outlined. The contrast should be warmed to body temperature. The dose is 0.5 to 1 mL/kg body weight of a preparation containing 400 mg iodine/mL. The kilovoltage should be increased by 10 kV. A catheter can be introduced into the right atrium, right ventricle, and pulmonary artery trunk through a jugular or cephalic vein. The left atrium, left ventricle, and aorta can be entered through a carotid artery or a femoral artery. It is usually more satisfactory to expose a vessel surgically before introducing a catheter. Percutaneous introduction is not always easy, particularly in the case of arteries, and it makes accurate positioning of the cannula carrying the catheter more difficult. The use of pressure injection equipment is recommended for selective angiocardiography. The reader is referred to

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Figure 3-29, cont’d F1 to F5, Normal lateral radiographs showing breed variations in cardiac and thoracic conformation of a Bassett Hound (F1), Bearded Collie (F2), Labrador Retriever (F3), Poodle (F4), and a Pug (F5).
Figure 3-29, cont’d G1 to G5, Normal dorsoventral radiographs showing breed variations in cardiac and thoracic conformation of a Bassett Hound (G1), Bearded Collie (G2), Labrador Retriever (G3), Poodle (G4), and a Pug (G5).
standard works on radiographic technique for details of the procedure.

Nonselective angiocardiography is done by rapid injection of contrast medium into a jugular vein and the making of serial radiographs after the injection. The injection should be made through as large a catheter as possible (up to 14 gauge) so that a compact bolus of contrast medium can be injected in a short space of time. The amount of contrast medium to be injected is from 0.5 to 1.0 mL/kg body weight of a preparation containing 400 to 450 mg iodine/mL. Some reflux into the caudal vena cava is common with this method. The larger doses are used with the less-concentrated agents. Although pressure injection equipment facilitates the introduction of a compact bolus of contrast medium, rapid injection with a syringe and wide-bore catheter can give quite satisfactory results.

Nonselective studies can produce valuable information. A single radiograph, made a few seconds after injection of contrast medium into the jugular vein, can give a good picture of the status of the pulmonary artery tree. A simple hand-operated cassette changer can be made to produce four or five radiographs at a rate of approximately one per second. Even with sophisticated equipment, a rate of two films per second is rarely exceeded for selective or nonselective studies. The main disadvantage of nonselective angiocardiography is that it results in some overlapping of shadows. This disadvantage can be important in the
Figure 3-29, cont’d K and L, Right-sided, parasternal long-axis views of the heart. K, Four-chamber view. The atrioventricular valves are seen projecting into the right and left ventricles. L, Position optimized for the left ventricular outflow tract. RV, Right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium; Ao, aorta. M to O, Normal right-sided, parasternal short-axis (cross-sectional) echocardiograms of an 18-month-old dog. M, At level of the papillary muscles (arrows). RV, Right ventricle; LV, left ventricle; IVS, interventricular septum. N, Optimized for the aortic valve. RV, Right ventricle; LA, left atrium; RA, right atrium; PA, pulmonic valves (arrows). O, At the heart base optimized for the pulmonic valve (long arrow). RA, Right atrium, RV, right ventricle, Ao, aorta; MPA, main pulmonary artery; short arrow, tricuspid valve.

Continued
Figure 3-29, cont’d

P, Normal short-axis (cross-sectional) sonogram of a feline heart. The papillary muscles (arrows) protrude into the ventricular lumen (I). Q, Short-axis (cross-sectional) view at the level of the mitral valve in a dog. The two mitral leaflets (arrows) are seen within the left ventricular lumen. R and S, Right-sided, parasternal long-axis views. R, The upper portion of the interventricular septum is membranous and may not reflect echoes back to the transducer. Such an artifact is indicated by the arrow. S, Similarly, the area of the foramen ovale may cause a septal “drop-out” (arrow). ra, Right atrium; la, left atrium; rv, right ventricle; lv, left ventricle. T, Schematic diagram of M-mode. The M-mode tracing is obtained at the level of the papillary muscles just proximal to the mitral valves and chordae tendineae. A simultaneous ECG recording is necessary for accurate measurements. RVW, Right ventricular wall; RV, right ventricle; IVS, interventricular septum; LV, left ventricle; PVW, posterior left ventricular wall. Measurement locations A to F: A, interventricular septum in diastole; B, left ventricular lumen in diastole; C, posterior left ventricular wall in diastole; D, interventricular septum in systole; E, left ventricular lumen in systole; F, posterior left ventricular wall in systole. (T, courtesy E. Fitzpatrick.)
study of some structures. For example, opacification of the right atrium at the same time as the pulmonary artery trunk is opacified makes study of the pulmonary artery trunk difficult with this method. In most cases, when angiocardiography is used, lateral views are the most informative.

**Normal Appearance**

Because the heart contrasts well with the air-filled lungs, it is readily available for study on plain radiographs. It may appear larger on expiratory films. There are changes in size and shape of the cardiac silhouette between systole and diastole. The diameter of the caudal vena cava varies with the respiratory phase; it is smaller at full inspiration than at expiration.

A clock face analogy is often used to describe positions along the cardiac borders on both lateral and dorsoventral (ventrodorsal) views. The 12 o’clock position on the lateral view is at the center of the base of the heart; on the dorsoventral view, it is over the aortic arch. The margins of individual chambers are not identifiable on plain radiographs.

**Lateral View.** On the lateral view, the cardiac outline varies considerably in different breeds and types of dogs. Dogs with a deep, narrow thorax have an upright cardiac silhouette, the long axis being almost at right angles to the spine. The heart is ovoid in shape. In dogs with a shallow or medium thorax, the long axis of the heart is directed more cranially so that the heart is not quite as upright as with a deeper thorax. In dogs with a wide, barrel-shaped, or shallow thorax, the heart is rounder in appearance and less upright than with other conformations, and more of the cranial border is in contact with the sternum. The cardiac silhouette is relatively larger and more rounded in younger dogs.

The cranial, or right heart, border forms a gentle curve that lies about the level of the third intercostal space. Dorsally the curve is formed by the ascending aorta and right auricular appendage and sometimes by the pulmonary artery; the middle and ventral thirds are formed by the ventricular outflow tract and the wall of the right ventricle. Sometimes a shallow depression is formed where the ventral edge of the cranial mediastinum meets the right heart border. The cranial border of the heart makes contact with the sternum for a variable distance, depending on the stage of the respiratory and cardiac cycles and the conformation of the animal.

The caudal, or left heart, border is not as curved as the right. It lies at approximately the level of the eighth rib. It is formed for the most part by the wall of the left ventricle. The dorsal edge of the caudal vena cava lies at the junction of the left atrium and ventricle, which corresponds to the position of the atrioventricular groove. The caudal left atrial border is obscured by many superimposed vascular shadows.

There are slight differences in cardiac outline between studies made in right and in left lateral recumbency. In right lateral recumbency, the right heart border is somewhat more rounded, which may simulate right ventricular enlargement. In left lateral recumbency, on inspiratory films the cardiac apex may be separated from the sternum because of the interposition of inflated lung between the heart and the sternum.

The distance between the diaphragm and the caudal cardiac border varies with inspiration and expiration and with the conformation of the animal. At expiration and in dogs with a shallow thorax, the diaphragmatic shadow may overlie the caudal cardiac

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**Figure 3-29, cont’d U, This is a duplex ultrasonographic image. The 2-D image (top) shows the cursor location through the left ventricle. The M-mode (bottom) shows the normal M-mode through the mitral valve. The distance between the septal leaflet and the interventricular septum is indicated by the arrow. The E point septal separation (EPSS) is the maximal diastolic excursion of the septal leaflet of the mitral valve. This is measured to assess ventricular dilation. V, Parasternal apical four-chamber view from the left side. The apex of the heart is in the near field and the atria in the far field. This view permits best alignment of the Doppler signal with the heart valves, which should be parallel with the blood flow. RA, Right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; interventricular septum (short arrow); atrioventricular valves (long arrows).**
The cardiac apex is at the level of the interventricular septum. The base, or dorsal border, of the heart is not clearly defined. It is formed by the right and left atria and by the pulmonary arteries and veins. On the lateral view, the apicobasilar length of the heart is approximately two thirds the length of a line drawn from the cardiac apex through the tracheal bifurcation to the lower border of the thoracic vertebrae. The tracheal bifurcation is recognized as a prominent circular lucency over the base of the heart. Cranial and dorsal to the tracheal bifurcation, the left pulmonary artery crosses the trachea. The right pulmonary artery is sometimes seen as a rounded soft tissue opacity ventral to the tracheal bifurcation. The shadow of the ascending aorta also crosses the trachea cranial to its bifurcation. The cranio-caudal diameter of the heart is approximately from 2.5 intercostal spaces in dogs with a narrow thorax to 3.5 intercostal spaces in dogs with a wide thorax.

A vertebral heart score (VHS) system has been devised relating cardiac size to the length of vertebral bodies. The sum of the apicobasilar length and the cranio-caudal maximal width measured at right angles to each other is compared with the length of the vertebral bodies starting at the cranial aspect of T4. The normal range in dogs is 8.7 to 10.5 vertebral bodies. Breed variations occur, with the Labrador, Golden Retriever, the Cavalier King Charles Spaniel, and the Boxer being outside the normal range. Determination of cardiac enlargement, particularly in the early stages, is usually based on experience in examining thoracic radiographs and, if possible, a study of a series of radiographs of the same animal made over a period of time.

On the lateral view, the trachea forms an acute angle with the vertebræ in the cranial thorax. In dogs with a deep thorax, the angle is wider (less acute) than in dogs with a wide, shallow thorax. The position of the trachea is important in assessment of the cardiac silhouette (Figure 3-29, F).

The cardiac shadow in cats is oval shaped on both lateral and dorsoventral views. Because there are fewer conformational differences in cats, there is less variability in the appearance of the cardiac outline than in dogs. The long axis of the heart is directed more cranially in cats, so that the cardiac silhouette lies at an angle of 45 degrees to the sternum. In cats, the cranio-caudal diameter is measured at right angles to the long axis of the heart and then compared with the intercostal spaces in the horizontal plane. The normal measurement is two intercostal spaces. In older cats, the heart tends to tilt cranially and in elderly patients may be orientated with the long axis almost cranial to caudal on the lateral view. Because of the change in the position of the heart, the aortic arch extends cranially (see Figure 3-6, K and L).

**Dorsoventral View (Ventrodorsal).** On the dorsoventral view, dogs with a deep thorax, such as the Greyhound, show an oval-shaped cardiac outline. In dogs with a less deeply conformed thorax, a rounded heart is seen, with the apex to the left of the midline. In dogs with a wide, shallow thorax, a rounded cardiac silhouette, obliquely positioned, is seen, with the apex well to the left of the midline. There is marked shortening of the heart shadow on the dorsoventral view, particularly in animals with an upright heart and deep thorax. Depending on the conformation of the dog, the cardiac silhouette may occupy half (deep chested) to two thirds (shallow chested) the width of the thorax. On well-penetrated views, the aortic arch can often be seen. The cardiac outline extends from roughly the third to the eighth rib. Approximately equal amounts of lung fields should be visible on either side of the heart (Figure 3-29, G).

The right cardiac border is curved and is composed of the walls of the right atrium (9 to 11 o’clock position) and right ventricle (9 to 5 o’clock position). It extends caudally to just beyond the midline on the left. With the right hemidiaphragm, the cardiac margin forms the right cardiophrenic angle and the caudal vena cava crosses this area in a caudocranial direction. Cranially, the left heart border is composed of the aorta (12 to 1 o’clock position) and the pulmonary artery segment (1 to 2 o’clock position). The pulmonary artery appears more prominent at ventricular systole. Caudal to the pulmonary artery segment, the left ventricle overlies the left auricle (2 to 3 o’clock position). Under normal circumstances, the left auricle does not contribute to the cardiac edge. The remainder of the wall and the apex are formed by the wall of the left ventricle (3 to 5 o’clock position). The left ventricular segment is straight on a ventrodorsal view, somewhat curved on a dorsoventral. The left atrium does not normally contribute to the cardiac silhouette on the dorsoventral (ventrodorsal) view. It is centrally located just caudal to the bifurcation of the trachea, which can be seen on adequately penetrated views. The maximum width of the heart is at approximately the level of the fourth rib. Cranially and centrally, the heart shadow merges with the cranial mediastinal shadow.

On the dorsoventral view, the cranial border is made up of the aortic arch, the right auricle, the cranial vena cava, and the pulmonary artery trunk. These structures are superimposed on one another in a complex fashion, and some cannot be individually distinguished. The aortic arch overlies the right auricle. The cranial vena cava forms the right edge of the mediastinal shadow. The left subclavian artery forms the left border of the cranial mediastinal shadow. The aorta arches caudally and to the left, running obliquely caudally toward the midline. The pulmonary artery trunk divides into left and right pulmonary arteries to the left of the midline (Figure 3-29, G). In older cats, the aortic arch is seen extending cranially on the left side of the mediastinum, forming a prominent knuckle (see Figure 3-6, K and L). There is considerable overlapping of structures on both the lateral and dorsoventral (ventrodorsal) views (Figure 3-29, A to J).

**Ultrasonography**

Echocardiography has become a major diagnostic aid in evaluating cardiac disorders. The reader is referred to specialized texts for detailed description and discussion of this topic.
Echocardiography is a complementary technique to radiography and not a substitute. Radiographs provide more information regarding overall cardiac size and shape, whereas ultrasonography enables assessment of the cardiac structures and function. Radiography provides the best assessment of congestive heart failure. The thickness, size, and shape of the cardiac structures can be accurately assessed by ultrasonographic examination. The presence of masses or pericardial fluid can be established. Cardiac motion and valvular disease can be evaluated by using two-dimensional (2-D) B-mode, M-mode, and Doppler modalities. Accurate planes of section and correct orientation of the transducer are important to avoid erroneous conclusions. The 5- to 7.5-MHz transducers usually provide good resolution and depth of penetration for most dogs and cats. Large dogs may need a 3-5-MHz transducer. The transducer groove point or notch should be directed toward the heart base or cranially for correct orientation.

For cardiac assessment, the transducer location is over the area of the apex beat. This is usually from the fourth to the sixth intercostal spaces. The animal should be examined from the right and left sides. Imaging from the dependent side while the animal is in a recumbent position improves the image quality because the lung tends to move away from the ribs. If a cutout tabletop is not available, the animal can be placed close to the table edge, with the sternum projecting beyond the table top. Alternatively, if the animal is distressed, the heart can be imaged with the animal in the standing or sitting position and the appropriate forelimb drawn cranially. The acoustic windows are mainly in three positions, right parasternal, left cranial parasternal, and left caudal parasternal. The subxiphoid or subcostal window is used to achieve an optimal Doppler angle when evaluating flow in the left ventricular outflow tract.

**Right-Sided, Parasternal Long-Axis View.** Imaging the heart through the cranioventral thoracic window between the fourth and sixth intercostal spaces, with the transducer plane of section directed along the long axis of the heart, is termed a parasternal long-axis plane or view. This view permits examination of the cardiac chambers and the atrioventricular valves. The ultrasound machine will display the cardiac image lying on its side. The atria should be displayed to the right of the screen and the ventricles to the left. On a right-sided parasternal image, the right atrium and ventricle are seen closest to the transducer or skin (in the near field). The right ventricular wall is poorly defined because it lies close to the transducer. The interventricular septum runs horizontally across the image, and the left atrium and ventricle are seen in the far field (farther away from the transducer). The left ventricular free wall (posterior wall) lies farthest away from the transducer and is paralleled by a hyperechoic rim, which represents the pericardial/lung interface. The interatrial septum is seen between the two atria. Occasionally an anechoic gap appears in the atrial septum; this is termed septal dropout. It occurs when the septal thickness is very thin. Slight angulation of the transducer may help define the septum clearly. Septal dropout may also occur high in the interventricular septum. These dropout areas should not be mistaken for septal defects, and if septal defects are suspected, they should be confirmed on several image planes and with Doppler. The maximal image of the left atrium and ventricle should be obtained. Once the optimal image is found, the transducer location on the chest wall should not be moved. The left ventricle is usually two to three times the size of the right ventricle. The atria are similar in size.

The mitral and tricuspid valves move toward the ventricular lumens in a double-action flowing movement that is best appreciated with slow heart rates. The initial movement of the double action represents passive diastolic filling. It is followed by atrial contraction that moves the valves toward the ventricles in a secondary movement. During systole, the valves move into apposition. Subtle angulation of the transducer is required to image other areas of the heart. Rotating the transducer angle 5 to 10 degrees counterclockwise (with the animal recumbent) in a dorsocranial direction brings the left ventricular outflow tract into view, and then two of the aortic valve leaflets can be seen. They open outward during systole toward the long axis of the aortic arch, which courses toward the right side of the screen. Often the tricuspid valve is profiled at its best in this plane. A left papillary muscle is seen in the longitudinal plane extending from the left ventricular free wall into the lumen. Attached to this muscle are the chordae tendineae, which look like thin, hyperechoic strands. These strands can be followed up to their attachments on the mitral valve. The mitral valve and aortic outflow tract cannot be seen clearly in the same image plane (Figure 3-29, K, L, R, and S).

**Right-Sided, Parasternal Short-Axis View.** As the transducer is maintained in the parasternal long-axis position, it is rotated through 90 degrees in a clockwise direction. This gives a cross-sectional plane, or parasternal short-axis view, that shows the right and left ventricles in a horizontal plane. Angling the transducer from a ventral to dorsal direction from the apex to the base allows examination of the cardiac chambers, the tricuspid and mitral valves, and the aortic and pulmonic valves. The orientation of the image should be with the right ventricular outflow tract and the pulmonic valve to the right side of the centrally placed aorta. The mitral valve leaflets can be seen moving in the left ventricular lumen. They have been described as looking like the mouth of a fish opening and closing. The papillary muscles are identified as two projections from the posterior wall extending into the ventricular lumen at the 5 and 9 o’clock positions. The chordae tendineae are seen in cross-section as focal hyperechoic points on the margin of the papillary muscles (Figure 3-29, M to Q.)

Directing the plane of section dorsally to the heart base and cranial rotation of the transducer of approximately 5 degrees brings the aortic outflow tract into
view. The aortic valves are identified in cross-section as a “Mercedes Benz sign” or an inverted Y or shamrock shape. A slightly dorsal and steeper angle shows the pulmonic valve to the right of the aortic valve looking somewhat like a seagull’s wings. These leaflets are seen moving during the cardiac cycle.

**Left-Sided, Parasternal Positions.** Long-axis parasternal views can be made from the left side. The transducer is placed on the fourth or fifth intercostal space (left caudal parasternal position) and is rotated slightly dorsocranially (clockwise). The transducer angle is directed cranially toward the heart base until the left ventricular outflow tract and the long axis of the aorta come into the plane of section. By angling the transducer ventrally, the tricuspid valve can be seen. Directing the beam angle dorsally will bring the right ventricular outflow tract into view. Rotating the transducer cranially through 90 degrees produces a left-sided, parasternal short-axis view.

Moving the transducer cranially to the third or fourth intercostal space (left cranial parasternal position) and rotating clockwise to direct the beam in a craniocaudal direction brings the aorta clearly into view lying across the monitor. Angling the beam dorsally causes the aorta to appear to change shape, and the pulmonic valve is seen in the near field perpendicular to the aorta. The pulmonary artery division is located at the 5 o’clock position. Angling the transducer ventrally brings the right side of the heart into the imaging plane.

The transducer may be placed farther caudally, at the fifth to the seventh intercostal space, low down near the sternum. By careful positioning, a parasternal apical long-axis view can be obtained. The atria and ventricles are seen with the apices of the ventricles nearest the transducer and the atria in the far field. This so-called *four-chamber study* gives an excellent view of the heart. Rotating the transducer clockwise brings the aortic outflow tract into view with the four chambers, which is termed a five-chamber view. The right side of the heart should be displayed on the left side of the screen (Figure 3-29, V).

**Cardiac Mensuration**

Cardiac measurements can be made on the 2-D image. They are more accurately made by using the M-mode modality because it provides a more rapid sampling rate and better resolution. A simultaneous electrocardiographic (ECG) recording is necessary when measurements are to be obtained. A right-sided, parasternal 2-D short-axis (cross-sectional) view of the left ventricle is obtained. The plane of section obtained is just below the mitral valve at the level of the chordae tendineae, with the papillary muscles in a symmetric position. The M-mode cursor is moved across the moving 2-D image until the ventricle is bisected. The M-mode command is then engaged. A tracing scrolls across the screen. This tracing represents the cardiac movement plotted against time. It permits accurate measurements of the interventricular septum, left ventricular lumen, and left ventricular free wall during diastole and systole (Figure 3-29, T and U).

Calculations of cardiac function such as fractional shortening can be made. Fractional shortening is the measurement used to assess the degree of contractility of the left ventricle expressed as a percentage figure. The normal ranges of fractional shortening are of the order of 28% to 45% in the dog and 29% to 55% in the cat. Some giant breeds may have normal fractional shortening as low as 22%. The fractional shortening is affected by the heart rate. The end-diastolic measurements should be made at the Q or peak R wave of the ECG tracing. The systolic measurements are taken at the level of the maximal downward excursion (nadir) of the interventricular septum. To ensure accurate measurements that can be compared to standard reference values, the precise location for measurement has been established internationally in both human and veterinary medicine. The measurements are usually made from leading edge to leading edge. The leading edge is the margin of the structure closest to the transducer, representing the acoustic interface between blood and heart muscle. Some clinicians use a variation of this technique. The right ventricular free wall is not usually identified unless pericardial effusion is present. Therefore measurement of the right ventricular lumen and free wall is often not possible.

The M-mode cursor can be placed across the various valve leaflets and the tracing examined for a normal outline and thickness. The valve leaflets are seen as thin echo tracings within the various chambers and vessels. Measurement and assessment of the position of the leaflets in relation to other structures is also possible. The mitral valve opens during diastole. The point of maximal excursion of the first diastolic movement of the anterior or septal mitral valve leaflet (the leaflet closest to the septum) is called the *E point.* The distance between the E point in diastole and the septum is termed the E point septal separation (EPSS). It is an indicator of left ventricular enlargement and is usually less than 1 cm. In some giant breeds it may be 1.4 cm. The following measurements can be obtained:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVIDs</td>
<td>Left ventricular internal dimension, systole</td>
</tr>
<tr>
<td>LVIDd</td>
<td>Left ventricular internal dimension, diastole</td>
</tr>
<tr>
<td>LVFWs</td>
<td>Left ventricular free wall, systole</td>
</tr>
<tr>
<td>LVFWd</td>
<td>Left ventricular free wall, diastole</td>
</tr>
<tr>
<td>IVSs</td>
<td>Interventricular septum, systole</td>
</tr>
<tr>
<td>IVSd</td>
<td>Interventricular septum, diastole</td>
</tr>
<tr>
<td>AO</td>
<td>Aortic root, diastole</td>
</tr>
<tr>
<td>LA</td>
<td>Left atrium, systole</td>
</tr>
<tr>
<td>LA/AO</td>
<td>The ratio of the left atrium to the aortic root, usually 0.8 to 1.2 in dogs</td>
</tr>
<tr>
<td>EPSS</td>
<td>E point septal separation</td>
</tr>
<tr>
<td>EF%</td>
<td>Ejection fraction percentage</td>
</tr>
</tbody>
</table>

The formula for fractional shortening (FS) is as follows:

$$FS\% = \frac{(LVIDd - LVIDs)}{LVIDd} \times 100$$
The normal M-mode parameters are documented for the dog and cat. The ranges for the dog are quite wide, primarily because of the variations in body size and weight that exist among dogs. In cats the normal ranges are not as wide. Measurements are also available for a variety of specific breeds (Tables 3-2 and 3-3). The heart rate and the use of sedatives or anesthetics will affect the cardiac measurements obtained.

The general principles of Doppler ultrasound are dealt with in Chapter 1 (see p. 13). Specialized texts on cardiac assessment using Doppler techniques should be consulted because such procedures are outside the scope of this book.

### Contrast Echocardiography

Contrast echocardiography involves the injection of a fluid that contains microscopic bubbles into the circulation while the heart is being imaged. This material appears markedly hyperechoic compared with blood and can be briefly seen and followed by using

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#### Table 3-2 Normal Echocardiographic Values in Cats

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Moise and Dietz (N = 11)</th>
<th>Pipers et al. (N = 25)</th>
<th>Jacobs and Knight (N = 30)</th>
<th>Bonagura et al. (NG)</th>
<th>Fox et al. (N = 30)</th>
<th>Soderberg et al. (N = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEDD (cm)</td>
<td>1.51 ± 0.21*</td>
<td>1.48 ± 0.26*</td>
<td>1.59 ± 0.19*</td>
<td>1.10-1.60</td>
<td>1.40 ± 0.13*</td>
<td>0.28 ± 0.17</td>
</tr>
<tr>
<td>LVESD (cm)</td>
<td>0.69 ± 0.22</td>
<td>0.88 ± 0.24</td>
<td>0.80 ± 0.14</td>
<td>0.60-1.00</td>
<td>0.81 ± 0.16</td>
<td>0.83 ± 0.15</td>
</tr>
<tr>
<td>AO (cm)</td>
<td>0.85 ± 0.15</td>
<td>0.75 ± 0.18</td>
<td>0.95 ± 0.11</td>
<td>0.65-1.10</td>
<td>0.94 ± 0.11</td>
<td>0.94 ± 0.15</td>
</tr>
<tr>
<td>LA (cm)</td>
<td>1.21 ± 0.18</td>
<td>0.74 ± 0.17</td>
<td>1.23 ± 0.14</td>
<td>0.85-1.25</td>
<td>1.03 ± 0.14</td>
<td>0.98 ± 0.17</td>
</tr>
<tr>
<td>LA/AO (cm)</td>
<td>1.29 ± 0.23</td>
<td>—</td>
<td>1.30 ± 0.17</td>
<td>0.80-1.30</td>
<td>1.10 ± 0.18</td>
<td>1.09 ± 0.27</td>
</tr>
<tr>
<td>IVS (cm)</td>
<td>0.50 ± 0.07</td>
<td>0.45 ± 0.09</td>
<td>0.31 ± 0.04</td>
<td>0.25-0.50</td>
<td>0.36 ± 0.08</td>
<td>—</td>
</tr>
<tr>
<td>IVS (cm)</td>
<td>0.76 ± 0.12</td>
<td>—</td>
<td>0.58 ± 0.06</td>
<td>0.50-0.90</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>LVWVD (cm)</td>
<td>0.46 ± 0.05</td>
<td>0.37 ± 0.08</td>
<td>0.33 ± 0.06</td>
<td>0.25-0.50</td>
<td>0.35 ± 0.08</td>
<td>0.31 ± 0.11</td>
</tr>
<tr>
<td>LVWES (cm)</td>
<td>0.78 ± 0.10</td>
<td>—</td>
<td>0.68 ± 0.07</td>
<td>0.40-0.90</td>
<td>—</td>
<td>0.55 ± 0.88</td>
</tr>
<tr>
<td>RVED (cm)</td>
<td>0.54 ± 0.10</td>
<td>—</td>
<td>0.60 ± 0.15</td>
<td>—</td>
<td>0.50 ± 0.21</td>
<td>—</td>
</tr>
<tr>
<td>LVWA (cm)</td>
<td>0.50 ± 0.07</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.32 ± 0.11</td>
<td>—</td>
</tr>
<tr>
<td>EPSS (cm)</td>
<td>0.04 ± 0.07</td>
<td>—</td>
<td>0.02 ± 0.09</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>AA (cm)</td>
<td>0.36 ± 0.10</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MVEFS (mm/sec)</td>
<td>54.4 ± 13.4</td>
<td>87.2 ± 25.9</td>
<td>—</td>
<td>83.78 ± 23.81</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>ΔD (%)</td>
<td>55.0 ± 10.2</td>
<td>41.0 ± 7.3</td>
<td>49.8 ± 5.3</td>
<td>29.35-35</td>
<td>42.7 ± 8.1</td>
<td>34.5 ± 12.6</td>
</tr>
<tr>
<td>LVWT (%)</td>
<td>39.5 ± 7.6</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IVST (%)</td>
<td>33.5 ± 8.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>182 ± 22</td>
<td>167 ± 29</td>
<td>194 ± 23</td>
<td>—</td>
<td>255 ± 36</td>
<td>—</td>
</tr>
</tbody>
</table>

\* Cats anesthetized with ketamine.
\*\* Mean ± SD.
\† Normal range.

AA, Aortic amplitude; AO, aorta; ΔD, left ventricular fractional shortening; EPSS, E point to septal separation; HR, heart rate; IVS, interventricular septum in end systole; IVS, interventricular septum in end systole; IVST, interventricular septum thickening; LA, left atrium; LV, left atrium/aortic ratio; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVWVD, left ventricular wall thickness in end diastole; LVWES, left ventricular wall thickness in end systole; LVWT, left ventricular wall thickness; MVEFS, mitral valve E-F slope; RV, right ventricular end-diastolic dimension.


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#### Table 3-3 Normal Mean Echocardiographic Values (cm) in Dogs

<table>
<thead>
<tr>
<th>BW (kg)</th>
<th>EDD</th>
<th>ESD</th>
<th>IVSD</th>
<th>LVWD</th>
<th>EPSS</th>
<th>AO</th>
<th>LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2.0</td>
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AO, Aortic root diameter; BW, body weight; EDD, end-diastolic diameter; EPSS, E point to septal separation; ESD, end-systolic diameter; IVSD, interventricular septal thickness in diastole; LA, left atrial diameter; LVWD, left ventricular free wall thickness in diastole. The formula is the formula of the line of best fit for the data. The number represents the number of dogs sampled.

either 2-D or M-mode modalities. A simple echocontrast agent is agitated saline, producing microbubbles, rapidly injected into a peripheral vein. The contrast echoes are seen in the right heart and are removed from the circulation by passage through the pulmonary capillary bed. The presence of these echoes in the left side of the heart is indicative of a right-to-left shunting lesion. Dilution of the microbubbles by anechoic blood passing from the left to the right indicates a ventricular or atrial septal defect. Ultrasoundographic contrast agents are not widely used in veterinary medicine. Contrast echocardiography is a useful technique when trying to confirm an observation made on 2-D echocardiography. It is often colloquially termed a “bubble study.”

Spontaneous echo contrast, forming swirls in the cardiac chamber, may be seen in dogs with slow heart rates or undergoing prolonged general anesthesia. Commercial microbubble contrast agents are now available. These agents have stable microbubbles that reach the systemic arterial circulation after peripheral intravenous injection. These agents have some application in echocardiography but are predominantly used for abdominal applications in veterinary medicine.

Abnormalities
The radiologic diagnosis of cardiac enlargement is based on changes in cardiac size, shape, and position and by displacement of adjacent structures. Cardiac disease may also be manifested by changes in the pulmonary vasculature and pulmonary parenchyma, pleural effusion, pericardial effusion, hepatomegaly, and ascites. Knowledge of normal cardiac function and the various compensatory mechanisms that are activated by cardiac or extracardiac abnormalities is essential for a reasoned and logical approach to the interpretation of radiographs of the heart.

An enlarged cardiac silhouette does not necessarily mean an enlarged heart. If the pericardial sac contains fluid, fat, or abdominal organs, the cardiac silhouette will appear enlarged even in a normal heart.

Enlargement of Individual Chambers. Because of the interrelationship between the actions of the left and right sides of the heart, marked enlargement of an individual chamber is rare. If it does occur, it will be short lived because compensatory mechanisms will usually produce enlargement elsewhere.

Right-Side Enlargement: Right Ventricle. Any condition that increases the workload of the right side of the heart will eventually result in right ventricular enlargement. Such conditions include pulmonic or tricuspid valve incompetence and septal defects in the ventricle or atrium. It is also seen associated with heartworm disease, chronic lung pathology, and tetralogy of Fallot.

Radiologic Signs

* Lateral View
  1. The cranial border of the heart becomes rounder in the area of the ventricle.

  2. The enlarged ventricle may indirectly cause elevation of the trachea. However, the ventral bend in the terminal trachea remains.

  3. The craniocaudal diameter of the heart is increased.

  4. More of the cardiac silhouette than usual is in contact with the sternum.

  5. The enlarged ventricle may cause the heart to tilt, displacing the apex caudally and dorsally. This displacement may give the impression that the left ventricle is enlarged.

Dorsoventral View

1. The right border comes closer to the right thoracic wall.

2. The enlarged ventricle bulges out on the right side of the heart, giving that side of the heart the appearance of a reversed D.

3. The cardiac apex may be displaced to the left because the left ventricle is displaced by the enlarged right ventricle. As a result, the left cardiac border appears closer to the left thoracic wall, giving the impression of left ventricular enlargement. The position of the cardiac apex can be determined by locating the pleural reflection in the left caudal thorax.

4. In the early stages of right ventricular enlargement, the pulmonary artery may appear excessively prominent (Figure 3-30).

Ultrasonography. On the right-sided parasternal view, the right ventricular lumen in end diastole should be roughly one third to one half the size of the left ventricle. Enlargement of the ventricular lumen or hypertrophy of the ventricular wall may be seen. Tricuspid valve conformation and movement can be assessed.

Right-Side Enlargement: Right Atrium. The right atrium may be enlarged if the efficiency of the tricuspid valve is impaired. It may also be enlarged with atrial septal defect, right ventricular enlargement, and tetralogy of Fallot. Hemangiosarcoma is occasionally seen affecting the right atrium.

Right atrial enlargement is rarely encountered as a single entity, and it is difficult to determine radiologically. There is usually an associated right ventricular enlargement.

Radiologic Signs

1. The trachea is elevated cranial to its bifurcation, and the right main stem bronchus is elevated. The ventral bend in the terminal trachea remains.

2. The caudal vena cava is often enlarged.

3. On the dorsoventral view, the enlarged atrium may cause a bulging of the cardiac silhouette cranially (in the 9 to 11 o’clock position).

4. On the lateral view, an enlarged pulmonary artery or an enlarged aorta may form part of the apparent cardiac shadow dorsocranially as it projects into the cranial mediastinum. Such structures may be mistaken for an enlarged right atrium.

Ultrasonography. Right atrial measurements have not been established. The right atrial free wall...
is difficult to appreciate unless surrounded by fluid, such as with pericardial effusion. As a rule, the right and left atria should be the same size on right-sided, parasternal long-axis views. The interatrial septum should be continuous with and parallel to the interventricular septum and should bisect the atrial lumens. An enlarged right atrium may displace the interatrial septum toward the left side. Masses around or within the atrium can be identified, particularly in the presence of pericardial fluid.

**Left-Side Enlargement: Left Ventricle.** Left ventricular enlargement is seen with incompetence of the aortic or mitral valves, aortic stenosis, left-to-right shunts, and septal defects. Left ventricular enlargement may arise from a number of causes. Endocardiosis of the mitral valve results in increased preload, which causes dilation and eccentric hypertrophy of the left ventricle. Dilation and eccentric hypertrophy of the left ventricle will usually result in radiologically visible left-sided cardiac enlargement. Concentric hypertrophy of the left ventricle may occur as a result of subaortic stenosis or idiopathic hypertrophic cardiomyopathy. Subaortic stenosis results in an increase in afterload on the left ventricle, which causes a concentric hypertrophy of the left ventricular myocardium in response to the increased pressures that the left ventricle must generate to eject blood. Concentric hypertrophy of the left ventricle may cause no appreciable alteration in the size and shape of the left heart. This is frequently the case in cats with idiopathic hypertrophic cardiomyopathy. If there is severe concentric left ventricular myocardial hypertrophy, the heart may appear elongated on both the lateral and ventrodorsal/dorsoventral views, or there may be straightening of the caudal cardiac border. In many cases, radiologic signs of left-sided cardiac enlargement may only be evident when left atrial enlargement occurs.

**Radiologic Signs**

**Lateral View**

1. In early cases or diseases characterized by concentric hypertrophy, there may be little change from normal. The caudal border of the heart loses its inward curve.
2. The caudal cardiac border becomes more upright, that is, more nearly at right angles to the sternum. In advanced cases it may become somewhat convex.
3. The caudal cardiac margin extends farther caudally than usual, but the craniocaudal diameter is not usually increased to the same extent as with right ventricular enlargement.

*Figure 3-30 A and B, Right heart enlargement. The right ventricle is enlarged, and there is increased sternal contact. The craniocaudal diameter of the heart is increased, and there is loss of the cranial cardiac waist. The trachea maintains its normal bend caudally, indicating that there is no left-sided enlargement. On the ventrodorsal view, the right heart is rounder and larger than usual, and the pulmonary artery is visible. The thymus gland (arrow) can be seen on the left side between the third and fourth ribs.*
4. Elongation of the left ventricle causes a dorsal displacement of the terminal trachea, the ventral bend of which is lost.

5. The angle between the trachea and the spine becomes more acute.

6. Very often an accompanying enlargement of the left atrium projects dorsocaudally.

Dorsoventral View
1. The left cardiac border approaches the left thoracic wall so that less of the lung field is seen on that side.
2. The left ventricular border becomes rounded. The cardiac apex may also be rounded (Figure 3-31, A and B).

Ultrasonography. Enlargement of the ventricular lumen and thickening or thinning of the walls and mitral valve pathology can be assessed.

Left-Side Enlargement: Left Atrium. Left atrial enlargement is most commonly associated with mitral valve endocardiosis and dilated cardiomyopathy. It may also be seen associated with left-to-right shunts, persistent ductus arteriosus, or atrial septal defect.

Radiologic Signs

Lateral View
1. The terminal trachea is elevated, and its caudal ventral bend is lost.
2. The left main stem bronchus is elevated—“splitting” the bronchi.
3. The left atrium may sometimes be seen extending dorsally between the caudal lobe bronchi, which are separated, forming a V shape.
4. The enlarged left atrium may be seen as an opacity extending into the caudodorsal lung fields. It frequently has a wedge-shaped appearance.
5. Signs of congestive heart failure may be seen, but this is uncommon in patients evaluated for a murmur without other signs of cardiac compromise.

Dorsoventral View
1. The left auricle (2 to 3 o’clock position) may extend laterally beyond the left cardiac border in the central part of the cardiac outline. If the left ventricle is also enlarged, this sign may not be seen.
2. The enlarged left atrium often casts a shadow where it is superimposed on the right ventricle so that the edge of the atrium may be seen within the cardiac shadow as a line close to and paralleling the border of the right ventricle and sometimes part of the left ventricular border.
3. The atrium, if the enlargement is severe, may be seen to spread apart the stem bronchi (Figure 3-31, C and D).

Ultrasonography. On the image that brings the left ventricular outflow tract into view, the relative size of the left atrium compared with the aortic outflow diameter can be measured at the level of the aortic valves. This measurement is taken on a right-sided parasternal cross-sectional view at the level of the aortic valves. Using M-mode, the left atrium to aorta (LA/AO) ratio is normally in the region of 0.8 to 1.2 in dogs. On the M-mode tracing, the aortic dimension is taken at end diastole, and the atrial dimension is taken at end systole. However, the M-mode cursor, when directed through the aortic root, does not pass through the body of the left atrium. Hence, the ratio may underestimate the degree of left atrial enlargement. Measurement techniques based on a 2-D short-axis B-mode image have been described to address this problem. The left atrium may be assessed from the right-sided parasternal position, where its relative size can be compared with the right atrium. Enlargement or intraatrial masses can be identified. The atrium can also be examined on the short-axis view and from the left side on the four-chamber view.

Generalized Cardiac Enlargement (Cardiomegaly). Minimal changes in cardiac outline are difficult to demonstrate or evaluate. The wide variation in normal heart shapes in different types of dogs complicates the problem. The variations in cardiac outline and the difficulties encountered in accurate positioning make results unreliable.

Generalized cardiac enlargement may be the result of hypertrophy of the cardiac muscle or dilation. Hypertrophy and dilation are indistinguishable on plain radiographs. Concentric hypertrophy does not exhibit the same degree of cardiac enlargement radiographically as dilation. The hypertrophied muscle tends to reduce the intraventricular volume rather than cause a marked change in outline. Ultrasonography or positive contrast studies enable evaluation of the thickness of the ventricular walls. If individual chambers are enlarged, the heart will have an asymmetric appearance. Both lateral and dorsoventral radiographs should be examined. Dilation can be differentiated from hypertrophy only by angiocardiography or echocardiography.

Generalized cardiac enlargement may be the result of a variety of conditions, including valvular lesions, myocardial disease, chronic anemia, and infectious or metabolic diseases.

Radiologic Signs

Lateral View
1. The heart is rounded in outline. The cranioventral diameter is increased. A diastolic image of the heart is larger than a systolic one. This may be significant with low-output machines when exposure times may be inadequate to stop movement blur. This is also more of an issue with high-output/high-frequency machines that may make the exposure during systole only.
2. The heart appears large relative to the rest of the thorax. An expiratory film may cause a normal heart to appear relatively large.
3. The right heart border becomes rounder, and there is increased sternal contact. The left heart border becomes straighter and more upright.
4. Because of an increase in the apicobasilar length of the heart, the trachea and main stem bronchi are elevated. The angle formed between the trachea and the spine becomes more acute, and the terminal bend in the trachea is lost. In severe cases, the
Figure 3-31  A and B, Left ventricular enlargement. On the lateral view, the left heart is enlarged. The trachea is displaced dorsally. It is difficult to evaluate the right heart because it has been displaced cranially by the enlarged left side. On the dorsoventral view, there is enlargement of the left ventricle, which approaches the left thoracic wall. C and D, Left atrial enlargement. The trachea is elevated on the lateral view (C). The atrium is extending into the caudal lung fields. The atrium pushes up between the bronchi supplying the caudal lung lobes. The right cranial lobar vein (arrows) is seen to be distended as it crosses the cardiac shadow. On the dorsoventral view (D) the margin of the enlarged left atrium (arrows) can be seen within the cardiac shadow. There is marked prominence of the left cardiac border in the area of the left auricle.
trachea may run parallel to the spine. Apparent elevation of the trachea may result from improper positioning, that is, rotation of the animal.

5. The main stem bronchi may be compressed by an enlarged left atrium.
6. The heart may be overlapped by the diaphragm.
7. The caudal vena cava is directed dorsocranially.

**Dorsoventral View**
1. The heart is increased, and less of the lung fields are seen on either side of it.
2. The apex of the heart is displaced caudally and to the left.
3. The diaphragm may be compressed or overlapped.
4. There may be irregularities in the cardiac outline.

When possible, cardiac enlargement should be evaluated by comparing current radiographs with those made earlier in the animal’s life, before cardiac problems arose (Figure 3-32, A and B).

**Ultrasonography.** Ultrasonography enables assessment of the pericardium, cardiac chamber size, and the sizes of the chambers relative to each other. Individual chambers and valves can be examined, and the cause of the radiographic signs of cardiomegaly established.

**Microcardia.** A decrease in heart size may be seen with adrenal cortical insufficiency (Addison’s disease) or when there is a decrease in circulating blood volume, such as in hypovolemic shock. The heart may appear to be smaller than usual at maximal inflation or hyperinflation of the lungs. The heart appears...
relatively small in deep-chested animals. The pulmonary arteries and veins may also be small, which renders the lungs hyperlucent (Figure 3-32, C).

**Enlargement of the Pulmonary Artery.** On the lateral view, an enlarged pulmonary artery trunk causes a bulging of the cranial cardiac border dorsally as it projects into the cranial mediastinum. On the dorsoventral view, there will be prominence of the pulmonary artery segment at the 1 to 2 o’clock position. The pulmonary artery segment normally appears most prominent during right ventricular systole and on ventrodorsal projections (Figure 3-33, A to C).

Causes of pulmonary artery enlargement include pulmonic stenosis with poststenotic dilation, patent ductus arteriosus, heartworm infestation, pulmonary hypertension, and cor pulmonale.

**Ultrasonography.** The pulmonary artery is seen best from a right-sided, short-axis location, with the transducer angled steeply to the heart base. The pulmonary artery should be the same width throughout its length to its bifurcation. The pulmonary artery is approximately the same width as the aorta at the level just above the aortic valves (Figure 3-33, D to F).

**Enlargement of the Aorta.** On the lateral view, an enlarged aortic arch causes a bulge in the cardiac outline dorsocranially. On the dorsoventral view, it causes an apparent increase in the length of the heart and prominence of the cardiac silhouette in the 12 to 1 o’clock area (Figure 3-34, A and B).

Causes include subaortic stenosis with poststenotic dilation, patent ductus arteriosus, aortic body tumor, and rarely an aneurysm. The pulmonary artery segment normally appears most prominent during right ventricular systole. This prominent segment should not be mistaken for an enlarged aorta. In older cats, because of a change in the angulation of the heart, the aortic arch becomes more prominent. It may also appear more prominent in the brachycephalic breeds and in older dogs.

**Figure 3-33 Pulmonic stenosis.** A and B, This dog of unknown age showed no clinical signs of disease. A murmur was detected over the pulmonic valve area during a routine examination. A, On the plain lateral radiograph, an unusual shadow—the pulmonary artery (arrow)—crosses the trachea. The right ventricle is enlarged. B, Selective catheterization of the right ventricle and angiocardiography demonstrate a narrowed valvular outlet from the right ventricle and a large poststenotic dilation of the pulmonary artery. Catheter partly overlies the pulmonic valve area. C, An enlarged pulmonary artery segment (arrows) associated with a pulmonic stenosis.

*Continued*
Ultrasonography. The aortic outflow tract is best seen from a right-sided, parasternal long-axis view, with slight cranial rotation of the transducer angle. The aortic valves are visible, and the sinus of Valsalva is seen as a slight dilation above (distal to) the valves. The air-filled lungs usually preclude further examination of the aortic arch (Figure 3-34, C).

Cardiac Disease and Cardiac Failure. When assessing clinical patients, it is important to keep in mind the distinction between cardiac disease and cardiac failure. Many middle-aged and older patients have cardiac disease, but the lesions may be mild or the cardiovascular system has compensated for the changes in cardiovascular function. Clinically, cardiac failure is defined as present when cardiac disease alters the normal exercise tolerance, causes clinical signs such as coughing or orthopnea, or changes behavior. Such clinical signs of cardiac failure will almost always precede radiologic signs of failure.

Right Heart Failure. Radiographically, right heart failure is characterized by systemic venous congestion that leads to distention of the venae cavae, hepatomegaly, pleural effusion, ascites and, eventually, peripheral edema in dependent parts. Enlargement of the right heart is not necessarily obvious.

Left Heart Failure. Left heart failure is characterized by congestion of the pulmonary veins. This progresses to interstitial edema, causing blurring or haziness of vascular structures and peribronchial cuffs, that usually has a symmetric perihilar distribution. Later there is more severe and extensive pulmonary edema, preferentially affecting the caudal lobes, with an alveolar type of pattern.

Specific Conditions. Changes that arise in the cardiac outline are often not specific for one disease condition. A rational approach to the interpretation of radiographs of the heart presupposes an understanding of basic cardiac hemodynamics. An abnormality in one chamber of the heart affects the other chambers, either directly or indirectly, and compensatory mechanisms are then activated. A ventricular overload, for whatever reason, results first in some degree of dilatation and then in hypertrophy. Increased resistance to the outflow of blood results in ventricular hypertrophy.
The pulmonary circulation is closely related to cardiac function, and any radiographic evaluation of the heart must include evaluation of the lung fields. Abnormalities of the left side of the heart may affect the pulmonary circulation, causing changes that in turn affect the right side. Abnormalities of the right side may also affect the pulmonary circulation. Interference with venous return to the right side of the heart will have systemic effects. Cor pulmonale is a term sometimes used to describe enlargement of the right side of the heart caused by an abnormality in the pulmonary vessels or parenchyma, resulting in increased resistance to blood flow through the lungs. Congestive heart failure is characterized by low cardiac output, pulmonary or systemic venous engorgement, or both.

The heart may fail because of incompetence of either the left or right side. If the left heart becomes incompetent, the venous return from the lungs is impaired and the pulmonary veins become congested. If the condition persists for a time, interstitial and eventually alveolar edema occurs. This increases the workload of the right side. If the right heart becomes incompetent, the venous return from the systemic circulation is impaired. If this condition persists for some time, pleural effusion, distention of the venae cavae, hepatomegaly, and ascites occur.
These various compensatory mechanisms should be kept in mind when assessing the significance of the radiologic signs listed for the various conditions.

**Caudal Vena Cava Abnormalities.** The caudal vena cava is usually 1.5 times the diameter of the descending aorta measured at the same level but varies depending on the phase of the cardiac and respiratory cycles. Any abnormality causing changes in intraabdominal or intrathoracic pressure or interference with outflow from the right atrium will cause an increase in diameter of the caudal vena cava. Common causes are tricuspid valve disease, tamponade from pericardial effusion, dicrofilaria, and pulmonary hypertension. Less-common causes of an increase in diameter include thrombosis or invasion by tumors. Stenosis of the vena cava has been described. The vena cava is normally wider in the systolic phase of the cardiac cycle.

The diameter of the vena cava is reduced where there is reduced blood volume reaching the right atrium. This may occur in severe dehydration, pulmonary hyperinflation, or hypovolemic shock (see Figure 3-32, C). It has also been described associated with hypoadrenocorticism (Addison’s disease). Dilation of the caudal vena cava, in the absence of other radiologic abnormalities, may have no clinical significance.

**Caval Syndrome.** Caval syndrome is an uncommon and life-threatening manifestation of heartworm disease. It occurs when a very large number of parasites are present within both the right heart and the caudal vena cava. The large parasite burden results in acute right heart failure from pulmonary hypertension. The parasites and associated thrombus formation within the right heart and caudal vena cava cause intravascular hemolysis. Right-sided heart failure and obstruction of flow within the caudal vena cava cause hepatic and renal failure and ascites. Patients present in a state of collapse, with anemia, icterus, and ascites. Thoracic radiographs reveal right-sided cardiomegally, enlarged tortuous pulmonary arteries, dilation of the caudal vena cava, and ascites (see p. 336).

**Congenital Cardiac Disease**

**Patent Ductus Arteriosus.** In the fetus, the ductus arteriosus carries blood from the pulmonary artery to the aorta, thus bypassing the pulmonary circulation. Blood flow usually ceases within a few hours of birth because of physiologic contraction. A permanent closure takes place during the first few weeks of life. If the ductus arteriosus remains patent, a left-to-right shunt results, with blood flowing from the aorta into the pulmonary artery. Rarely, a right-to-left shunt develops.

The passage of blood from the aorta into the pulmonary artery results in pulmonary hypertension and eventual dilation of the pulmonary artery. The right ventricle becomes enlarged. A dilation of the aorta develops at the level of the ductus arteriosus because of weakness of the aortic wall at this point.

The clinical signs are variable. Some puppies die within the first 10 weeks of life from left-sided heart failure. Some dogs remain apparently healthy for varying periods of time, possibly up to several years. When clinical signs develop, they include inability to exercise, coughing, hindlimb weakness, weight loss, dyspnea, and recurrent episodes of congestive heart failure. Cyanosis is not usually a feature, but it may develop if there is reverse shunting of blood caused by pulmonary hypertension. A continuous machinery-like murmur is heard that is most marked over the left third intercostal space and that may extend into the carotid arteries. Palpation of the thorax may reveal a continuous thrill over the left cranial thorax. Patent ductus arteriosus is rarely seen in cats.
A right-to-left shunt is easily confirmed with a “bubble study.” The abdominal aorta is imaged while agitated saline or colloid is injected as a bolus through a jugular or cephalic venous catheter. If a shunt is present, the bubbles bypass the pulmonary circulation and are seen as a transient marked increase in echogenicity within the abdominal aorta. This will be seen with right-to-left patent ductus arteriosus anomalies and ventricular septal defects (Figure 3-35, G and H).

Pulmonic Stenosis. Pulmonic stenosis is a narrowing of the outflow tract from the right ventricle. It interferes with the passage of blood from the right ventricle into the pulmonary artery trunk. The stenosis may affect the infundibulum, the pulmonic valve, or the pulmonary artery distal to (beyond) the valve. In dogs, the valvular and subvalvular (infundibular) types are the most commonly encountered. Pulmonic stenosis is rare in cats. Infundibular stenosis may develop secondarily to valvular stenosis as a result of hypertrophy of the ventricular muscle. A poststenotic dilation of the pulmonary artery trunk develops. The mechanics of poststenotic dilation are complex. They are significantly influenced by turbulence in the blood flow.

Initially, clinical signs depend on the severity of the condition and the animal’s age. They may be absent initially, and the condition may be discovered during a routine examination when a systolic murmur is heard over the pulmonic valve. A systolic thrill may be felt at the lower third of the thorax over the third intercostal space. Affected animals may show stunted growth, and exercise intolerance becomes apparent as the condition progresses. Dogs may live to be 5 years old or more before right heart failure occurs. Dyspnea after exercise may be the first clinical sign.

Radiologic Signs

Lateral View

1. The right heart border becomes rounded on both the lateral and the dorsoventral views. In early cases, the right ventricular enlargement is subtle as the ventricle hypertrophies concentrically, which changes the shape of the heart rather than the size. If right ventricular myocardial failure develops, the ventricle will dilate and appear much more enlarged.

2. The protrusion of the poststenotic dilation of the pulmonary artery may be seen, which may form part of the cranial cardiac border.

3. On the lateral view the poststenotic dilation of the pulmonary artery may be seen in the cranial mediastinum, overlying the tracheal shadow. The size of the dilation is greater the more severe the stenosis.

4. On the lateral view, the cardiac apex is displaced caudodorsally as a result of right ventricular hypertrophy.

5. The trachea is usually elevated over the right heart, but its ventral bend is preserved.

6. The pulmonary vasculature, beyond the point of bifurcation of the pulmonary artery trunk, is usually normal. In severe pulmonic stenosis, the pulmonary vessels may be small.

Ultrasonography. Patent ductus arteriosus is a difficult condition to identify without Doppler studies. The secondary changes are seen on 2-D mode. A left cranial parasternal short-axis view is the best acoustic window from which to identify the shunt, with steep dorsal angulation. The left atrium and ventricle are dilated, and the pulmonary artery is enlarged. The interventricular septum and left ventricle appear hyperdynamic, and their thicknesses are normal. Fractional shortening is usually reduced, but it may be normal or even increased. Doppler ultrasonography demonstrates a continuous turbulent flow in the pulmonary artery (Figure 3-35, D to F).
Dorsoventral View

1. On the dorsoventral view, the right heart border approaches the right thoracic wall, forming a reversed D shape.
2. The cardiac apex may be displaced toward the left side.
3. The pulmonary artery segment is enlarged and protrudes markedly cranilaterally (1 to 2 o’clock position).

Selective angiocardiography, by injection of contrast medium into the right ventricle, will outline the stenosis and demonstrate the extent of the poststenotic dilation. Nonselective angiocardiography, through a jugular vein, can also give useful information, although contrast medium in the right atrium may obscure the area of the pulmonic valve. The poststenotic dilation, however, will be seen and hypertrophy of the right ventricular free wall myocardium can usually be appreciated (see Figure 3-33, A to C).

The pulmonary artery trunk may increase in diameter as a result of increased blood flow through it. Therefore dilation of the pulmonary artery itself does
Figure 3-35, cont’d E, Patent ductus arteriosus in a dog. Right-sided, parasternal short-axis view of the main pulmonary artery. A color-flow Doppler sample volume has been placed over the pulmonary artery. Flow within the pulmonary artery is away from the transducer and is coded blue. There is a mosaic pattern of flow within the ductus arteriosus that runs parallel to the pulmonary artery. The mosaic pattern, a random mixture of all colors from the color map, indicates turbulent flow. RPA, Right pulmonary artery; PDA, patent ductus arteriosus. (See Color Plate 3-35, E.) F, Patent ductus arteriosus in a dog. This is a right-sided, parasternal short-axis view of the main pulmonary artery. A continuous-wave Doppler cursor has been placed in the pulmonary artery, distal to the pulmonic valve. The Doppler trace shows continuous flow within the pulmonary artery, which is an abnormal finding. (See Color Plate 3-35, F.) G and H, Reverse patent ductus arteriosus in a dog. G, The first image is a dorsal plane view of the caudal abdominal aorta (AO) obtained through a paralumbar window. H, A bolus of agitated colloid solution was injected into a cephalic vein while the abdominal aorta was imaged. A few seconds after injection, bubbles appeared within the abdominal aorta (arrows), seen as a marked increased in echogenicity in this second image. This indicates the presence of a right-to-left shunt, although not specifically a reverse patent ductus arteriosus.

not necessarily mean that there is a pulmonic stenosis. The differential diagnosis should include patent ductus arteriosus, tetralogy of Fallot, and heartworm disease. However, with heartworm disease, peripheral pulmonary arterial changes are usually present before the main pulmonary artery enlarges.

Ultrasonography. The pulmonic valve is located most easily on a right-sided, short-axis view with angulation toward the heart base. Thickening of the pulmonic valves with associated increased echogenicity is seen with 2-D imaging. Dilation of the pulmonary outflow tract and hypertrophy of the right ventricular wall and interventricular septum are also features. A poststenotic dilation might be identified on the short-axis view. The pulmonic valves may bulge toward the outflow tract. If there is right ventricular dilation and an increased right ventricular pressure, paradoxical septal movement usually ensues; that is, the septal movement parallels the left ventricular free wall movement. Tricuspid regurgitation is seen on Doppler studies in the later stages. Pressure gradients across the valves of the order of 50 mm Hg are considered mild, and values in excess of 100 mm Hg severe. A trivial pulmonic insufficiency jet is seen with color Doppler evaluation in most normal dogs (see Figure 3-33, D to F).
**Aortic Stenosis.** Aortic stenosis is a narrowing of the outflow tract from the left ventricle in the area of the aortic valve. It interferes with the flow of blood from the left ventricle to the aorta. It may affect the valve (valvular stenosis), the aorta (supravalvular stenosis), or the ventricular outlet (subvalvular or subaortic stenosis). Subaortic stenosis is the most common form of the condition in dogs; supravalvular stenosis occurs congenitally in cats. The narrowing is caused by a fibrocartilaginous ring. A poststenotic dilation develops in the aorta. The condition is hereditary and is more common in larger breeds such as the Newfoundland and the Boxer. Evaluation for this condition either by auscultation or echocardiography is often performed before using dogs for breeding. The Orthopedic Foundation for Animals has developed criteria for evaluating dogs but does not consider this a screening program because the diagnosis is often difficult and the disease has not been proven to be heritable in all breeds.

Affected animals frequently show no clinical signs of the condition, which is variable in severity and often mild; it may be first detected at a routine physical examination. Syncope, coughing, pulmonary edema, and sudden death in puppies have been described. A precordial thrill may be palpated on the lower third of the thorax on the left side at the fourth or fifth intercostal space. This thrill may radiate and be felt over the carotid arteries. A systolic murmur can be auscultated in the same region. The femoral artery may be absent or minimal and nonspecific. When clinical signs develop, they include exercise intolerance, coughing, and dyspnea.

**Radiologic Signs.** Radiologic signs of aortic stenosis may be absent or minimal and nonspecific. When present, they include the following:

1. There is protrusion of the poststenotic dilation into the cranial mediastinum. The cranial cardiac border bulges dorsally at the level of the aorta.
2. The caudal cardiac border is straighter than usual on the lateral view as a result of ventricular hypertrophy. Signs of hypertrophy may be minimal because of its concentric nature.
3. Mitral insufficiency may develop secondary to stenosis and ventricular hypertrophy. The result is enlargement of the left atrium, elevation of the trachea, and prominence of the pulmonary veins entering the left atrium.
4. On the dorsoventral view, the aortic arch is enlarged and bulges between the 12 and 1 o’clock positions, increasing the length of the cardiac shadow.
5. The lung fields remain normal unless myocardial failure develops, causing congestive left heart failure, in which case there may be pulmonary edema.
6. Selective angiocardiology, by injection of contrast medium into the left ventricle, outlines the area of stenosis and poststenotic dilation. Nonselective studies are less satisfactory because residual contrast medium in the right cardiac chambers and pulmonary artery may at least partially mask the lesion. However, if an adequate bolus of contrast medium is injected rapidly into the jugular vein, the result is often diagnostic (see Figure 3-34, A and B).

**Ultrasoноgraphy.** In moderate or severe cases, the site of the stenosis is identified on the parasternal long-axis view. A hyperechoic thickening or band may be seen below (subvalvular) the aortic valves or along the outflow tract. The subvalvular type is the more common. In mildly affected animals, there are usually no sonographically visible morphologic changes in the left ventricular outflow tract, aortic valve, or aorta. Valvular lesions may be seen with valvular stenosis. Supravalvular thickening can cause narrowing of the outflow tract.

There is hypertrophy of the left ventricular free wall and interventricular septum. Poststenotic dilation may be difficult to appreciate. Fractional shortening is normal or slightly increased. Fluttering of the aortic valve and midsystolic closure are often seen associated with subaortic stenosis. An M-mode study taken through the mitral valve on a cross-sectional view will reveal that instead of the leaflets being apposed in systole, the anterior (septal) leaflet is seen to move toward the interventricular septum in early systole. Pressure gradients across the aortic valve of 50 mm Hg are considered mild, and those in excess of 75 mm Hg severe (see Figure 3-34, C to E).

**Ventricular Septal Defect.** In ventricular septal defect, there is failure of closure of the interventricular septum that separates the right and left ventricles. Defects in the septum most often occur in the upper third. They are the most common congenital defects found in cats. Ventricular septal defects may be associated with other cardiac anomalies, particularly atrial septal defects.

The defect is often small, and affected animals may show no clinical signs. The condition is often detected on a routine clinical examination when a systolic murmur is heard, loudest over the right side of the sternum at the third or fourth intercostal space. A thrill may be felt at that site. Congestive heart failure may develop with its associated signs.

**Radiologic Signs.** The signs associated with ventricular septal defect will depend on the severity of the condition. The shunt is usually from left to right.

1. There is some degree of right ventricular enlargement, with increased sternal contact.
2. The left atrium and ventricle enlarge to a variable degree; changes are often minimal.
3. The pulmonary artery segment is prominent on the dorsoventral view.
4. Selective angiocardiology, by injection of contrast medium into the left ventricle, will outline the defect or show simultaneous filling of the aorta and the pulmonary artery. The right ventricle will opacify after the injection in most cases.
5. The lung fields are usually normal in appearance. Severe cases may show hypervascularity. Lung field appearance will depend on the severity of the condition.
6. The radiologic signs are variable because the shunting of blood into the right ventricle increases blood volume in the pulmonary artery, pulmonary veins, left atrium, and left ventricle, and all these structures will eventually enlarge (Figure 3-36, A to C).

Ultrasoundography. Ventricular septal defect is usually seen high in the interventricular septum just below the aortic valve. It should be identified on several imaging planes. It is best seen on a right-sided, parasternal long-axis view optimized for the aortic outflow tract. It is important not to mistake a membranous septum for a septal defect. The free edge of the septum is often thickened. A contrast echocardiogram is useful to confirm the presence of the defect; jets of anechoic blood will be seen pulsing into the right ventricle during systole. The aortic valve leaflets may prolapse into the defect. Doppler ultrasonography is the most reliable method of diagnosing a ventricular septal defect. It may also demonstrate aortic regurgitation and increased velocities across the defect (Figure 3-36, D to G).

Atrial Septal Defect. Atrial septal defect as a single entity is not common, but it may be encountered in association with other congenital defects. The majority of cases show no clinical signs because the defect often is small. Right heart failure may develop. A murmur may be heard over the pulmonic valve as a result of the high volume of blood that it must accommodate. A patent foramen ovale has no clinical significance because shunting of blood, if it does occur at all, is minimal.

Radiologic Signs. Small atrial septal defects show no radiologic signs. Significant defects may be associated with the following signs:
1. The right atrium enlarges as a result of the increased amount of blood it must accommodate because of the defect.

Continued
2. Right ventricular hypertrophy is caused by an increased amount of blood reaching the pulmonary artery.
3. The pulmonary artery trunk increases in size because of increased blood flow through it.
4. The increased blood flow results in an increase in pulmonary vascular shadows (hypervascularization).
5. Passage of a catheter into the right atrium, and through the defect—if it is large enough—into the left atrium enables contrast medium to be injected into the left atrium. Contrast medium will demonstrate the defect. Injection of contrast medium into the right ventricle may also be useful (Figure 3-37, A to D).

Ultrasonography. It is important not to mistake a septal dropout for a defect. A septal dropout occurs when a very thin membrane of tissue replaces the normal septum. It may occur at the site of the foramen ovale. The tissue is too thin to generate echoes, and a defect is perceived. It may be differentiated from a true defect by its location, but occasionally a contrast echo (bubble) study or Doppler study may have to be performed. The bubbles may pass through to the left atrium, or anechoic blood may be seen pulsing from the left to the right atrium.

Atrial septal defects occur either low (primum) or high (secundum) in the septum. With left-to-right shunting, the right atrium enlarges. Subsequently, enlargement of the right ventricle occurs, and tricuspid valve prolapse may be seen. If the defect is sited low in the septum, there may be distortion of the left and right atrioventricular valves, and defects in the interventricular and interatrial septa may occur. Paradoxic septal movement may be seen on the M-mode
Atrial septal defect. A to D, A 10-month-old Samoyed bitch had ascites, labored breathing, and a reduced appetite for approximately 1 week. A loud systolic murmur was heard on the left side at approximately the middle of the fourth intercostal space. A and B, Lateral and dorsoventral radiographs show right heart enlargement. The caudal vena cava is directed craniodorsally. The left heart appears large on the dorsoventral view, and its apex approaches the left thoracic wall. This is caused by displacement by the enlarged right heart. An interlobar fissure is seen on the right side. C, After injection of contrast medium into the right ventricle (RV), the ventricle was seen to be displaced caudally with an unopacified mass cranial to it. The pulmonary arteries opacified normally. As the contrast material reached the left atrium (LA), the mass cranial to the right ventricle opacified. This proved to be the right atrium (RA), which is grossly distended. D, A selective injection into the right atrium (RA) shows the full extent of the dilation. A little contrast material has reached the right ventricle, and there is reflux into the cranial and caudal venae cavae (CVC). At autopsy there was an atrial septal defect. Atrial septal defect as a single entity is rare. It is more usually associated with aortic or pulmonic stenosis.

Tetralogy of Fallot. The tetralogy of Fallot is a combination of cardiovascular anomalies: pulmonic stenosis, right ventricular hypertrophy, high ventricular septal defect, and overriding of the aorta, which allows the aorta to receive blood from both right and left ventricles.

Most animals show clinical signs within the first year of life, but those with mild changes may show no signs. More severely affected animals show dyspnea, low exercise tolerance, retarded growth, and cyanosis, which become progressively worse with age. A holosystolic murmur may be present. Some animals show cyanosis at rest, others only after exercise.
Mitral Valve Dysplasia. Congenital atrioventricular valve lesions
(septal movement is seen on the M-mode modality thickening of the interventricular septum. Paradoxic tricus- 
ticles. The right ventricle is enlarged, and there is defect, and the aorta overrides the right and left ven-
tricular septal defect is seen as an echolucent 

Radiologic Signs
1. There is a mild degree of right ventricular enlargement.
2. The pulmonary artery trunk is often hypoplastic, and as a result the expected poststenotic dilation is not always seen. The pulmonary artery may fail to form part of the cardiac shadow on the dorsoventral view, giving a shallow appearance to the cardiac edge in that region.
3. The aortic arch is elongated and enlarged. The left ventricle appears normal or even reduced in size. The left atrium is small because of reduced venous return from the lungs.
4. On the dorsoventral view, the aorta extends well beyond the cranial border of the heart.
5. The lung fields appear excessively radiolucent because of a reduction in pulmonary vascular markings (hypovascularization) and hyperventilation. The vessels that are seen are smaller than usual (Figure 3-38, A and B).

Ultrasonography. On 2-D ultrasonography, the ventricular septal defect is seen as an echolucent defect, and the aorta overrides the right and left ventricles. The right ventricle is enlarged, and there is thickening of the interventricular septum. Paradoxical septal movement is seen on the M-mode modality (Figure 3-38, C).

Congenital Atrioventricular Valve Lesions Mitral Valve Dysplasia. Congenital mitral valve dysplasia has been described in both dogs and cats. It is most often encountered in the Great Dane, Bull Terrier, and German Shepherd and is one of the most common congenital defects in cats. In congenital mitral valve dysplasia, one or both mitral valve leaflets are shortened and club shaped and do not move or meet normally. The radiologic signs are those of mitral insufficiency. Mitral valve dysplasia lesions are often severe, and radiologic changes and congestive cardiac failure occur at an early age (see p. 309).

Tricuspid Valve Dysplasia. Congenital tricuspid anomalies are referred to as tricuspid dysplasia. The radiologic signs are those seen with tricuspid valve insufficiency. These anomalies are more common in cats and, as with mitral valve defects, are usually severe and result in early onset of cardiac failure.

Acquired Cardiac Disease Pericardial Effusion (Hydropericardium). Marked pericardial effusion causes the cardiac shadow to enlarge. Small effusions may be difficult to detect with certainty. Cardiac tamponade is compression of the right atrium and sometimes right ventricle by the fluid, which prevents filling of these chambers and causes right heart failure. The fluid may be blood, inflammatory exudate, or a noninflammatory transudate. Pericardial effusion may also be associated with neoplasia, particularly heart base tumors. In German Shepherds with pericardial effusion, hemangiosarcoma is commonly encountered, though it is not exclusive to this breed. Idiopathic effusions are seen in the Golden Retriever and the Saint Bernard. Hemorrhage may also occur with rupture of the left atrium in dogs with severe left atrial enlargement caused by mitral valve endocardiosis.

Clinically, in the acute form, such as with pericardial hemorrhage, there is acute circulatory collapse with extreme weakness or shock. In chronic cases there are signs of right heart failure, including weakness, exercise intolerance, and pleural or peritoneal effusions. This is the most common presentation. The diagnostic signs include muffled heart sounds, engorged veins, and a weak, rapid arterial pulse.

Radiologic Signs
1. The cardiac shadow enlarges and becomes rounded in outline on both the lateral and dorsoventral views. It is usually sharply defined. The degree of enlargement may be quite mild in acute cases because the pericardial sac does not have time to stretch to accommodate the fluid.
2. Individual prominences on the cardiac shadow are lost.

Figure 3-37, cont’d E. This puppy presented for vaccination when a loud murmur was auscultated. A large interatrial septal defect (arrow) is seen on this right-sided, parasternal long-axis view. Diagnosis: interatrial septal defect. ra, Right atrium; la, left atrium; lv, left ventricle; rv, right ventricle. F. This is a right-sided, parasternal long-axis view with a color-flow Doppler sample volume placed over the interatrial septum. A defect is seen in the interatrial septum (arrows). A large jet (coded red) is seen passing from the left atrium (LA) to the right atrium (RA). LV, Left ventricle; RV, right ventricle. (See Color Plate 3-37, F.)
3. The cardiac outline may appear flattened where it makes contact with the thoracic wall.
4. The trachea is elevated.
5. The caudal vena cava is dilated. Pleural effusion may be seen.
6. The pulmonary vasculature is usually clearly defined and may be small because of reduced right heart output if there is tamponade.
7. There may be associated hepatomegaly or ascites (Figure 3-39, A and B).

Ultrasonography. Even a small volume of pericardial fluid can be seen. The fluid is identified as a predominantly anechoic area surrounding the heart and separating it from the pericardium. The pericardium is identified as a hyperechoic curved rim and represents the interface between the pericardium and the lungs. The heart oscillates within the fluid. If there is a cellular content in the fluid, such as blood, the fluid may become more echogenic. If the condition is chronic, fibrin tags can be seen moving...
Figure 3-39 Pericardial effusion (hydropericardium). A and B, The heart is globular in outline and on the dorsoventral view appears to fill almost the entire thorax. The trachea is elevated. An interlobar fissure (arrow) is seen on the left side through the cardiac silhouette.

The cause of the pericardial effusion might not be identified, but the cardiac margin should be carefully examined in all planes for the presence of neoplastic masses. They are quite variable in appearance and echogenicity. The area of the heart base, right atrial appendage, and aortic outflow tract should be particularly examined. Distinguishing a tumor from a clot can be difficult; however, a clot will change appearance within a few days. Neoplastic masses include hemangiomas, hemangiosarcomas, and heart base tumors. Sometimes a tumor may not be demonstrated on the ultrasonographic study (Figure 3-39, C to E).

Pneumopericardium, that is, air in the pericardial sac, may be seen after surgery or as a result of trauma. The pericardium is outlined by the air within the pericardial sac and the radiolucency of the adjacent lung field (Figure 3-39, F).

**Mitral Endocardiosis.** Mitral endocardiosis is the most common acquired cardiac abnormality in middle-aged and older dogs, particularly in small and toy breeds. It is also seen in cats. Myxomatous degeneration of the valve leaflets results in deformity and incompetence. As a result of incompetence of the mitral valve complex, blood is regurgitated from the left ventricle into the left atrium at systole.

The clinical signs include coughing, initially at night. There are varying degrees of respiratory distress, particularly after exercise, and most patients show these signs before radiologic signs of heart failure. The disease is progressive and eventually causes pulmonary edema. Advanced cases, in the absence of treatment, will show pleural effusion, hepatomegaly, and ascites caused by a failing right heart. Mitral murmurs are heard, with maximal intensity over the fifth or sixth intercostal space on the left side just below the costochondral junction. There may be bouts of cardiac failure followed by periods of apparent recovery over time.

**Radiologic Signs**

**Lateral View**

1. The left atrium enlarges, causing the trachea to be elevated, with obliteration of its terminal bend. The left main stem bronchus is elevated.

2. The enlarged atrium extends dorsally, separating the left and right main stem bronchi, which may be compressed, particularly the left. The atrium may extend into the caudal lung fields.
3. The left ventricular border becomes more upright as a result of ventricular enlargement. The ventricular border approaches, or may be overlapped by, the diaphragm.
4. The caudal vena cava becomes prominent and courses craniodorsally.
5. Right ventricular enlargement is common in the advanced stages, and the heart size is increased in the craniocaudal diameter, with increased sternal contact.
6. As the condition progresses, the pulmonary veins entering the left atrium become congested and enlarged.

7. The pulmonary veins are larger than the pulmonary arteries, best seen in the cranial thorax.

**Dorsoventral View**
1. The left ventricular border is rounded and approaches the left thoracic wall. The cardiac apex is rounded and displaced to the right.
2. The enlarged left atrium spreads the main stem bronchi apart.
3. The edge of the enlarged atrium is sometimes seen as a shadow paralleling the right ventricular border and sometimes paralleling part of the left border within or beyond the cardiac outline.
4. The opaque left atrium may be seen within the cardiac shadow.

5. The left auricle may project well beyond the middle region of the left cardiac border when there is severe left atrial enlargement.

On both views, the pulmonary vessels frequently have a hazy appearance because of interstitial edema. The veins may be larger than the arteries. If alveolar edema develops, fluffy infiltrates and air bronchograms are seen. In the dog, the edema spreads out symmetrically from the hilus and affects the caudal lobes first and more severely. In animals with acute-onset failure, there may be edema only in the right caudal lung lobe or rarely in the left caudal lung lobe. Edema may not be symmetric in the cat. In most cases, the disease is slowly progressive, and animals may survive for years with medical management.

If there is severe left atrial enlargement, the left atrial wall may split, resulting in hemopericardium. This condition gives the heart a globular appearance as in hydropericardium. The enlarged left atrium can still be identified on the lateral view. The extent of the signs varies with the degree of severity of the condition (Figure 3-40, A, B, H, I, N, and O).

Ultrasonography. The left atrium is usually enlarged, and the interatrial septum may be displaced toward the right side. The left ventricle is enlarged and the
left ventricular wall may be normal or become thin in advanced cases. The papillary muscles may be prominent. Endocardiosis causes thickened extensions on the valve leaflets. The leaflets may prolapse into the left atrium. Rupture of the chordae tendineae may be seen. Fractional shortening is increased initially as the heart attempts to increase cardiac output. The LA/AO ratio is abnormal. In late-stage disease, myocardial failure develops and cardiac contractility decreases (Figure 3-40, C to G, J to L, Q).

**Tricuspid Endocardiosis.** Tricuspid endocardiosis is most often concurrent with mitral endocardiosis. It is not commonly encountered as a single entity. Tricuspid endocardiosis may have no clinical signs and be detected only during a routine examination. If clinical signs develop as a result of right heart incompetence, they include respiratory distress when there is a concurrent mitral incompetence. Other clinical signs are associated with a failing right heart and include distention of the abdomen, weight loss, anorexia, vomiting, and diarrhea. A systolic murmur is detected on the right side from the third to the fifth intercostal spaces.

**Radiologic Signs.** Radiologically, it may be difficult to distinguish tricuspid insufficiency from mitral insufficiency. The following signs may be observed:
1. If right atrial enlargement is marked, the trachea is elevated cranial to the carina and the right auricle may bulge the cardiac border craniodorsally.
2. The caudal vena cava is more radiopaque than normal and may be seen within the cardiac shadow.
3. The right ventricle is enlarged, resulting in increased sternal contact.
4. On the dorsoventral view, the enlarged right atrium causes a bulge of the right cardiac border cranilaterally, and the caudal vena cava may be displaced to the right before it enters the atrium. There is a reversed D sign.

**Figure 3-40, cont’d E,** This dog has left ventricular dilation (LV). The M-mode cursor has been located across the mitral valve leaflets (2-D upper image). There is an increased E point septal separation (EPSS), which is the distance between the septal mitral valve leaflet (long white arrow) and the interventricular septum (IVS). Diagnosis: left ventricular enlargement. PVW, Left ventricular free wall; short arrows, mural leaflet of mitral valve. F and G, Color-flow Doppler sonograms from the right parasternal (F) and left parasternal (G) apical four-chamber locations. These two cases show mitral valve regurgitation, which is seen as a green jet extending into the left atrium during systole. Diagnosis: mitral valve insufficiency. (See Color Plates 3-40, F and G.)

Continued
Figure 3-40, cont’d  H to L, A 5-year-old Cavalier King Charles Spaniel showed dyspnea and weight loss. Lateral (H) and dorsoventral (I) views show cardiomegaly. On the lateral view, there is elevation of the mainstem bronchi and a mild left atrial enlargement. Right-sided, parasternal long-axis (J and K) and short-axis (L) views were obtained. J, A huge left atrium with displacement of the interatrial septum (IAS) to the right and prolapse of the mitral valve (MV) into the left atrium (LA). K, Gross thickening of the mitral valve leaflets (arrows). RA, Right atrium; RV, right ventricle; LV, left ventricle; MV, mitral valve; IAS, interatrial septum; AO, aorta. L, The short-axis view shows the thickened cusp of the mitral valve (arrow). MV, Mitral valve; LV, left ventricle. M, This 2-year-old dog presented with ascites. Echocardiography demonstrates a marked enlargement of the right atrium. The tricuspid valve (arrow) is thickened. ra, Right atrium; rv, right ventricle; a, aortic outflow tract. Diagnosis: tricuspid valve thickening.
5. Signs of right heart failure including hepatomegaly, and peritoneal and pleural effusions are seen in advanced cases.

When the condition coexists with mitral valve endocardiosis, the radiologic picture can be difficult to evaluate because both sides of the heart undergo profound changes. The diagnosis can be confirmed by selective angiography, but ultrasound is more often used. Injection of contrast medium into the right ventricle will demonstrate regurgitation of the medium into the right atrium.

Ultrasonography. The changes associated with tricuspid disease are similar to those described for the mitral valve, except that the interatrial septum is displaced to the left side (Figure 3-40, M and P).

**Bacterial Valvular Endocarditis.** Bacterial endocarditis is an uncommon condition in dogs and very rare in cats. Bacteremia results in colonization of the endocardium, usually at one of the heart valves. Endocarditis most often affects the mitral or aortic valve leaflets. Affected animals are usually febrile and
may have a history of a waxing and waning illness. Distribution of septic emboli through the circulation can result in lesions and signs affecting many organs. In chronic cases, damage to the valves may result in severe incompetence, and the clinical presentation is complicated by signs of congestive cardiac failure. Treatment is difficult, and even if it is successful the damage to the valve leaflets is permanent, and heart failure may persist or develop later.

Ultrasonography. The sonographic features of mitral valve endocarditis are similar to endocardiosis, and the diagnosis is based in part on clinical signs. Similar lesions may be seen on the aortic valve leaflets, but these lesions are specific to bacterial endocarditis. Lesions of the tricuspid and pulmonic valves are very rare. The valve leaflets are thickened, nodular, and hyperechoic. They may be seen to close incompletely. The valves may have small tags attached to them that flap during the cardiac cycle. The vegetations on the mitral valves may prolapse into the left atrium. Aortic valve endocarditis causes moderate or severe aortic insufficiency. If the lesion is large, there may also be dynamic aortic stenosis because the vegetation as acts as a ball valve (Figure 3-34, E).

Cardiomyopathy. Cardiomyopathy refers to an abnormality of the myocardium of unknown cause (primary) or as a sequel to systemic disease (secondary). Secondary cardiomyopathy may have infectious, metabolic, toxic, infiltrative, or endocrine causes. Idiopathic cardiomyopathy means that no specific pathologic process can be identified as the cause of the myocardial abnormality. Cardiomyopathy may be dilated (congestive), hypertrophic, or restrictive because of fibrosis. Affected animals show a generalized cardiomegaly with varying degrees of pulmonary edema, ascites, and hepatomegaly. The hypertrophic and restrictive forms are very rare in dogs but common in cats. Radiologic signs of cardiac enlargement may not be obvious with these two types. It is difficult to distinguish between the different types radiographically. Definitive diagnosis depends on echocardiography.

Dilated Cardiomyopathy. Dilated cardiomyopathy is seen in large- and giant-breed dogs. Doberman Pinschers, Great Danes, and Newfoundlands are over-represented. There is usually an acute onset of signs of cardiac failure. In some dogs with paracardial failure, there may only be mild left-sided cardiomegaly. In many dogs with dilated cardiomyopathy, the left atrium is moderately or severely enlarged and projects dorsally from the dorsocaudal margin of the heart. Left ventricular enlargement, which may be quite severe, is present in the later stages. Perihilar pulmonary edema and venous congestion are also evident. The edema becomes more widespread as the condition progresses (Figure 3-41, A and B).

Ultrasonography. Dilated cardiomyopathy is more common in dogs than in cats. The left ventricular lumen is enlarged. The left atrium is enlarged to a variable degree depending on the severity and chronicity of the condition. The interventricular septum and left ventricular free wall are thinner than normal. Fractional shortening is reduced. If there is compensatory hypertrophy, the left ventricular free wall and interventricular septal measurements may lie within normal ranges. Doppler examination may indicate reduced pulmonic and aortic velocities. There is often incompetence of the mitral valve because the valve ring is stretched as the ventricle dilates and the valve leaflets no longer meet. There is an increased LA/AO ratio because of the enlarged left atrium (Figure 3-41, C to I, L).

Hypertrophic Cardiomyopathy. Idiopathic hypertrophic cardiomyopathy is common in cats and rare in dogs. In the dog with hypertrophic cardiomyopathy, the cardiac silhouette may lie within normal parameters. The left atrium and ventricle may be slightly enlarged, with pulmonary edema evident in the perihilar region.

Ultrasonography. The left ventricular lumen appears reduced in size because of the marked thickening of the interventricular septum and left ventricular free wall. This thickening may be asymmetric. The left atrium is usually enlarged. Echogenic masses in the lumen may represent blood clots. Fractional shortening may be normal or increased (Figure 3-41, J and K).

Feline cardiomyopathy. Cardiomyopathy represents the most common type of acquired cardiac disease in cats. The disease is classified according to both morphologic and functional criteria. Five types are recognized: hypertrophic, restricted, dilated, arrhythmogenic right ventricular, and unclassified.

Hypertrophic cardiomyopathy is characterized by thickening of the myocardium of the left ventricle, right ventricle, or both. The entire circumference of the left ventricle may be affected. The hypertrophy of the myocardium is concentric, and the lumen of the left ventricle is reduced. However, in many cases the myocardial hypertrophy is nonuniform and may affect the left ventricular free wall only or the interventricular septum only, or there may be focal hypertrophy of part of the interventricular septum or free wall. The myocardial changes are usually accompanied by left atrial enlargement.

Restrictive cardiomyopathy is characterized by loss of compliance of the myocardium, which results in diastolic dysfunction and left-sided cardiac failure. The myocardium of the left ventricle is usually normal in thickness but may be mildly hypertrophied. The loss of compliance in the left ventricle compromises left ventricular filling because the ventricle does not relax normally. This causes backup of blood and left atrial enlargement.

Dilated cardiomyopathy is now a rare clinical entity. It has been shown to occur as a result of deficiency of the amino acid taurine. Once this was recognized, the formulation of commercial diets was altered, and
Figure 3-41 A to L, Canine cardiomyopathy. A and B, This dog presented with a history of congestive heart failure. A, The trachea is displaced dorsally. The cardiac silhouette is taller and wider than normal. There is a widespread, slightly asymmetric alveolar infiltrate in the lung fields, particularly in the caudodorsal lung fields. B, The dorsoventral view shows that the pulmonary infiltrate is more marked on the right side, with border effacement with the heart and diaphragm. The heart is wide and occupies more than two thirds of the thoracic width. C to E, This dog was presented with an increased resting respiratory rate and exercise intolerance. These are right-sided, parasternal long-axis sonograms. C, Pericardial (PE FL) and pleural fluid (PF) are seen on either side of the pericardium (P). D, Further cranially, there is generalized cardiac enlargement and pericardial fluid (pe) within the pericardial sac. E, The M-mode study shows a marked enlargement of the left ventricular lumen. The fractional shortening was 18%. Diagnosis: dilated cardiomyopathy. rv, Right ventricle; lv, left ventricle; ra, right atrium; la, left atrium; ivs, interventricular septum; w, right ventricular wall; pvw, left posterior ventricular wall; f, pericardial fluid. F, This 3½-year-old Irish Wolfhound had atrial fibrillation. A right-sided, parasternal long-axis echocardiogram demonstrates an enlarged left atrium (LA). The interatrial septum lying between the right atrium (RA) and left atrium is displaced toward the right side. Diagnosis: dilated cardiomyopathy. rv, Right ventricle; lv, left ventricle.

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Figure 3-41, cont’d  G and H, A 1-year-old Saint Bernard had a history of exercise intolerance. The short-axis views of diastolic (G) and systolic (H) frames show little difference in the size of the left ventricle, suggesting poor cardiac contractility. The fractional shortening was 5.59%. I, This is a duplex ultrasound image of a dog with dilated cardiomyopathy. It shows the 2-D image (top) indicating the position of alignment of the M-mode cursor through the left ventricle (LV) to obtain an M-mode image. The interventricular septum (IVS) is contracting, but the left ventricular free wall (PVW) is hardly moving. The left ventricular lumen is enlarged. The fractional shortening was 15%. J and K, This 2-year-old Boxer presented with collapse after exertion. Thoracic radiographs were unremarkable. Right-sided, parasternal short-axis echocardiograms were obtained. Short-axis diastolic (K) and systolic (L) images taken at the level of the papillary muscles show that the left ventricular lumen is grossly narrowed and the myocardium surrounding the left ventricular lumen is markedly thickened. Diagnosis: hypertrophic cardiomyopathy. w, Left ventricular wall; l, left ventricular lumen; p, pericardium; i, interventricular septum; r, right ventricle. L, This dog had dilated cardiomyopathy. This duplex image shows the M-mode cursor paced across the mitral valves in the left ventricle on this right-sided, parasternal, cross-sectional 2-D image (top). The corresponding M-mode trace shows that the distance (double-headed arrow, EPSS) between the E point of the septal leaflet of the mitral valve in the left ventricle and the interventricular septum is increased.
Taurine deficiency cardiomyopathy is now only seen when unusual or homemade diets are fed. Dilated cardiomyopathy is encountered sporadically in cats with normal plasma levels of taurine. The etiology of these cases has not been determined. Dilated cardiomyopathy is characterized by dilation of the left ventricle, right ventricle, or both and left atrial enlargement.

Arrhythmogenic right ventricular cardiomyopathy is characterized by dilation of the right ventricle, which has a thin myocardium and markedly reduced contractility. The right atrium is enlarged. Usually the left ventricle and left atrium are spared.

Some cases of cardiomyopathy in cats have features that do not fit the classifications just outlined or may have features from several categories. These are considered unclassified cardiomyopathies.

Normal Radiographic Appearance. Unlike dogs, there is relatively little morphologic variation among cats, which simplifies assessment of the heart. On a lateral radiograph, the heart appears lemon shaped and is tilted cranially. When measuring from cranial to caudal, this tilt must be corrected for by drawing an imaginary line from the heart base to the apex and measuring perpendicular to this line. The normal heart measures 2 to 2.5 intercostal spaces in width. It is especially important to compensate for the tilt of the heart in geriatric patients because the degree of tilt gradually increases with age. On the ventrodorsal radiograph, the heart occupies approximately half the width of the thorax. The cardiac apex is usually located just left of the midline. The normal pulmonary vessels are quite small, and on good-quality radiographs they may create a herringbone-type appearance in the caudal lung lobes. Both the arteries and veins should measure less than the width of the proximal third of the fourth rib (cranial lobe) or ninth rib (caudal lobe) where they cross these structures (see Figure 3-6, I and J).

Radiologic Features of Cardiomyopathy. Because myocardial hypertrophy is concentric, it does not alter the size or shape of the left ventricle on radiographs. Therefore normal thoracic radiographs do not exclude the possibility of significant myocardial disease in cats. Unless there is moderate or severe left atrial enlargement, there will be no radiologic abnormalities. The enlarged left atrium is seen as a round bulge at the caudodorsal aspect of the cardiac silhouette on the lateral radiograph. This alters the normal shape of the heart and may make it appear somewhat kidney shaped. It causes dorsal displacement of the trachea and caudal lobar bronchi. If left atrial enlargement is severe, enlargement of the left atrial appendage results in a bulge from the left lateral border of the heart on the ventrodorsal view. There may also be enlargement of the right atrium. This causes a bulge of the right cranial aspect of the heart on the ventrodorsal view. If both the right atrium and left atrial appendages are enlarged, the two bulges create the so-called “Valentine heart” appearance on the ventrodorsal view.

Moderate or severe enlargement of the left atrium also results in displacement of the cardiac apex, which will lie to the right of the midline on the ventrodorsal view. The radiologic appearance of restrictive and unclassified cardiomyopathy is similar to that of hypertrophic cardiomyopathy (Figure 3-42, A to E).

Arrhythmogenic right ventricular cardiomyopathy results in moderate to severe dilation of the right ventricle. On the lateral radiograph, the heart appears rounded and is wider than normal from cranial to caudal. On the ventrodorsal radiograph, the right cardiac border is rounded and bulges toward the right thoracic wall.

Dilated cardiomyopathy causes moderate or severe enlargement of both the left ventricle and the left atrium. There may also be right-sided cardiac enlargement. On radiographs, there is generalized enlargement of the heart, which appears somewhat rounded on both projections (Figure 3-42, M and N).

Cardiomyopathy and Heart Failure. Left-sided cardiac failure occurs when the capacity of the left atrium to dilate has been exceeded. The earliest radiologic sign of left-sided heart failure is pulmonary venous congestion. This is difficult to recognize in the cat. Frequently only the hilar segment of the vein is affected, and if the vein is measured as it crosses the fourth or ninth rib, it will measure within the normal range. Cardiogenic pulmonary edema has a variable appearance in cats. Edema may occur first in the hilar region of the left and right caudal lung lobes and then extend to the periphery as failure progresses, similar to dogs with mitral endocardiosis. However, many cats present with rapid onset of severe signs of cardiac decompression. In such cases, the cardiogenic pulmonary edema has a random or patchy distribution or may be present in all lung lobes. Edema, if early, appears as an unstructured interstitial pattern that blurs or partly obscures the pulmonary vessels and the heart if the affected lung is in contact with the heart. As failure progresses, an alveolar pattern develops (Figure 3-42, C1 and D).

Some patients present with signs of right-sided cardiac failure, although most of the changes affect the left side of the heart. There may be a moderate or large volume of pleural fluid, which obscures the outline of the heart and diaphragm. Multiple pleural fissure lines are seen, and the lung lobe borders are retracted from the thoracic wall. Concurrent left- and right-sided cardiac failure is common in cats, and there is radiologic evidence of both cardiogenic pulmonary edema and pleural fluid (Figure 3-42, C and C1).

Echocardiography of Feline Myocardial Disease

Hypertrophic Cardiomyopathy. Hypertrophy of the interventricular septum and left ventricular free wall may be appreciated on both B-mode and M-mode imaging of the heart. The normal interventricular septum and left ventricular free wall measure less than 6 mm in thickness in most patients. If there is severe hypertrophy of the myocardium, the left ventricular lumen may appear obliterated. In some patients, hypertrophy may be confined to a segment of the interventricular septum or left ventricular free wall.
Figure 3-42  Feline cardiomyopathy. A and B, This cat has hypertrophic cardiomyopathy. There is severe cardiomegaly with gross enlargement of the left atrium (arrows) between the 1 and 3 o’clock positions and marked dilation of the left atrial appendage; this gives the so-called “Valentine heart” shape to the heart on the dorsoventral view. The cardiac apex is displaced just right of midline. There is no evidence of edema or pleural fluid. C, Hypertrophic cardiomyopathy and cardiac failure in a cat. The outline of the heart and the cupola of the diaphragm are obscured by increased soft tissue opacity. The cranial lung lobes are retracted caudally. The dorsal borders of the caudal lung lobes are displaced ventrally. These findings indicate the presence of a moderate volume of pleural fluid, which precludes evaluation of the heart. Ultrasonography confirmed the diagnosis. Congestive cardiac failure in hypertrophic cardiomyopathy may cause pleural effusion, pulmonary edema, or a combination of both. C1, Hypertrophic cardiomyopathy and cardiac failure in a cat. There is severe pulmonary edema completely obscuring the heart and diaphragm. A small volume of pleural fluid is also seen along the right side of the thorax. C2, Hypertrophic cardiomyopathy and cardiac failure in a cat. This is a left-sided, parasternal long-axis sonogram. The left atrium (arrowhead) is severely enlarged. Fluid in the pleural space (arrows) surrounds the heart (long arrow, left ventricle).
Figure 3-42, cont'd D1 and D2, This is an adult cat. The cardiac silhouette is enlarged, and the apex is displaced to the left. The tracheal bifurcation is displaced dorsally, indicating left atrial enlargement. There is a widespread pulmonary infiltration with air bronchograms obscuring the diaphragmatic outline. Diagnosis: pulmonary edema from congestive heart failure resulting from hypertrophic cardiomyopathy. D3, In this case the dorsoventral view shows the “Valentine heart” shape from an enlargement of both left and right atria. A small volume of pleural fluid is present (arrows). E and E1, Feline hypertrophic cardiomyopathy. Right lateral (E) and ventrodorsal (E1) projections of the thorax. The heart is tilted slightly cranially. The cardiac silhouette is moderately increased in length. A round bulge is seen at the caudodorsal aspect of the heart (arrow). There is dorsal displacement of the caudal lobar bronchi. This indicates moderate enlargement of the left atrium.

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Figure 3-42, cont’d  F to J, Hypertrophic cardiomyopathy in a cat.  F, This is a right-sided, parasternal short-axis view of the aorta and left atrium (LA). There is severe enlargement of the left atrium. Distal to the aorta (AO, arrow) and to the right, there is also dilation of the left atrial appendage.  G, This is a short-axis, right-sided parasternal view of the left and right ventricles. The image was obtained at end diastole. There is moderate to severe thickening of the left intraventricular septum (medium arrow), which measures slightly greater than 8 mm in thickness. The left ventricular free wall (long arrow) measures approximately 6 mm in thickness, which is at the upper limit of the normal range. The hypoechoic band (short arrows) between the transducer the pericardium of the right ventricular free wall in the near field is fluid within the pleural space.  H, An M-mode trace of the aorta (AO) and left atrium (LA) was obtained with a right parasternal window. There is severe enlargement of the left atrium. A normal left atrium measures between 1 and 1.5 times the width of the root of the aorta.  I, Right-sided, parasternal, long-axis, four-chamber view; moderate to severe hypertrophy of the interventricular septum is present. There is also moderate hypertrophy of the left ventricular free wall. A color Doppler sample volume is in place over the mitral valve. A small regurgitant jet lesion is noted. There is moderate enlargement of the left atrium in this view.  LA, Left atrium; LV, left ventricular; RA, right atrium; MI, mitral insufficiency. (See Color Plate 3-42, I.)  J, This duplex image shows an M-mode trace obtained by using a right-sided, parasternal short-axis view. There is severe hypertrophy of the interventricular septum and left ventricular free wall. In the B-mode reference image seen in the top part of the image, there is almost complete obliteration of the left ventricular lumen at end systole.  RV, Right ventricle; LV, left ventricle; IVS, interventricular septum; LVFW, left ventricular free wall.  J2, Aortic embolus in a cat. This cat had hypertrophic cardiomyopathy and presented with acute-onset pelvic limb paresis. A slightly oblique sagittal ultrasound image of the caudal abdominal aorta shows an echogenic thrombus, indicated by the cursors, within the lumen of the aorta. Color-flow Doppler evaluation shows only limited flow around the periphery of the thrombus and flow within one of the lumbar arterial branches. (See Color Plate 3-42, J2.)
Hypertrophic obstructive cardiomyopathy. There is focal hypertrophy of the proximal aspect of the intraventricular septum of the left ventricular outflow tract. This causes turbulence in the left ventricular outflow tract, which pulls the septal leaflet of the mitral valve toward the septum in systole. (See Color Plates 3-42, K and L) K, In the first right-sided, parasternal long-axis view, there is moderate to severe hypertrophy of both the intraventricular septum and left ventricular free wall. The interventricular septum bulges (arrow) into the left ventricular outflow tract. A color Doppler sample volume was placed at the left ventricular outflow tract and mitral valve. A large regurgitant jet is seen within the left atrium (LA) because anterior displacement of the septal leaflet toward the septum during systole results in mitral incompetence (MI). AO, Aorta. L, The second image was obtained at a slightly more cranial location and is a view of the left ventricular outflow tract (LVOT). Color Doppler interrogation shows a mosaic pattern of flow within the left ventricular outflow tract indicative of turbulence; anterior septal motion of the mitral valve leaflet causes a dynamic obstruction of the left ventricular outflow tract. LA, Left atrium; LV, left ventricle. M and N, Dilated cardiomyopathy in a cat. M, A right-sided lateral radiograph of the thorax demonstrates the presence of a moderate volume of pleural effusion. This is evidenced by caudal displacement of the apical margin of both the left and right cranial lung lobes. The outline of the heart and the cupola of the diaphragm are partially obscured. There is also ventral displacement of the caudodorsal lung lobe borders by fluid opacity. A small, poorly defined mass lesion is present within a cranial lung lobe superimposed on the costochondral junction of the fourth rib. This is unrelated to the cardiac disease, and a definitive diagnosis was not obtained. N, On the ventrodorsal view, the pleural fluid and pulmonary changes largely obscure the outline of the heart. This patient has severe cardiomegaly with left atrial enlargement, interstitial cardiogenic pulmonary edema, and a moderate volume of pleural effusion.

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Figure 3-42, cont’d O1 to O4, Dilated cardiomyopathy in a cat. O1, The right-sided, parasternal, long-axis, four-chamber view demonstrates moderate dilation of the left ventricle. The apex of the ventricle is rounded. O2, A right-sided parasternal short-axis view of the left ventricle demonstrates severe dilation of the left ventricular lumen. The interventricular septum is thin, measuring approximately 2 to 3 mm in thickness. The left ventricular free wall measurement is also thin. O3, The M-mode trace of the left ventricle (LV) shows severe dilation of the left ventricular lumen. The excursion of the left ventricular free wall is markedly reduced. Cursors, interventricular septum; RV, right ventricle. O4, This an apical four-chamber view from the right-sided parasternal position. A color Doppler sample volume has been placed at the level of the mitral valve, and there is a small incompetence or regurgitant jet. RA, Right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; MI, mitral insufficiency. (See Color Plate 3-42, O.) P and Q, Dilated cardiomyopathy in a cat. P, This right-sided, parasternal short-axis view at the level of the aortic valve (arrow) and left atrium shows severe enlargement of the left atrium. The width of the atrium is approximately 3 to 4 times the width of the aortic valve. RV, Right ventricle; LV, left ventricle; RA, right atrium; Ao, aorta. Q, On the left-sided, parasternal, long-axis, four-chamber view, the left ventricle is dilated. The apex of the ventricle is rounded. The full extent of the left atrial enlargement is not evident on this view. A color Doppler sample volume placed over the mitral valve shows the presence of a small regurgitant or incompetent jet. (See Color Plate 3-42, Q.)
Figure 3-42, cont'd R to U, Arrhythmogenic right ventricular cardiomyopathy in a cat. R, On the lateral radiograph, the heart is increased in width and is taller than normal, causing dorsal displacement of the trachea. There is severe widening of the caudal vena cava. Indistinct, increased soft tissue opacity is present in the cranial thorax, which partly obscures the cranial cardiac border. S, On the ventrodorsal view, there is severe enlargement of the heart that extends almost to the left thoracic wall. The cardiac apex is displaced to the left. The right middle lung lobe is retracted slightly medially, and a small volume of fluid is present between the lateral border of this lung lobe and the thoracic wall. There is mild medial displacement of the lateral border of the left caudal lung lobe. These findings indicate the presence of a small to moderate volume of pleural fluid. T, A right-sided, parasternal, long-axis, four-chamber view of the heart shows severe dilation of the right atrium (RA), right ventricle (RV), and left ventricle (LV). There is mild to moderate enlargement of the left atrium (LA). U, A right-sided, parasternal short-axis B-mode image shows severe dilation of the right ventricle (RV), which fills the near field. This view was obtained at the level of the mitral valves (MV). There is also dilation of the left ventricle (LV), and both the interventricular septum and the left ventricular free wall appear thin. V, Arrhythmogenic right ventricular cardiomyopathy in a cat. An M-mode trace, obtained from a right-sided parasternal short-axis view, shows dilation of both the left and right ventricles. The trace was obtained at the level of the mitral valve. The E point septal separation measurement (between cursors) is greatly increased. LV, Left ventricle; RV, right ventricle.

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and may be easiest to appreciate on B-mode images (Figure 3-42, F, G, I, and J). There may be anterior motion of the septal leaflet of the mitral valve during systole. This results in a dynamic obstruction of the left ventricular outflow tract. The abnormal motion of the septal leaflet of the mitral valve is best demonstrated by M-mode imaging. Doppler evaluation of the left ventricular outflow tract reveals abrupt termination of left ventricular ejection and increased blood flow velocity. This pattern of abnormalities is termed hypertrophic obstructive cardiomyopathy (Figure 3-42, K and L). Enlargement of the left atrium can be assessed on both B-mode and M-mode images. The maximal diameter of the left atrium is less than 1.4 cm, and the LA/AO ratio should be less than 1:3. Patients with hypertrophic cardiomyopathy or restrictive cardiomyopathy may have severe left atrial enlargement, and spontaneous echo contrast may be seen within the lumen of the atrium (Figure 3-42, C2, F, H, and I).

This finding suggests that the patient is at risk for thrombus formation and may develop aortic thromboembolism. Thrombi ejected into the aorta most frequently become lodged at the origin of the external iliac arteries, a so-called saddle thrombus, which results in acute-onset paraparesis of both hindlimbs. If the thrombi are smaller, they may enter either external iliac artery. This may result in paraparesis of one or both hindlimbs (Figure 3-42, J2, W, and X). In rare cases, a thrombus enters the left subclavian artery and the cat will present with a left forelimb monoparesis or monoplegia.

Restrictive Cardiomyopathy. In patients with restrictive cardiomyopathy, the left ventricular free wall and septum may appear normal or show minimal thickening. There is moderate or severe left atrial enlargement. Pulsed-wave Doppler evaluation of the left ventricular inflow at the mitral valve may reveal abnormal flow patterns. However, this is often obscured by the rapid heart rate of most cats with this disease. The diagnosis may be based on exclusion of other forms of cardiomyopathy.

Dilated Cardiomyopathy. Dilated cardiomyopathy is characterized by moderate or severe dilation of the left ventricle. The left ventricular free wall and septum appear thin. Cardiac contractility is markedly reduced. There is usually moderate to severe left atrial enlargement. A mitral insufficiency jet is frequently seen (Figure 3-42, O to Q).

Arrhythmogenic Right Ventricular Cardiomyopathy. There is moderate or severe dilation of the right ventricle in arrhythmogenic right ventricular cardiomyopathy. Color Doppler evaluation usually detects an insufficiency jet at the tricuspid valve. The right atrium is enlarged to a varying degree (Figure 3-42, R to V).

Myocarditis. Myocarditis is uncommon. The myocardium is not identified as a radiographic entity. No abnormality may be seen. Ultrasonography may show patchy areas of altered echogenicity in the muscle. Depending on the severity of the condition, there may be atrial and ventricular enlargement and valvular regurgitation. Ventricular contractility may be reduced, and pericardial effusion may be present.

Parasitic Conditions

Dirofilariasis (Heartworm Disease). Heartworm in dogs, Dirofilaria immitis, has a widespread distribution in the United States, the Caribbean, Australia, and Japan. It is also found in Africa, Asia, and southern Europe. It may be encountered wherever mosquitoes are found. The parasite also infests cats, but parasite burdens are usually small, and the diagnosis may be difficult. Heartworm disease is something of a misnomer because the changes induced in the pulmonary arteries by the presence of parasites and their antigens cause secondary changes in the heart. The worms live in the right ventricle and pulmonary artery. They may also be found in the right atrium and cranial and caudal venae cavae. The parasites cause obstruction of the pulmonary arteries, either by provoking thickening of the vascular intima or thrombus formation or
Radiologic Signs

Larvae cannot be demonstrated in the blood. Help establish a diagnosis in cases in which microfilariae cannot be demonstrated in the blood. This may occur as a result of the condition itself or as a result of treatment. The nature and extent of the changes seen will depend on the severity and duration of the condition (Figure 3-43).

Heartworm disease in cats may result in similar abnormalities to those seen in dogs. However, cats usually have only a few parasites and there are often no radiologic changes. Abnormalities may be confined to segmental or generalized dilation of the right caudal lobar artery or a few lobar arteries. Patchy, segmental, lobar, or generalized interstitial infiltrates and a bronchial pattern may be present; these signs are similar to those of feline allergic airway disease. Cardiomegaly is extremely rare in affected cats.

Ultrasonography. There may be hypertrophy of the right ventricular wall with dilation of the right atrium and pulmonary artery. If adult parasites are present in the heart, they appear as thin, paired, parallel hyperechoic lines in longitudinal section and small round structures in cross-section (Figure 3-43).

Pulmonary Thromboembolism. Pulmonary thromboembolism is a complication of heartworm disease, especially after adulticide treatment. The radiologic signs of pulmonary thromboembolism are quite variable.

There may be no radiologic abnormalities. This is probably the most common radiologic manifestation of pulmonary thromboembolism. However, patients with heartworm and pulmonary thromboembolism will usually have some abnormalities. Patients with pulmonary thromboembolism after adulticide therapy may show no radiologic changes.

Abnormalities of the pulmonary arteries may be seen. The pulmonary arteries may be truncated (abruptly terminate or be pruned); that is, a loss of the normal branches of a major pulmonary artery.

If there is truncation or pruning, the corresponding pulmonary veins usually collapse and are not seen. The pulmonary artery may appear normal, whereas the corresponding vein may be substantially smaller or absent. Absence of normal pulmonary arterial and venous structures may create a hyperlucent or dark appearance of a segment or lobe.

There may be an alveolar pattern within a segment of a lobe, a single lobe, or multiple lobes. Segmental alveolar patterns caused by pulmonary thromboembolism are roughly triangular in shape and have a base at the visceral pleura and the apex pointed toward the heart base. Focal pleural fluid accumulations adjacent to the affected segment or lobe are common in acute cases (Figure 3-43, M).

Angiostrongylosis. The adult worm of Angiostrongylus vasorum lives in the right ventricle and pulmonary arteries of the dog and the fox. The intermediate
Figure 3-43 *Dirofilaria immitis* infestation. **A** and **B**, A 5-year-old Afghan Hound had a history of coughing. On the lateral view, there is some enlargement of the right ventricle. The pulmonary vasculature is abnormal, with distended and tortuous vessels. The vasculature is obscured in places. On the dorsoventral view, the pulmonary artery segment is prominent, and a large abnormal vessel is seen in the right caudal thorax. There is a superimposed interstitial pattern. **C** and **D**, Dirofilariasis (heartworm infestation) in a dog. **C**, On the lateral view of the thorax, the cranial cardiac border is rounded and bulges cranially. Increased soft tissue opacity is noted cranial and dorsal to the tracheal bifurcation, which is in the region of the main pulmonary artery. There is severe enlargement of multiple pulmonary arterial segments (arrows). A dense interstitial infiltrate is noted at the periphery of the cranial lung lobe, between the cranial cardiac border and sternum. A similar infiltrate is seen in the periphery of the lung superimposed on the cardiac apex. **D**, On the ventrodorsal view, a large bulge is present at the left craniolateral aspect of the cardiac silhouette. This is severe enlargement of the main pulmonary artery trunk (asterisk). The right cardiac border bulges and is rounded, creating the so-called “reverse D” appearance. Both left and right caudal lobar arteries are severely enlarged (arrows). These findings are consistent with chronic severe heartworm infestation. The changes in the right heart are the result of hypertrophy of the myocardium of the right ventricle from chronic severe pulmonary hypertension. The interstitial pulmonary infiltrates are caused by pulmonary infiltration with eosinophilia or possibly pulmonary thromboembolism.
Figure 3-43, cont’d  E, A nonselective angiocardiogram through a jugular vein shows ballooning and distortion of the left pulmonary artery. Several large vessels are seen to be truncated (pruned) because of obstruction by worms. Nonselective angiocardiography is useful in the diagnosis of *Dirofilaria immitis* when the findings on plain radiographs are equivocal.  F and G, Dirofilariasis in a 4-year-old Weimaraner.  F, An enlarged right ventricle has displaced the trachea dorsally. The right cranial lung lobe artery *(straight arrows)* is dilated. Where that artery crosses the fourth rib, its width is greater than the most dorsal part of the fourth rib (a guideline for arterial enlargement). A dilated branch of that artery *(curved arrows)* is seen in cross-section adjacent to a cross-section of the bronchus it accompanies. There is a diffuse lung infiltrate, most apparent caudally, that obliterates the vessel borders in the caudal lung fields.  G, The contour of the main pulmonary artery is enlarged; the arteries of the right cranial and right caudal lung lobes *(arrows)* are dilated and tortuous. The artery of the left caudal lung lobe is obstructed and not visible. The contour of the heart in the ventrodorsal position vaguely resembles the mirror image of a D (sometimes referred to as the “reverse D” sign). This appearance is created by enlargement of the main pulmonary artery where it emerges from the left side of the heart and rounding of the right heart border caused by hypertrophy of the right side of the heart secondary to peripheral pulmonary arterial obstructive disease.

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Figure 3-43, cont’d H to J. Dirofilariasis (heartworm infestation) in a dog. H and I, There are multiple mineralized peripheral pulmonary artery segments (arrows) in this dog’s lungs. The changes are more severe in the caudal lung lobes. J, The close-up view shows irregular mineralization (arrows) of the pulmonary arteries in the peripheral zone of the caudal lung lobes. The cardiac silhouette and main pulmonary artery are within normal limits. Peripheral arterial mineralization such as this is usually a long-term sequela of infestation, and these patients frequently have no parasites.
host is a snail. It is found in Ireland, the United Kingdom, and Europe and is particularly common in France. The worm affects the clotting time of the blood, delaying coagulation. Vasculitis, perivasculitis, and thrombosing arteritis also occur. There may be consolidation of affected lung lobes. The larvae find their way from the blood vessels through the lung parenchyma to the bronchioles, where they are coughed up and swallowed. Having passed through the gastrointestinal tract, they are excreted in the feces. A fecal examination is diagnostic for the condition. If it is negative, it should be repeated some weeks later. Larvae can be recovered from the feces of affected dogs some 40 to 45 days after the primary infestation.

Systemic clinical signs are rare. Affected Greyhounds lose their racing form. There is some loss of condition. Spontaneous hematoma formation is common, particularly on the limbs, in the submandibular space, and on the ventral thorax. Limb edema with lameness of the affected limb is also commonly seen.

The radiologic findings are right ventricular enlargement and marked interstitial infiltration of the lung fields, which may have a nodular component. The lung changes are more marked in the middle and caudal lung lobes. The pulmonary changes are often quite severe. The vascular changes are similar to but not as severe as those seen in dirofilariasis. They chiefly affect the branches of the pulmonary artery rather than the trunk. Nonselective angiography is a method of demonstrating the vascular changes (Figure 3-44, A to E).

Ultrasoundography. Secondary effects on the right heart such as enlargement of the right atrium and ventricle may be seen (Figure 3-44, F to H).

Neoplasia

Heart Base Tumor (Chemodectoma, Aortic Body Tumor). As the name implies, heart base tumors are tumors that arise at the base of the heart near the origins of the great vessels. They arise from the chemoreceptor tissues of the aortic bodies. Less commonly, they arise from thyroid, parathyroid, lymphoid, or connective tissue. They are rare.

The radiographic findings are not characteristic. Pericardial effusion is common. A mass may be evident at the base of the heart, displacing the trachea or the esophagus dorsally. On the dorsoventral view, the trachea is displaced to the right. The mass may
simulate enlarged mediastinal lymph nodes. Nonselective angiocardiography will demonstrate displacement of cardiac chambers and may outline the mass. Pneumopericardiography has been used as a diagnostic aid. A needle-catheter complex is introduced into the pericardial sac ventrally at approximately the area of the fourth to the sixth intercostal space on the right side, and contrast medium is introduced. This technique has been superseded by ultrasound.

The clinical signs include edema of the head and neck, with a prominent jugular vein, as a result of invasion of or pressure on the cranial vena cava (superior caval syndrome). The forelimbs may also be edematous. Some cases show pericardial effusion, cardiac tamponade, and right heart failure (Figure 3-45, A to D).

Ultrasonography. If pericardial fluid is present, the mass may be seen at the heart base and particularly around the aorta (Figure 3-45, E to I).

**Hemangiosarcoma.** Hemangiosarcoma is sometimes seen affecting the right atrium, particularly in German Shepherds and Boxers. The usual site is in the area of the auricle. Radiologically, there is an increase in size of the cardiac silhouette from pericardial effusion. There may be pulmonary metastases. The spleen should be evaluated.
Figure 3-44, cont’d

D. This slightly oblique view of a Jack Russell Terrier shows a mixed pulmonary infiltration with a prominent pulmonary artery segment (arrow). E. Lateral view of the thorax shows loss of the cranial waist and increased cardiac sternal contact as a result of right heart enlargement. Diagnosis: angiostrongylosis.

F to H. This dog showed signs of exercise intolerance and tachycardia. F. This right-sided, parasternal long-axis sonogram in diastole shows gross enlargement of the right atrium (RA) and ventricle (RV). The left atrium (LA) and left ventricle (LV) are compressed, and the septa are displaced to the left. G. This view shows the relative sizes of the right and left atria. The right atrium is much larger than the left atrium. Angiostrongylosis was the final clinical diagnosis. H. The animal was reexamined 6 weeks after treatment. The right cardiac chambers have reduced in size, and the septa are in a normal position. TV, Tricuspid valve; MV, mitral valve; LA, left atrium; RA, right atrium; Cr, cranial.
Pericardial mesothelioma has been described but is extremely rare in dogs and cats. Lymphoma of the heart is also seen occasionally.

**Ultrasonography.** The presence of pericardial fluid enhances the ability to examine the cardiac margins for masses. Masses are often seen as hypoechoic entities around and attached to, or part of, the right auricular appendage, right atrium, and great vessels. They may invade the cardiac chambers. Right-sided, parasternal long- and short-axis studies should be made and the cardiac margins carefully examined.

**Rupture of Chordae Tendineae.** The chordae tendineae prevent eversion of the valve leaflets into the atrium during systole. Rupture of the chordae tendineae will result in incompetence of the associated valve. The condition may be acute or chronic. If acute, there will be little to see radiographically except pulmonary edema. Clinically, there is severe respiratory distress. If the rupture is subacute or chronic, the radiographic changes will be those associated with incompetence of the affected valve.

**Ultrasonography.** The atrium is grossly enlarged, and the valve leaflet prolapses into the atrium. If seen, ruptured chordae are identified as hyperechoic strands fluttering in the ventricular lumen.

**Dextrocardia.** In dextrocardia, the apex of the heart is shifted to the right and the heart lies mainly within the right hemithorax. It can occur as a normal feature.
in wide-chested dogs. It is also seen in pectus excavatum. Severe left heart enlargement, which particularly affects the left atrium in dogs and especially in cats, will sometimes cause displacement of the apex to the right. Determining the position of the apex is important to avoid misdiagnosing right-side cardiac enlargement. Situs inversus is a rare congenital abnormality in which the normal location of the thoracic (and abdominal) organs is reversed. The aortic arch, left ventricle, and cardiac apex are all on the right side. It may be associated with Kartagener's syndrome (see p. 218).
REFERENCES

Radiology


Biller DS, Meyer CW: Case examples demonstrating the clinical utility of obtaining both right and left lateral thoracic radiographs in small animals, J Am Anim Hosp Assoc 23:381, 1987.


Bones and Joints

Bones

Bone lends itself readily to radiographic examination. Being composed primarily of calcium and phosphorus, it is relatively dense and its radiographic opacity contrasts well with surrounding tissues. As living tissue, it frequently reflects changes in general metabolism, although changes may take time to develop.

Development

Bone develops in one of two ways: by (1) endochondral ossification or (2) intramembranous ossification. In endochondral ossification, bone develops on a preformed cartilaginous matrix. The long bones increase in length this way. Intramembranous ossification takes place in bands of connective tissue without any cartilaginous framework. Flat bones, such as those of the skull, form in this way. The increase in the diameter of long bones is by intramembranous ossification, which is initiated by the deeper layers of the periosteum.

Long bones have three main centers of ossification: one for the diaphysis (shaft) and one for each epiphysis (end). The cartilaginous matrices are elaborated at the growth plates and at the articular cartilages. Apophyses are accessory centers of ossification that do not contribute to the growth in the length of a bone. They are sites of attachment for muscles and ligaments. An example is the greater trochanter of the femur. Cartilage is radiolucent, and the first radiographic sign of bone formation in a long bone is the appearance of a collar of mineralized matrix around the cartilaginous shaft. Later other ossification centers appear.

Short bones, which develop by endochondral ossification, are found in the carpus and tarsus. Flat bones, which develop by intramembranous ossification, are found in the skull and pelvis. Irregularly shaped bones are found in the skull, vertebral column, and pelvis.

Sesamoid bones form in tendons where the direction of a tendon changes or where friction may develop. They have articular surfaces that are opposed to a long bone. The patella is a sesamoid bone.

The term fabella describes a small ossification in the medial and lateral heads of the gastrocnemius muscle. Fabellae may be bipartite. There is a fabella or sesamoid bone in the popliteus muscle at the caudolateral aspect of the proximal tibia. Two sesamoid bones are present proximal to the palmar (plantar) aspect of each metacarpophalangeal and metatarsophalangeal articulation. They are numbered 1 to 8, from the medial to the lateral side. The second and seventh are often bipartite with smooth, well-defined edges. This developmental anomaly, often seen in Greyhounds, should not be mistaken for fracture. In Rottweilers, fragmented sesamoids are occasionally seen in the second and fifth digits. The fragments are irregular in outline but are often of no clinical significance (Figure 4-1, C). A single sesamoid lies at the dorsal aspect of each metacarpophalangeal and metatarsophalangeal joint.

There is sometimes a small sesamoid bone on the craniolateral aspect of the proximal radius. It lies in the supinator muscle but has also been reported to lie in the lateral collateral ligament, the ulnaris lateralis, and the annular ligament (Figure 4-1, D). In the carpus a small sesamoid lies on the distomedial aspect of the radial carpal bone proximal to the first metacarpal bone. It lies in the abductor pollicis longus muscle.

Anatomic variation in the number and location of the fabellae (which are the small sesamoids in the head of the gastrocnemius muscle) at the caudal aspect of the stifle joint can occur in dogs and cats. It is often absent or occasionally displaced distally, particularly in smaller dog breeds (see Figure 4-12, I). Fracture or displacement of sesamoid bones is sometimes seen as a result of trauma (Figure 4-1, E).

Dewclaws, or first digits, normally have a metatarsal (metacarpal) bone and two phalanges. They are always present on the forelimbs, less often on the hindlimbs. They may or may not have associated sesamoid bones. The forelimb dewclaws articulate with the carpus, whereas the hindlimbs often have a soft tissue attachment. Some breeds such as the Pyrenean mountain dog have double dewclaws on the hindlimbs as a breed feature. This may also occur in cats.

Structure

During development, each long bone consists of a shaft (diaphysis), two metaphyses, and two extremities (epiphyses). The diaphysis is composed of
dense, compact bone. This dense bone surrounds the medullary cavity, which contains the bone marrow. The epiphyses are centers of growth at either end of the diaphysis. Between the epiphysis and the diaphysis is the \textit{physis}, or growth plate, and the \textit{metaphysis}, an area of spongy bone between the physis and the diaphysis. The physis is sometimes referred to as the \textit{physeal plate} or \textit{growth plate} in relation to radiographs. When a bone matures, the epiphysis fuses with the metaphysis, and the physis disappears.

Immature bone, also called \textit{woven bone}, does not have a lamellar structure. It is present only in early life or where new bone is being formed rapidly, such as in a healing fracture. Mature bone has a lamellar structure. Two types of bone can be recognized radiographically: compact bone is dense and radiopaque and is seen in the cortices of bones; cancellous, or \textit{spongy}, bone is less dense and is seen in the metaphyses and epiphyses. Cancellous bone shows varying degrees of trabeculation. Because compact bone is radiopaque, it shows no structure. It surrounds the medullary cavity, which is less opaque.

Living bone is constantly undergoing remodeling. The bone-forming cells are the \textit{osteoblasts}. They produce the matrix, often called \textit{osteoid}, in which mineralization occurs. They elaborate alkaline phosphatase, an indicator of osteoblastic activity. \textit{Osteoclasts} are responsible for bone resorption. \textit{Osteocytes} are osteoblasts that have become surrounded by mineralized osteoid.

\textbf{Figure 4-1} A, A marked trabecular pattern can be seen toward each end of the bone. B, A radiolucent, oblique linear shadow in the lateral tibial cortex is a nutrient foramen and should not be mistaken for a fracture. C, Bipartite sesamoids (arrows). The second and seventh sesamoids are most commonly affected by this anomaly.
They are found in lacunae within the bone, and they help maintain the calcified matrix. The normal functioning of bone therefore depends on the maintenance of a balance between the activities of these various cells.

The periosteum is a connective tissue layer that covers bone except at the articular surfaces. These surfaces are covered by articular cartilage. The periosteum has an outer fibrous layer that serves for muscle and ligament attachments and an inner, or cambium, layer capable of elaborating osteoblasts. The osteoblasts lay down new bone as the bone grows in width (intramembranous ossification); they also play a part in repair processes. The endosteum is a membrane lining the medullary cavity. It is composed of osteoblasts and osteoclasts. Both periosteum and endosteum elaborate the cells necessary for bone repair.

Blood vessels enter a long bone through the nutrient foramen (canal). The nutrient foramen appears as a radiolucent, sharply defined line in the caudal aspect of the cortex. It is directed obliquely cranially and distally. It is seen in the middle to proximal third of the bone diaphysis. There may be some endosteal irregularity in its vicinity. The nutrient foramen should not be mistaken for a fracture line. There is usually one in each bone (see Figure 4-1, A and B).

Radiography
At least two views, taken at right angles to one another, are required for proper evaluation of the status of a bone. It is important that studies of the skeleton be made in standard positions. The standard views for limb bones are craniocaudal (dorsopalmar, dorsoplantar) and mediolateral. Oblique, flexed, weight-bearing, and stressed studies are often useful. Stressed studies are studies made when lateral or medial leverage is applied distal to a joint under examination. They are useful in the evaluation of joint instability. The reader is referred to textbooks of radiographic technique for details of proper positioning.

Bone scintigraphy can be used to identify lesions not seen on conventional radiographs, such as subtle fractures, inflammatory foci, or metastases.

Normal Appearance
In normal bone, the diaphysis is seen as a band of compact, opaque bone surrounding the medullary cavity, which is more radiolucent. The epiphysis and metaphysis show trabeculations associated with cancellous bone. The trabeculations fade out at the diaphysis. In young animals, the physis (growth plates) appear as radiolucent bands or lines separating the epiphyses from the metaphyses (Figure 4-2). When growth ceases, the epiphyses fuse with the metaphyses and the physis are no longer seen. For some time
a band of increased opacity is seen at the junction of the epiphysis and metaphysis, representing the closed physis. This band is sometimes referred to as an epiphyseal or physeal scar (Figure 4-3, A).

It is important to know the positions of the various centers of ossification in the young animal and the times at which the physes close. Subsidiary centers of ossification may be mistaken for abnormalities. Young animals appear to have very wide joint spaces because the cartilaginous models on which the epiphyses and the small bones of the carpus and tarsus are developing are radiolucent. The physes are wide. Growth is completed in dogs by approximately 10 to 14 months of age. However, considerable variations may occur in the times of physeal closure, even in animals of the same breed. In the long bones, the proximal humeral epiphysis is the last to mineralize. The pelvic symphysis may not fuse for several years. The physes of the cat, particularly in the neutered cat, tend to close somewhat later than those of the dog (Table 4-1). Variations occur in the appearance of bones in some breeds, such as in chondrodystrophic animals. Variations such as
the irregular outline between the radius and ulna in small-breed dogs are usually of no clinical significance and are considered normal (Figure 4-3, C).

**Response of Bone to Injury or Disease**

Bone may respond to injury or disease in a number of ways. Disease or trauma may cause any or all of the following described changes. In many instances, several reactive processes will be visible at the site of a lesion.

**Decreased Opacity.** Bone may be resorbed or destroyed as a result of trauma, disuse, metabolic disorders, infection, or neoplasia. When bone tissue is lost, the bone at that site loses its radiographic opacity. In the case of a single bone lesion, this is readily observed because the surrounding bone offers a norm for comparison. Trabecular patterns become hazy or coarse and in some cases disappear altogether. Decreased opacity may be localized in one bone, or part of a bone, or it may be generalized throughout the skeleton. A decrease in cortical opacity is more readily observed than a decrease in medullary opacity. Occasionally a double cortical line may be seen in the diaphyses of affected bones. In the vertebrae the end plates become more prominent and appear sclerotic when in fact it is the vertebral bodies that have decreased opacity. A generalized (skeletal) decrease in bone opacity, particularly if it is not severe, may be difficult to determine because there is no norm for comparison within the affected animal. Comparison of radiographs of the affected animal with radiographs of a similar, but normal, animal is helpful. If earlier radiographs were made of the affected animal before the condition occurred, they should be consulted. A bone has to lose more than 50% of its mineral content before radiographic changes are discernible.

**Osteopenia** denotes a decreased opacity in bone. It may take the form of osteoporosis or osteomalacia. **Osteoporosis** denotes a deficiency of mineralization as well as a deficiency of osteoid tissue. **Osteomalacia** implies a sufficiency of osteoid but inadequate mineralization. Osteoporosis and osteomalacia are indistinguishable radiographically. Care is required with radiographic exposures because overexposed studies may simulate osteopenia.
### TABLE 4-1. Age at Appearance of Ossification Centers and of Bony Fusion in the Immature Canine

<table>
<thead>
<tr>
<th>Anatomic Site</th>
<th>Age of Appearance of Ossification Center</th>
<th>Age When Fusion Occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scapula</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Tuber scapulae</td>
<td>7 wk</td>
<td>4-7 mo</td>
</tr>
<tr>
<td><strong>Humerus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td>?</td>
</tr>
<tr>
<td>Proximal epiphysis</td>
<td>1-2</td>
<td>10-13</td>
</tr>
<tr>
<td><strong>Distal epiphysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trochlea of condyle (medial)</td>
<td>2-3 wk</td>
<td>6-8 mo to diaphysis</td>
</tr>
<tr>
<td>Capitum of condyle (lateral)</td>
<td>2-3 wk</td>
<td>6 wk to trochlea</td>
</tr>
<tr>
<td>Medial epicondyle</td>
<td>6-8 wk</td>
<td>6 mo to condyles</td>
</tr>
<tr>
<td><strong>Radius</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td>6-10 mo</td>
</tr>
<tr>
<td>Proximal epiphysis</td>
<td>8 wk</td>
<td>8-12 mo</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>8 wk</td>
<td></td>
</tr>
<tr>
<td><strong>Ulna</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td>6-10 mo</td>
</tr>
<tr>
<td>Proximal epiphysis</td>
<td>8 wk</td>
<td>8-12 mo</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>8 wk</td>
<td></td>
</tr>
<tr>
<td><strong>Ulna</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Carpus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulnar</td>
<td>4 wk</td>
<td>4 mo</td>
</tr>
<tr>
<td>Radial</td>
<td>3-4 wk</td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>4-5 wk</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>3-4 wk</td>
<td></td>
</tr>
<tr>
<td>Accessory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>2 wk</td>
<td></td>
</tr>
<tr>
<td>Epiphysis</td>
<td>7 wk</td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>3 wk</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>4 wk</td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>4 wk</td>
<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>3 wk</td>
<td></td>
</tr>
<tr>
<td>Sesamoid bone</td>
<td>4 mo</td>
<td></td>
</tr>
<tr>
<td><strong>Metacarpus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Distal epiphysis (2-5)*</td>
<td>4 wk</td>
<td>6 mo</td>
</tr>
<tr>
<td>Proximal epiphysis (1)*</td>
<td>5 wk</td>
<td>6 mo</td>
</tr>
<tr>
<td><strong>Phalanges</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First phalanx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis (1-5)*</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Distal epiphysis (2-5)*</td>
<td>4 wk</td>
<td>6 mo</td>
</tr>
<tr>
<td>Distal epiphysis (1)*</td>
<td>6 wk</td>
<td>6 mo</td>
</tr>
<tr>
<td>Second phalanx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis (2-5)*</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Proximal epiphysis (2-5)*</td>
<td>5 wk</td>
<td>6 mo</td>
</tr>
<tr>
<td>Second phalanx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent or fused with first in first digit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third phalanx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Palmar sesamoids</td>
<td>2 mo</td>
<td></td>
</tr>
<tr>
<td>Dorsal sesamoids</td>
<td>4 mo</td>
<td></td>
</tr>
<tr>
<td><strong>Pelvis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pubis</td>
<td>Birth</td>
<td>4-6 mo</td>
</tr>
<tr>
<td>Ilium</td>
<td>Birth</td>
<td>4-6 mo</td>
</tr>
<tr>
<td>Ischio</td>
<td>Birth</td>
<td>4-6 mo</td>
</tr>
<tr>
<td>Os acetabulum</td>
<td>7 wk</td>
<td>5 mo</td>
</tr>
<tr>
<td>Iliac crest</td>
<td>4 mo</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Tuber ischii</td>
<td>3 mo</td>
<td>8-10 mo</td>
</tr>
<tr>
<td>Ischial arch</td>
<td>6 mo</td>
<td>12 mo</td>
</tr>
<tr>
<td>Caudal symphysis pubis</td>
<td>7 mo</td>
<td>5 yr</td>
</tr>
<tr>
<td>Symphysis pubis</td>
<td>5 yr</td>
<td></td>
</tr>
<tr>
<td><strong>Femur</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td>7-11 mo</td>
</tr>
<tr>
<td>Proximal epiphysis (head)</td>
<td></td>
<td>6-10 mo</td>
</tr>
</tbody>
</table>
Osteolysis is a term used to describe areas of decreased bone opacity that are the result of bone destruction. Depending on the aggressiveness of the lesion, three broad categories are recognized: focal, also termed geographic; moth-eaten; and permeative. Focal is a well-defined, well-marginated osteolytic lesion with or without cortical expansion and usually benign, for example, a bone cyst. Moth-eaten describes several small areas of osteolysis that are less well defined and with a wider zone of transition. There may or may not be cortical erosion. This type is seen with malignant neoplasms and infection. Permeative osteolysis is a series of indistinct, almost pinpoint areas of lysis in a bone. The cortex is eroded. This is the most aggressive form of osteolysis and is seen in malignant neoplasms and in severe, uncontrolled osteomyelitis.

The term transitional zone is given to the area between a lesion and normal bone. In benign cases, this zone is usually narrow and well defined. With more aggressive lesions, the zone of transition is broad and poorly defined so that it is difficult to determine the exact margin of a lesion.

**TABLE 4-1. Age at Appearance of Ossification Centers and of Bony Fusion in the Immature Canine—cont’d**

<table>
<thead>
<tr>
<th>Anatomic Site</th>
<th>Age of Appearance of Ossification Center</th>
<th>Age When Fusion Occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trochanter major</td>
<td>8 wk</td>
<td>8-13 mo</td>
</tr>
<tr>
<td>Trochanter minor</td>
<td>8 wk</td>
<td>8-11 mo to diaphysis</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>2 wk</td>
<td>3 mo condyles to trochlea</td>
</tr>
<tr>
<td>Medial condyle</td>
<td>3 wk</td>
<td></td>
</tr>
<tr>
<td>Lateral condyle</td>
<td>3 wk</td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>9 wk</td>
<td></td>
</tr>
<tr>
<td><strong>Tibia</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Condyles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>3 wk</td>
<td>6 wk to lateral</td>
</tr>
<tr>
<td>Lateral</td>
<td>3 wk</td>
<td>6-12 mo to diaphysis</td>
</tr>
<tr>
<td>Tuberosity</td>
<td>8 wk</td>
<td>6-8 mo to condyles</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>3 wk</td>
<td>6-12 mo to diaphysis</td>
</tr>
<tr>
<td>Medial malleolus</td>
<td>3 mo</td>
<td>8-11 mo</td>
</tr>
<tr>
<td>Lateral malleolus</td>
<td>5 mo</td>
<td></td>
</tr>
<tr>
<td><strong>Fibula</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphysis</td>
<td>Birth</td>
<td></td>
</tr>
<tr>
<td>Proximal epiphysis</td>
<td>9 wk</td>
<td>8-12 mo</td>
</tr>
<tr>
<td>Distal epiphysis</td>
<td>2-7 wk</td>
<td>7-12 mo</td>
</tr>
<tr>
<td><strong>Tarsus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talus (tibial tarsal bone)</td>
<td>Birth-1 wk</td>
<td></td>
</tr>
<tr>
<td>Calcaneus (fibular tarsal bone)</td>
<td>Birth-1 wk</td>
<td></td>
</tr>
<tr>
<td>Tuber calcis</td>
<td>6 wk</td>
<td>3-8 mo</td>
</tr>
<tr>
<td>Central</td>
<td>3 wk</td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>4 wk</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>4 wk</td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>4 wk</td>
<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>2 wk</td>
<td></td>
</tr>
<tr>
<td>Metatarsus and pelvic limb phalanges are approximately the same as the metacarpus and pectoral limb phalanges.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sesamoids**

| Sesamoids | | |
|-----------|----------------|
| Fabellar | 3 mo |
| Popliteal | 3 mo |
| Plantar phalangeal | 2 mo |
| Dorsal phalangeal | 5 mo |

*Digit numbers.

**Increased Opacity.** Increased bone opacity is associated with increased mineralization or the production of new bone. It may result from disease processes within the bone, such as neoplasia, bone infarct, hypervitaminosis A, and osteopetrosis. It may be a response to trauma or stress. Continued abnormal stress on a bone results in cortical thickening along the line of greatest stress. Sclerosis is a term often used to describe increased radiographic opacity in bone. Sclerotic margins frequently surround areas of infection—a defense mechanism to confine the infection. Sclerosis of subchondral bone may be seen as a response to injury and be associated with inflammatory changes in a joint. Superimposition or impaction of bones may give the impression of increased bone opacity.

If for any reason growth is arrested, such a period of retarded development is reflected in the skeleton by transverse lines of increased opacity in the diaphyses of long bones adjacent to and parallel with the physes; these are known as growth arrest lines. They are of no clinical significance of themselves (see Figure 4-3, B).
Periosteal Reaction. The periosteum may react to irritation by the production of new bone. The type of periosteal reaction is often indicative of the severity of the lesion provoking it. In its earliest form it appears as a fine irregular reaction giving the bone a blurred or indistinct margin at the site of the lesion. Several kinds of periosteal reaction can be identified.

Smooth and solid: This is a response to continuous low-grade trauma, subperiosteal hematoma, or remodeling of bone. It represents a chronic process. It may be seen as the final, resolved stage of other types of periosteal new bone formation.

Lamellar or “onion skin”: This is the result of repeated episodes of periosteal irritation. Sheets of new bone are laid down approximately parallel to the cortex. It is often seen in metaphyseal osteopathy (hypertrophic osteodystrophy) in young dogs.

Palisade reaction: New bone is formed extending in columns outward at right angles from the cortex. The new bone forms a solid continuum. This type of
reaction is seen with hypertrophic osteopathy and sometimes osteomyelitis.

**Spicular:** Thin spicules of new bone are formed radiating outward from a lesion in the bone. This type of reaction is indicative of an aggressive process and is often seen with malignant bone tumors. The term “sunburst” is sometimes given to an exuberant type of this reaction.

**Amorphous:** This is a random or haphazard deposition of new bone in the soft tissues adjacent to a bone lesion. It is usually associated with malignancy.

**Codman’s triangle:** This term is used to describe a condition in which the periosteum is elevated and a triangle of new bone forms at the margin of a lesion beneath the elevated periosteum. It may be associated with malignancy or with a benign process such as osteomyelitis.

A reactive periostitis can usually be seen on radiographs 7 to 10 days after a bone has been injured. In young dogs it may appear a little earlier than in older animals. The aging of bone lesions on radiographic evidence alone is not an exact science. In general, periosteal reactions that are interrupted or that invade soft tissues suggest aggression, whereas smooth, solid, and organized reactions are likely to accompany benign lesions.

The term “aggressive” is often used to describe processes in bone that appear to be very destructive and are not being contained by an inflammatory or defensive reaction. The principal signs of aggression are a proliferative periosteal response that is interrupted in nature, a rapid destruction of bone, poor margination of the lesion, a disorganized reaction, and invasion of the surrounding soft tissues. With aggressive lesions there is a poorly defined transitional zone between affected and unaffected bone. Aggression may be associated with malignancy or with osteomyelitis (Figure 4-4).

**Change in Size or Contour.** Bones may be of an abnormal size or have an abnormal contour as a result of disease or trauma, particularly during the growth phase. Premature closure of a physis will cause a bone to be shorter than normal. The shortened bone may affect the growth and shape of bones in its immediate neighborhood and result in joint deformity. Bones may have an abnormal size or shape after fracture healing when reduction or immobilization has not been adequate. In the vertebrae, compression fractures result in foreshortening. Bone may remain thickened at the site of a healed fracture (Figure 4-5, A). The term valgus indicates an angulation away from the midline of

Figure 4-5  A, Thickening of the cortex (arrows) at the site of a healed fracture in a young dog. B, Mineralization (arrow) within the stifle joint of a cat is an incidental finding in this case.
the body and the term varus, an angulation toward the midline.

**Change in Trabecular Pattern.** A *trabecular pattern* is a wispy, lacelike appearance seen in the medullary cavity of a bone. Trabecular patterns are clearly seen in normal cancellous bone in the epiphysis and metaphysis. It is particularly evident in young animals and in aging animals. They tend to fade out in the diaphysis. Changes in trabecular pattern may be the first indication of a disease process. Such changes may be seen in destructive processes such as infection or neoplasia when the pattern tends to disappear. The pattern may be emphasized in remodeling bone or in cases of osteopenia. The use of a magnifying glass is helpful in making a detailed study. High-detail film-screen combinations are useful. Overexposure may obliterate the pattern.

**JOINTS**

**Anatomy**

A *synovial (diarthrodial) joint* consists of two apposing bone surfaces, each covered by articular cartilage and surrounded by a joint capsule. The term *enarthrodial* is used to describe a ball-and-socket joint, allowing movement in all directions. The inner layer of the joint capsule, or *synovial membrane*, secretes fluid, a thin layer of which separates the opposing articular cartilages. Some synovial joints contain intraarticular ligaments, menisci, fat pads, or synovial projections. Other types of joints are *synarthrodial*, meaning a fibrous joint, and *amphiarthrodial*, meaning a cartilaginous joint.

**Radiography**

Radiography of the joints of very young animals is often unrewarding because of the large amount of radiolucent tissue present. Even severe abnormalities may not be demonstrated.

*Arthrography*—injection of contrast medium into a joint—is not widely practiced in veterinary radiology. Its use has been confined mainly to the shoulder joint to demonstrate defects in the articular cartilage or cartilage flaps in osteochondrosis. It can also be used to demonstrate defects in the joint capsule and abnormalities in the bicipital tendon sheath. A positive contrast medium is preferred. A nonionic, low-osmolar, iodine-based contrast material is used. Iohexol or iopamidol may be used in a concentration of 100 mg/mL. Synovial fluid is first aspirated from the joint, and contrast medium is then injected. The contrast should be diluted to 50% with sterile saline. From 2 to 9 mL is used, depending
on the size of the animal. To enter the shoulder joint, a 20- to 22-gauge short bevel or spinal needle is inserted approximately 1 cm below and lateral to the acromion process. The needle is directed distally, medially, and caudally. The joint is manipulated to disperse the contrast material. Radiographs should be taken after 5 minutes. General anesthesia is required, and aseptic procedures are mandatory (see Figure 4-15, A).

Computed tomography, if available, gives a cross-sectional representation of a joint and enables small fragments or lesions to be identified and localized (see Figure 4-15, H and I).

**Normal Appearance**

The articular cartilages, synovial fluid, and joint capsule are not visible on radiographs. The subchondral bone (i.e., the bone just beneath the articular cartilage) is visible and merges smoothly with the cortex of the metaphysis in mature animals. The infrapatellar fat pad in the stifle joint can be seen on a lateral view as a triangular radiolucency lying caudal to the patellar ligament. The patellar ligament is seen as a soft tissue band attaching to the tibial tuberosity forming the cranial boundary of the fat pad. The fat pad provides contrast so that joint effusion or capsular thickening may be identified. In cats a small triangular mineralized opacity is often seen between the distal femur and proximal tibia (see Figure 4-5, B). The joints in young animals appear to be much wider than those in adults. This is because the immature, largely cartilaginous epiphyses and small cuboidal bones are not fully seen. In very young animals the incompletely ossified epiphysis often has an inhomogeneous mineralization and a stippled, ragged, and irregular margin particularly obvious in large breeds. It should not be mistaken for an abnormality.

Fascial planes are identified as linear radiolucencies because of fat interposed between muscle masses. These planes have characteristic contours around various joints.

Fat in the fascial planes adjacent to the caudal pouch of the shoulder joint may be displaced if there is moderate or severe joint swelling. The fascial planes at the caudal aspect of the stifle joint are oriented in a proximal to distal direction from the fabellae to the caudal aspect of the tibial plateau. They are displaced caudally by swelling of the joint.

**Abnormalities**

Congenital, developmental, metabolic, and various other conditions can affect bones and joints.

**Luxations.** Luxations usually present no problems of diagnosis, provided adequate radiographic studies are available. At least two standard views, made at right angles to one another, are necessary for proper evaluation of the degree and direction of the displacement. Luxations may easily be missed if only one view is relied on. A careful search should be made to detect small fracture fragments associated with a luxation because they may interfere with attempts at reduction. Sometimes small avulsion fractures are associated with collateral ligament damage. Intracapsular swelling will displace adjacent fascial planes. Luxations, as a rule, reduce the normal range of movement of a joint.

**Radiologic Signs**

1. The articular surfaces are displaced and do not articulate properly with one another.
2. There is disruption of adjacent fascial planes.
3. There may be associated avulsion fractures.
4. In the case of the stifle joint, there will be a disruption of the normal intraarticular fat pad.

In young animals, anatomic abnormalities of joint surfaces suggest that a luxation may be congenital. Comparison with the opposite limb, if normal, is advisable. Anatomic abnormalities of joint surfaces may also be associated with chronic luxations.

Subluxations (partial dislocations) are more difficult to evaluate than frank luxations. Stressed views or studies made with the animal bearing weight on the affected limb, if that is possible, may show a subluxation not seen on a conventional radiograph.

**Figures 4-6 through 4-12** show a selection of normal and abnormal joints.

**Luxation of the Shoulder Joint**

Congenital. Congenital luxation of the shoulder joint is occasionally seen in smaller breeds of dogs. It may be bilateral. The animal develops an abnormal stance as it grows.

**Radiologic Signs**

1. The head of the humerus is displaced medially.
2. On a craniocaudal view the medial displacement of the humeral head is obvious.
3. The glenoid cavity may be shallow, flattened, or otherwise malformed.
4. On a lateral view a normal joint space cannot be identified.

Acquired. Acquired luxation is the result of trauma. Varying degrees of displacement are encountered. There may be associated fractures (see Figure 4-6, H and I). Gas may be seen within the shoulder joint as result of the vacuum phenomenon (see Chapter 5, p. 520).

**Luxation of the Elbow Joint**

Congenital. Congenital luxation of the elbow joint is seen in smaller breeds of dogs. Clinically there is either a marked lameness or the limb is being carried. Two types of congenital luxation of the elbow joint are recognized. In one type the humeroulnar joint appears normal but the radial head is displaced laterally and caudally. In the second type the humeroradial joint appears normal but the proximal ulna is rotated through 90 degrees. No semilunar notch is seen on a lateral view of the ulna. Both types of luxation may coexist (see Figure 4-7, P).

Acquired. Traumatic luxation of the elbow without an associated fracture results in the radius and ulna being displaced laterally. A luxation associated with a fracture of the proximal ulna results in proximal and
Figure 4-6 The shoulder joint. 

Figure 4-6, cont’d The shoulder joint. E and F, Lateral and caudocranial views of the shoulder of a cat. A rudimentary clavicle is present (arrows). G, Separation of the proximal humeral epiphysis in a cat.
Figure 4-6, cont’d The shoulder joint. H and I, Luxation of the shoulder joint. The humerus is luxated medially, proximal to the glenoid. The displacement can easily be missed on a lateral view.
cranial luxation of the radial head and caudal displacement of the proximal ulnar fragment. The luxation of the humeroradial joint results in the humeral condyle lying caudal to the proximal radial metaphysis. This is known as Monteggia’s fracture. Subluxation of the elbow joint can occur associated with collateral ligament damage. In such cases stressed studies are useful. In all cases postreduction studies are advisable (see Figure 4-7, H to N).

**Luxation of the Hip Joint.** In hip joint luxation as a result of trauma, the femoral head is usually displaced dorsally and cranially. It may displace ventrally or come to lie immediately dorsal to the acetabulum, where it may be easily missed. Two views at right angles to one another are necessary because a dislocation may be missed on one or the other view. An extended ventrodorsal view is necessary to demonstrate a subluxation that may be missed on inadequately positioned or frog-leg views. An avulsion fracture associated with the ligament of the head of the femur (round ligament) may be seen within the acetabulum. There may also be chip fractures of the acetabular rim.Luxation may also occur as a result of degenerative conditions such as hip dysplasia (see Figure 4-10, E and F).
Figure 4-7, cont’d C and D, Craniocaudal view of the elbow joint. E, Flexed mediolateral view of the elbow joint of an immature dog. Note the growth plate associated with the medial epicondyle of the humerus (arrow).
Figure 4-7, cont'd F and G, Mediolateral and craniocaudal views of the elbow of a cat. H and I, Craniocaudal and mediolateral views of the elbow of a dog. There is a subluxation of the elbow joint. The displacement is not visible on the lateral view. J and K, Mediolateral and craniocaudal views of the radius and ulna of a dog. J, There is type II Salter-Harris fracture of the proximal radius (short arrow) with slight cranial displacement of the metaphysis in relation to the epiphysis (long arrow). K, On the craniocaudal view two fissure fracture lines (arrow) are evident at the proximal third of the radial diaphysis. The degree of displacement of the fracture is made clear on the mediolateral view. This case illustrates the importance of at least two views to evaluate a fracture.

Continued
Figure 4-7. cont'd L, Mediolateral view of the elbow showing a dislocation of the humeroradial joint with an associated fracture of the ulna (Monteggia’s fracture). M and N, Craniocaudal and mediolateral views of the elbow showing luxation of the elbow joint without an associated fracture. This may easily be missed on a lateral view and demonstrates the importance of two views.
Chapter 4  ■ Bones and Joints

Figure 4-7, cont’d O, Mediolateral view of a normal puppy elbow. P, An 8-week-old Jack Russell Terrier presented with a history of lameness of 2 weeks’ duration. The radius and ulna are rotated 90 degrees in a medial direction in relation to the distal humerus and displaced laterally on this cranio-caudal view. Diagnosis: congenital elbow luxation.

The Stifle Joint
Rupture of the Cranial Cruciate Ligament. Rupture of the cranial cruciate ligament from trauma may affect any breed of dog. In the larger breeds of dog such as the Rottweiler and Saint Bernard, it may result from degenerative changes in the ligament. It may appear as early as 5 months of age and is often bilateral. A definitive clinical diagnosis is made by demonstrating the cranial drawer sign, although its absence does not preclude a partial tear or disruption. A tibial compression test may also be used. Rupture of the caudal cruciate ligament is rare and usually occurs only with complete luxation of the stifle with rupture of the collateral ligaments and cranial cruciate ligament (see Figure 4-11, H to K).

Radiologic Signs
1. Early cases show an intraarticular soft tissue swelling.
2. Cranial displacement of the tibia relative to the femur may or may not be evident. The absence of evidence of displacement should not be relied on to exclude a diagnosis of a ruptured ligament.
3. When the rupture has been present for some time, inflammatory and degenerative joint changes will be evident.
4. Intracapsular swelling will displace adjacent fascial planes (see Figure 4-11, H and I).
5. Avulsion fracture fragments may be present within the joint.
6. In middle-aged, smaller breed dogs and in older dogs, rupture of the cranial cruciate ligament may be associated with medial luxation of the patella.

Collateral Ligament. Trauma may result in damage to one of the collateral ligaments of the stifle joint. An associated avulsion fragment may be present. A cranio-caudal view using medially or laterally applied stress will show widening of the joint space on the affected side.

Long Digital Extensor Tendon. Rarely, an avulsed fragment of bone is seen lateral to the lateral condyle of the femur on a cranio-caudal view of the stifle joint. A mediolateral view may show a radiolucent defect in the lateral condyle, and the fragment may be seen overlying the joint. These changes represent an avulsion fracture associated with the origin of the long digital extensor tendon.

Congenital Luxation of the Patella. Congenital patellar luxation may result from the following:
1. Malformation of the femoral trochlea.
2. Poor alignment between the distal femur and the proximal tibia.
3. Rotation of the proximal extremity of the tibia, which most commonly displaces the tibial tuberosity medially but sometimes laterally.
4. A combination of some or all of these disorders.

There may be an associated abnormal angulation of the distal femur because these abnormalities result in the patellar straight ligament being out of line with the trochlear groove. This abnormal angulation is most common in small dogs. The luxation is almost invariably medial. Lateral luxation of the patella is occasionally seen in large dogs with genu
Figure 4-8  

A and B, Mediolateral view of the normal carpus of a dog. C and D, Dorsopalmar view of the normal carpus (antebrachio-carpal joint).
Figure 4-8, cont’d E and F, Mediolateral and dorsopalmar views of the normal carpus of a cat. G, Dorsopalmar view showing a luxation of the radiocarpal joint. H, Mediolateral view of the antebrachiocarpal joint showing severe damage caused by a high-velocity bullet.
Figure 4.9 A and B, Mediolateral view of the metacarpus. C and D, Dorsopalmar view of the metacarpophalangeal region (manus).
valgum, that is, lateral deviation of the limb below the stifle joint.

Clinically, animals intermittently carry the affected limb. Palpation reveals the displacement, which can be readily reduced in most cases with the limb held in extension. The patella can also be easily displaced manually. Dogs may resent these maneuvers.

Radiologic Signs
1. The patella may be in normal position on all views.
2. If displaced, the patella lies to the medial or lateral side of the femur on the craniocaudal view. The displaced patella may be difficult to demonstrate in young animals before it has become fully mineralized.
3. On the mediolateral view, the patella is absent from the trochlear groove and lies superimposed on the femoral condyles.
4. A flexed proximocranial-distocranial ("skyline," or tangential) view of the distal femoral trochlea will show the displaced patella and possibly a shallow trochlear groove.
5. Associated bone abnormalities are frequently evident, including a shallow trochlear groove, rotation of the proximal tibia, curvature and rotation of the proximal tibia, and abnormal angulation of the femorotibial articulation. Some or all of these abnormalities may be present.
6. Secondary changes associated with degenerative joint disease may be present.

Luxation may also be the result of trauma, in which case it may be either medial or lateral.

Care should be taken not to rely entirely on the radiographic diagnosis. A luxating patella may be in its normal position when a radiograph is made because positioning the animal for radiography may bring about a temporary reduction of the luxation (Figure 4-11, L and M).

Luxation of the Tarsus. Luxation of the tarsus may be traumatic or congenital. Any of the bones of the tarsus may become displaced after trauma. Such abnormalities are readily detected on standard views (see Figure 4-12, G).

A progressive subluxation of the proximal intertarsal (calcaneoquartal) joint has been described in the Shetland Sheepdog and in Rough Collies. The condition is bilateral and is the result of degenerative change of the plantar ligaments of the hock. Radiographs show dorsal displacement of the distal tarsal bones relative to the talus and calcaneus and a curved contour to the plantar aspect of the tarsus. Secondary degenerative changes may be seen on the tarsal bones.

Luxation of the Carpus. Luxation of the carpus may occur as a result of trauma. Oblique studies are required to identify small fracture fragments associated with luxation. Carpal subluxation or luxation has been described as a syndrome in Shetland Sheepdogs.
Figure 4-10  A, A normal ventrodorsal view of the pelvis of a dog. Note how the line of the inner aspect of the shaft of the ilium blends smoothly with the line of the sacrum (arrows). The sacroiliac joint may disrupt the continuity of the line but not its direction. B, Ventrodorsal pelvis of an immature dog. Note the wide joint spaces and the several physes. Cartilaginous ossification centers at the caudal aspect of the ischium and the cranial aspect of the ilium may not fuse with the pelvis until the dog is several years old. Closure of the pelvic symphysis may be likewise delayed. C, Normal ventrodorsal view of the pelvis of a cat. The pelvis is slightly rotated. D, Bilateral sacroiliac subluxations. The lines of continuity between the ilia and the sacrum have been disrupted. The right femur is fractured.
Degenerative Joint Disease

Osteoarthrosis. Osteoarthrosis, or degenerative joint disease, is a condition that involves splintering and loss of articular cartilage. It may be primary or secondary. Primary degenerative joint disease is seen in old dogs and cats in whom there is no apparent reason for the condition. Secondary degenerative joint disease occurs as a result of abnormal stresses on a joint. Any condition that interferes with normal joint function can precipitate secondary degenerative changes. They may appear in a normal joint as a result of excessive exercise. The bone changes in secondary degenerative joint disease tend to be more severe than in those seen in the primary type.

Degenerative joint disease results in fissure formation and fragmentation of the articular cartilage, which then becomes less efficient in protecting the subchondral bone. This in turn precipitates remodeling changes on the articular surfaces and new bone formation around the edges of the joint. Gas accumulation has been described in the shoulder joint.

Figure 4-10, cont’d E and F. Luxation of the right hip joint of a dog. The lateral view is necessary to determine the direction and degree of displacement in the vertical plane, which in this case is dorsal and cranial. G. Severe trauma to the pelvis of a cat. There are fractures of the pubis and ischium on the right side, and the right sacroiliac joint is subluxated. The right hemipelvis is displaced cranially when compared with the left side.
Figure 4-11 A and B, Mediolateral view of a normal stifle. Arrows show normal fascial planes. C and D, Craniocaudal view of a normal stifle.
Figure 4-11, cont'd E, Skyline (flexed cranioproximal-craniodistal oblique) view of the normal patella and trochlear groove of the femur. F and G, Mediolateral and craniocaudal views of the normal stifle (femorotibial) joint of a cat. H, Subluxation of the stifle joint caused by rupture of the cranial cruciate ligament. This injury does not always produce a visible radiographic displacement. I, This was a 2-year-old Rottweiler with a cranial cruciate ligament injury. An intraarticular soft tissue or fluid opacity (long arrow) is seen within the femorotibial joint space displacing the fat pad (short arrow) cranially. This may occur with any intraarticular lesion.

Continued
Figure 4-11, cont’d J and K, Cruciate ligament rupture. Lateral and craniocaudal views of the stifle. J, There is a mineralized opacity visible in the caudal part of the joint. K, The opacity is superimposed on the joint space just medial to the midline. There is remodeling of the proximomedial tibia. This opacity is resulted from an avulsion of the attachment of the cruciate ligament to the bone. L, Luxation of the patella. The displaced patella can be seen on the medial aspect of the stifle (arrow). The stifle joint is deformed. The alignment of the femur to the tibia is abnormal. The tibial crest is rotated medially. There is an abnormal contour to the proximal tibial diaphysis, which is bowed medially. M, A skyline (tangential) view of a displaced patella.
Figure 4-12 A and B, Mediolateral view of the normal tarsus of a dog. C and D, Dorsoplantar view of the normal tarsus of a dog.

Continued
Figure 4-12, cont'd E and F, Mediolateral and dorsoplantar views of the normal tarsus of a cat. G, Luxation of the talocrural joint. The tarsus is luxated lateral to the tibia. H, Avulsion fracture of the medial malleolus of the tibia. There is disruption of the skin on the medial aspect of the distal tibia. I, This puppy had been in a road traffic accident. The medial fabella (arrow) is displaced and lies at the distomedial aspect of the femur. The medial fabella on the opposite hindleg was in a similar position. This is a transverse fracture of the proximal tibia. Diagnosis: incidental finding—fabellar displacement.
associated with degenerative changes. This is known as the \textit{vacuum phenomenon} (see Chapter 5, p. 520).

An \textit{enthesophyte} is new bone formation at the site of attachment of a muscle, tendon, or ligament. An \textit{osteoophyte} is an osseous outgrowth on a bone.

The term \textit{osteoarthritis} implies inflammation of a joint and adjacent bones.

\textbf{Radiologic Signs}
1. Lipping of the joint margins with osteophyte and enthesophyte formation is common.
2. Sclerosis of the subchondral bone results from damage to, fissuring of, or erosion of the articular cartilage.
3. There is narrowing of the joint space, although it is sometimes difficult to demonstrate in dogs and cats.
4. Subluxation can sometimes be demonstrated on weight-bearing studies, as can narrowing of the joint space. Radiation safety precautions should be observed.
5. Radiolucent cystic areas may develop in the subchondral bone. These are not common in dogs and cats and are seen most often in the hip.
6. Remodeling of bone occurs on either side of the affected joint.
7. Mineralized opacities are seen within the joint, or periarticular tissues may become calcified.
8. Distention of the joint capsule from synovial effusion may displace adjacent fascial planes. This displacement is most readily recognized caudal to the stifle joint (see Figures 4-13 and 6-4, A).

\textbf{Inflammatory Joint Disease}
\textit{Arthritis.} \textit{Arthritis} is inflammation of a joint and may be infectious or noninfectious. The condition involves inflammation of the synovial membrane with a variable degree of involvement of the surrounding joint structures. Noninfectious arthritis is usually the result of immune-mediated disease. A definitive diagnosis often requires arthrocentesis, biopsy, and blood tests. Bone scintigraphy is occasionally helpful in localizing an inflammatory site (see Color Plate 4-30, Z1).

\textit{Infectious (Septic) Arthritis.} Infectious arthritis may result from wounds or spread of an infectious process from neighboring structures. It may also result from invasion of the joint by blood-borne agents. Clinically, severe lameness, distention of the joint capsule, heat, and pain on palpation occur. Joint movements are limited. Arthrocentesis is the diagnostic method of choice.
Chapter 4  ■  Bones and Joints

Figure 4-13, cont'd  Joint disease. E and F, Mediolateral views of the elbow and stifle joints in a cat showing chondromatosis (osteochondromatosis). This condition may or may not be associated with arthritis. Parts of the synovial membrane become cartilaginous, and later they may become mineralized. The etiology is unknown. This cat had a stilted gait for approximately a year but was not disabled. Similar changes may be seen with hypervitaminosis A.

Radiologic Signs
1. There may be little radiologic evidence of infectious arthritis in early cases.
2. Distention of the joint capsule may displace adjacent fascial planes. Normal periarticular radiolucencies associated with periarticular fat in fascial planes are lost because of inflammatory exudate within the joint and edema around the joint.
3. In the stifle joint, the infrapatellar fat pad becomes obscured or lost.
4. Periosteal reaction occurs on the bones surrounding the joint, usually at the attachments of the joint capsule.
5. Spread of the infectious process will produce changes in adjacent bones.
6. There may be subchondral and perichondral bone destruction once the disease process destroys articular cartilage and spreads to the subchondral bone.
7. In longstanding cases there will be changes of secondary degenerative joint disease. The joint space becomes narrower (Figures 4-13 and 4-14, A and B).

Immune-Mediated or Aseptic Arthritis
Polyarthritis. Many different breed-specific immune-mediated polyarthritides have been reported. These are usually not erosive in nature, and radiographic changes are limited to soft tissue swelling. Heritable polyarthritis have been reported in the Akita, Boxer, and Weimaraner. Arthritis may be accompanied by a synovial vasculitis, which has a variable response to immunosuppressive therapy. Progressive polyarthritis and renal amyloidosis have been reported in the Shar-Pei (“Shar-Pei fever”) and is characterized by episodic fever and swelling of the carpal and tarsal joints. Immune-mediated arthritis may be erosive or nonerosive.

Erosive
Rheumatoid Arthritis. This type of erosive arthritis is rare in dogs and even rarer in cats. It affects multiple joints symmetrically, particularly the carpus and hock, which are swollen and painful. It occurs in middle age in medium-sized and small dogs. Radiologic changes include periarticular soft tissue swelling and rarefaction and loss of trabecular patterns in adjacent bones. Cystlike lesions or focal radiolucencies develop in the subchondral bone, which is subsequently destroyed. The joint space is narrowed. Areas of bone lysis may occur at points of ligamentous attachments and subluxation, or luxation may follow.

Radiologic Signs
1. It affects multiple joints, especially the carpal joints.
2. Soft tissue swelling is present.
3. There is articular and periarticular bone lysis, especially the small, cuboidal carpal bones.
4. Collapse of the joint space occurs in chronic cases.
5. Subluxation may be present.
Figure 4-13, cont’d. Joint disease. G to I, Erosive arthritis. G and H, There is destruction of the medial radial head, subchondral bone erosion of the articular margin of the distomedial humerus, and a narrowed joint space laterally. This is severe, chronic, degenerative osteoarthritis. I, A study of the same limb made 3 months earlier shows the rapid progression of the lesion.

Continued
Feline Polyarthritis. Feline polyarthritis may be proliferative or destructive. The proliferative form is acute with fever, lameness, swollen and painful joints, muscle wasting, and peripheral lymphadenopathy. It occurs in male cats between 1 and 5 years of age. The joints involved are usually those of the lower limbs, including the carpus and tarsus. Lesions are bilaterally symmetric. Radiographically there is periosteal new bone formation, mainly around joints. There are subchondral bone erosions. Ankylosis may occur.

The destructive form is less common, occurs in older cats, and is more chronic in nature. There are subchondral bone erosions, joint deformities, instability and, occasionally, luxations. Bone is often eroded at the site of tendon insertions.

Erosion of joint surfaces may occur associated with a variety of arthritides as a result of infection, inflammation, or neoplasia.

Nonerosive
Systemic Lupus Erythematosus. Systemic lupus erythematosus (SLE) may be a cause of inflammatory joint disease. Several joints are affected. Radiologic signs are usually minimal. Periarticular soft tissue swelling and displacement of adjacent fascial planes are seen as the joint capsule is distended. The joint space may be narrowed. Longstanding cases may show changes indicative of secondary degenerative joint disease.

Lymphocytic-Plasmocytic Synovitis. Lymphocytic-plasmocytic synovitis is a form of arthritis affecting primarily the stifle joints of the larger breeds of dog. There are radiologic signs of degenerative joint disease. The cruciate ligament may be ruptured.

Idiopathic. Idiopathic arthritis is arthritis arising from no apparent cause.

Villonodular Synovitis. Villonodular synovitis is a rare condition caused by nodular hyperplasia of the synovial membrane. There is swelling of the joint capsule and cortical erosions at the chondrosynovial junction. Intraarticular masses are demonstrable on ultrasonographic examination.

Disseminated Idiopathic Skeletal Hyperostosis. Disseminated idiopathic skeletal hyperostosis, a generalized condition affecting the spine and joints, of a large dog has been reported. Proliferative new bone formation is seen affecting joints and tendon insertions on bony prominences such as the great trochanter of the femur. Changes are also seen on the vertebrae (see Figure 5-35, F).

Synovial Osteochondromatosis. Mineralized chondromas within joint capsules and in the surrounding soft tissues have been described in middle-aged and older larger breed dogs. They are believed to be caused by synovial metaplasia. There may be associated periarticular osteophyte formation. Intraarticular chondromas that do not calcify require demonstration by contrast arthrography, ultrasonography, or magnetic resonance imaging. It is commonly seen in older
cats with chronic severe osteoarthrosis. In this species, lesions in the stifle joint must be differentiated from meniscal calcification (see Figure 4-5, B and C).

**Bicipital Tenosynovitis.** Bicipital tenosynovitis is inflammation of the sheath of the bicipital tendon. Plain radiographs may show a sclerosis in the intertubercular groove with enthesophytes on the supraglenoid tubercle. Arthrography will show irregular distention or incomplete filling, caused by adhesions, of the bicipital sheath. Ultrasonography will demonstrate anechoic fluid in the tendon sheath surrounding the tendon. The tendon may or may not be normal. It may be enlarged or torn. Comparison with the opposite side is useful. Lameness is chronic, affecting one or both forelimbs, and may be intermittent. It

*Figure 4-13, cont’d L to O, This is a 10-year-old Rough Collie that was lethargic. There is severe bilateral carpometacarpal osteoarthritis.*
Figure 4-14 A and B. Gross destruction of this carpal joint in a cat is the result of septic arthritis. The metacarpal bones are luxated, and the normal carpal bone alignment is disrupted. There is a large associated soft tissue swelling. C, This Collie has a slight soft tissue swelling around the calcaneus. The close-up view shows a smooth mineralization (arrow) within the gastrocnemius (Achilles) tendon. New bone formation is also seen on the plantarodistal aspect of the calcaneus and dorsal aspect of the tarsus. Diagnosis—calcifying tendinopathy.

is exacerbated on exercise. Pain is elicited on palpation of the shoulder joint and tendon (see Figure 6-7, H and J). Rupture of the biceps brachii tendon sheath has been reported. Arthrography demonstrates leakage of contrast into the soft tissues.

Calcifying Tendinopathy. Calcifying tendinopathy may be associated with bicipital tenosynovitis. Small mineralized opacities may be seen cranial to the intertubercular groove. A tangential (skyline), flexed, proximocranial-distocranial view of the groove will show where the mineralization lies. Ultrasonography may show fiber irregularities and mineralization within the tendon as hyperechoic foci. There may be acoustic shadowing. Movement of the limb in flexion and extension during examination is often helpful.
Distension of the joint capsule or tendon sheath may also be seen. It is seen in large breeds, may be bilateral, and may or may not be of clinical significance.

Calciﬁng tendinopathy may also affect the tendons of the supraspinatus, infraspinatus, coracobrachialis, and gastrocnemius tendons (see Figure 4-14, C).

Developmental Anomalies

Osteochondrosis. Osteochondrosis is an abnormality in endochondral ossiﬁcation. Articular cartilage becomes thickened in the affected area, and chondrocytes in the deeper layers die. The surrounding cartilaginous matrix then fails to ossify. Fissures appear in the articular cartilage. In some cases normal endochondral ossiﬁcation is reestablished, and the lesion regresses. More frequently, an area of devitalized thickened cartilage develops and overlies a defect in the subchondral bone, the defect being an area in which normal endochondral ossiﬁcation has failed to occur. The area of dead cartilage may remain attached at the junction of cartilage and subchondral bone, or it may become separated, forming a flap or a free fragment. The condition is then termed osteochondritis dissecans. Cartilaginous ﬂaps may become mineralized and are visible on radiographs as a thin curvilinear mineral opaque structure. Sometimes part of the ﬂap becomes detached and floats free in the affected joint. Such a loose body may grow larger after it has become detached. When such bodies lie loose within the joint or adhere to the synovium, they are often called joint mice.

Osteochondrosis occurs in larger dog breeds, usually between 4 and 9 months of age. Aﬀected animals show lameness. Manipulation of an aﬀected joint is resisted. A deﬁnitive diagnosis is usually made radiographically. The most common site in the dog is the caudal third of the humeral head, but the trochlea of the humeral condyle, the femoral condyles, the medial and lateral malleoli of the tibia, the medial and lateral trochlear ridges of the talus, and the cranial endplate of the sacrum (see Chapter 5, p. 521) may also be aﬀected. Ununited anconeal process and fragmented medial coronoid process of the ulna are believed to be manifestations of osteochondrosis. The condition is frequently bilateral.

If osteochondrosis occurs at an apophysis, it may result in apophyseal separation such as has been reported in the tibial tuberosity.

Computed tomography is particularly useful in the location and identiﬁcation of small osteochondral fragments in joints, particularly the elbow and tarsus (Figure 4-15, H and I).

Osteochondrosis of the Shoulder Joint. Clinically there is lameness, and extension of the shoulder joint evokes pain. Three views of the shoulder joint are necessary to demonstrate adequately the caudal third of the humeral head. If a single mediolateral study is uninformative, then mediolateral views with the proximal limb rotated cranially (pronation) and caudally (supination) should be made. These views are achieved by rotation of the elbow joint. Sedation combined with analgesics is advisable because these movements may be resisted. Both shoulders should be examined. Arthrography may be useful, especially in demonstrating a ﬂap of cartilage overlying a subchondral bone defect.

Radiologic Signs
1. There is a ﬂattened area or broad, shallow concave defect in the subchondral bone at the caudal third of the articular surface of the humeral head.
2. The defect frequently has a sclerotic margin.
3. A loose ﬂap of calciﬁed cartilage may be seen overlying the bone defect.
4. Radiopaque fragments of calciﬁed cartilage may be seen lying free within the joint. These fragments may be found in the caudal recess or in the cranial pouch.
5. Advanced cases show secondary degenerative changes in and around the joint (Figure 4-15, B to D). Occasionally a small discrete bone opacity is seen at the caudal aspect of the glenoid cavity of the humerus. This opacity represents a separate center of ossiﬁcation and should not be considered abnormal (Figure 4-15, K).

Elbow Dysplasia. The term elbow dysplasia is sometimes used to characterize three developmental disorders of the elbow joint. These are nonunion of the processus anconeus, fragmented coronoid process, and osteochondrosis of the distal humerus. Inherited polygenic traits cause these three conditions, which may occur independently or concurrently. It has been suggested that asynchronous growth of the radius and ulna and incongruity of the elbow joint may be causal factors in nonunion of the processus anconeus and fragmented coronoid process. The syndrome occurs in large and giant dog breeds. An oblique, 20-degree cranilateral-caudomedial view is most helpful in evaluating the medial coronoid process. Screening programs have been established in several countries with a view to eliminating these defects.

An International Elbow Working Group (www.iewg-vet.org) has been set up to study the question of elbow dysplasia. It recommends a grading system for classifying degrees of severity. Grade 0 is a normal elbow, grade 1 represents mild osteoarthritis, grade 2 is moderate osteoarthritis, and grade 3 is severe osteoarthritis. These screening programs are based on the premise that the presence of osteoarthritis in the elbow of a young dog is secondary to some form of elbow dysplasia rather than detection of the primary lesion.

Osteochondrosis of the Medial Humeral Condyle. This condition manifests itself as a defect on the articular surface of the medial trochlea of the distal humerus. Clinically there is an elbow lameness, and manipulation of the elbow joint is resisted.

Lateral and craniocaudal views of the elbow should be made. If the results are negative, an oblique craniocaudal view should be obtained. Radiologic signs include a semicircular subchondral defect, widening
Figure 4-15  A, Positive contrast arthrogram on a mediolateral study of the shoulder joint of a dog. The articular cartilages are clearly outlined as radiolucent lines between the contrast material and the subchondral bone. Contrast material is seen in the tendon sheath of the biceps brachii muscle cranially (open arrows) and in the caudal recess of the shoulder joint (arrows). The linear metallic object is a marker in an endotracheal tube. B to D, Osteochondrosis. B, A radiolucent defect is seen in the caudal third of the humeral head (arrows). C, Calcification of a cartilaginous flap (arrows). The flap covers a large defect in the subchondral bone. D, Cartilaginous debris is free in the caudal pouch of the joint capsule forming a “joint mouse” (arrow).
Ununited Anconeal Process. Nonunion of the anconeal process (processus anconeus) of the ulna is seen most frequently in the larger dog breeds, particularly the German Shepherd. It has also been reported in the Irish Wolfhound, the Bassett Hound, the Dachshund, and the Great Dane. In some large dog breeds there is a separate center of ossification for the anconeal process that is absent in small breeds. This center normally fuses with the diaphysis of the ulna between 4 and 5 months of age. Persistence of the growth plate beyond this time is abnormal. If fusion does not take place at the usual time, the anconeal process becomes partially or wholly detached from the ulna. It may be due to disturbance of endochondral ossification of the elbow and be a form of osteochondrosis. It has been suggested that incongruity of growth between the radius and ulna or trauma may predispose to nonunion. The result is instability of the elbow joint and a loose piece of bone within the joint. This condition precipitates secondary degenerative joint disease.

The clinical signs are lameness and a painful elbow on manipulation. A mediolateral view of the elbow joint, taken with the joint in extreme flexion, is required for a definitive diagnosis. Because the condition is frequently bilateral, both elbows should be examined.

Radiologic Signs
1. A radiolucent line of separation is seen between the anconeal process and the ulna. The medial epicondylar physis of the humerus should be separately identified.
2. The line of separation often has sclerotic edges.
3. If the condition has been present for some time, changes associated with secondary degenerative joint disease will be seen, including spurs of new bone around the margins of the joint.
4. Sclerosis of the adjacent medullary cavity of the ulna is seen (Figure 4-16, A).

It has recently been postulated that there is no separate center of ossification for the processus anconeus and that any separation in this area is abnormal.

Fragmented (Ununited) Coronoid Process. Fragmentation of the medial coronoid process is the most common developmental anomaly affecting the elbow joint of the dog. The coronoid process of the ulna lies just distal to the semilunar (trochlear) notch. It has a prominent medial projection and a smaller lateral component. The fragmented process may
Figure 4-15, cont’d Osteochondrosis. H and I. This 7-month-old Labrador Retriever had hock lameness for 3 months. The computed tomographic images show a lesion in the lateral trochlear ridge (arrow). J. Craniocaudal view of the elbow. A small semicircular depression (black arrow) is evident on the medial articular margin of the distal humerus. New bone formation is evident at the medial coronoid process (white arrow). Diagnosis: osteochondrosis and osteoarthritis. K. A 6-month-old male Golden Retriever. The tiny mineralized opacity (arrow) visible at the distocaudal aspect of the glenoid represents an ossification center and should not be mistaken for a fracture fragment. (H and I, Courtesy Dr. Yannick Ruel.)
be cartilaginous or ossified. It may be incompletely or completely separated from the ulna. The condition affects the larger breeds of dog, some of which have a genetic predisposition. It is more common in males. The lateral process is less commonly affected. The fragmentation is occasionally bilateral. In many cases, the fragment is not identified on radiographs and the diagnosis is based on excluding other forms of elbow dysplasia and detection of elbow osteoarthritis. Computed tomography is superior for detecting fragments or fissures of the coronoid process and allows the diagnosis to be made before radiographic signs of osteoarthritis are present.

Clinical signs include lameness and resentment of passive movement of the elbow joint. The affected limb may have the elbow held at an unusual angle, and there may be an altered gait. The condition should be suspected in cases of lameness associated with the elbow joint and where the anconeal process is normal and there is no evidence of osteochondritis dissecans of the humeral condyle.

**Fragmentation of the Medial Coronoid Process.** There is evidence of elbow degenerative joint disease. Osteophyte formation is first seen on the anconeal process. Osteophytes develop later on the medial humeral epicondyle and the radial head. In more chronic cases, an osteophyte forms on the medial coronoid process of the ulna. This may cause the medial coronoid process to appear enlarged and blunted, or the osteophyte may have a hooklike shape.

On the mediolateral view, the normal medial coronoid process is seen as a triangular structure through the head of the radius. In cases of fragmentation, the cranial border of the medial coronoid process may appear rounded or blunted, or the process may appear foreshortened.

There may be sclerosis of the ulna adjacent to the medial coronoid process. In chronic cases, a “kissing” defect may be seen (an area of localized decreased bone opacity).

**Radiologic Signs**
1. The most common findings are those of degenerative joint disease, which is the usual outcome.
2. Subchondral sclerosis is seen adjacent to the medial coronoid process.
3. A fragment may be present adjacent to the medial coronoid process. This may be seen on the mediolateral view through the head of the radius. If the fragmented portion is ossified, it is often seen on an oblique craniocaudal view of the elbow joint (Figure 4-16, C).
4. If the fragmented portion is cartilaginous, it will not be seen on radiographs.
5. A “kissing defect” may be seen in the subchondral bone of the humeral condyle adjacent to the medial coronoid process. This defect is close to the medial border of the humeral condyle articular surface and should not be mistaken for an osteochondrosis lesion.
6. In some cases there is a step defect between the head of the radius and the medial coronoid process, with distal malpositioning of the radial head.
7. The normal triangular outline of the medial coronoid process on a mediolateral projection may be absent.

**Figure 4-16** A, Nonunion of the processus anconeus of the ulna. This is best demonstrated with the elbow in extreme flexion. The line of separation is indistinct, and there is sclerosis of the processus anconeus and the main body of the ulna. B, Normal elbow, flexed.

*Continued*
Figure 4-16, cont’d C, A 9-month-old Labrador Retriever with a 4-month history of lameness in the left forelimb. A large mineralized triangular opacity (arrow) is present at the proximomedial aspect of the ulna. Diagnosis: fragmented medial coronoid process. D, This 15-month-old Labrador Retriever had a swelling on the medial aspect of the elbow joint for some months. A craniocaudal view shows two small mineralized opacities at the medial aspect of the medial epicondyle. Osteophyte formation is evident at the humeroulnar articulation. Diagnosis: ununited medial epicondyle. E, A retained cartilaginous core in the ulna (black arrows). The core has a sclerotic margin (white arrows). Interference with the distal ulnar growth has caused the radius to bend cranially.
8. On a mediolateral view there is a distinct step between the caudal margin of the radius and the cranial aspect of the ulna, indicating joint incongruity.
9. On a mediolateral view, the medial coronoid process may have a rounded, blunted outline rather than appearing as a triangular structure.

A laterally located sesamoid bone in the supinator muscle is seen in some dogs and is normal (Figure 4-1, D).

**Osteochondrosis of the Stifle.** Lesions of osteochondrosis sometimes affect the medial aspect of the articular margin of the lateral femoral condyle and less commonly the medial femoral condyle. These lesions have the usual manifestations of osteochondrosis in other joints. They are often bilateral.

Clinically there is lameness, swelling of the joint, and pain on manipulation.

**Radiologic Signs**
1. An intraarticular soft tissue opacity with cranial displacement of the normal fat pad is seen.
2. Subchondral bone defects of varying sizes are seen. These may be easiest to see on a slightly oblique lateral view where the two femoral condyles are not superimposed. Lesions range from subtle flattening of the subchondral bone to large concave defects.
3. The joint space appears widened at the site of the defect.
4. “Joint mice” are sometimes seen lying caudal to the femoral condyle within the joint capsule.
5. The caudal fascial planes are displaced because of the intraarticular swelling.
6. Changes associated with secondary degenerative joint disease are seen (see Figure 4-15, F).

**Osteochondrosis of the Hock.** The medial ridge of the talus is often affected by osteochondrosis. The lateral ridge is less commonly affected. It is most common in Rottweilers, Labrador Retrievers, and Bull Terriers. It may be bilateral. Clinically there is lameness and joint swelling.

A flexed dorsoplantar view of the hock is often necessary to demonstrate osteochondrosis of the lateral trochlear ridge of the talus. If the lesion affects the plantar aspect of the trochlea, a flexed mediolateral view will profile the lesion. Oblique craniocaudal views with a 30-degree lateral and medial rotation of the limb are often useful in evaluating the hock joints.

**Radiologic Signs**
1. Flattening of the medial trochlea of the talus.
2. Widening of the joint space at the site of the lesion.
3. There is marked joint effusion evidenced by soft tissue swelling.
4. “Joint mice” may be seen.
5. There is secondary degenerative joint disease (Figure 4-15, G to I).

**Ununited Medial Humeral Epicondyle.** Occasionally a separated linear bone fragment is located on the medial aspect of the humeral epicondyle on craniocaudal views of the elbow joint. On a lateral view a discrete mineralized fragment may be seen overlying the distal and caudal aspects of the epicondyle. Opinion is divided as to whether this is a traumatic or a developmental condition. An ununited medial humeral epicondyle is occasionally seen in young dogs of larger breeds. There is forelimb lameness exacerbated by exercise. Lameness may be pronounced after rest (see Figure 4-16, D).

**Retained Ulnar Cartilage Core.** Retained endochondral cartilage cores are sometimes found in the distal ulnar metaphyses of large, rapidly growing dogs. The etiology of the condition is unclear. Because of inadequate mineralization of the distal ulna, it may not grow as rapidly as the radius. This results in deformity of the radius, which continues to grow at a normal rate. It bows cranially. Valgus deformity is common. The abnormality may cause changes in the elbow and carpal joints. The animal is usually presented because of an angular limb deformity. In some cases the condition is seen as an incidental finding. Many animals show no clinical signs, and growth eventually progresses normally.

**Radiologic Signs**
1. A conical-shaped wedge of radiolucent cartilage is seen in the distal ulnar metaphysis, extending proximally from the physis. The base of the wedge is aligned with the physis.
2. The cartilaginous wedge is often surrounded by a zone of sclerosis.
3. Cranial bowing of the radius is common.
4. On a craniocaudal view, a valgus deformity will be evident if there is associated growth disturbance. Weight-bearing studies may be required to demonstrate the degree of angulation.
5. The distal radial epiphysis becomes distorted as a result of the growth disturbance in the ulna (Figure 4-16, E).

Retained cartilage cores in the lateral femoral condyles have been reported to be a cause of genu valgum in giant dog breeds. The retained cores may be seen radiographically.

**Hip Dysplasia.** Hip dysplasia is a developmental disease that affects the coxofemoral joints of the larger (over 12 kg), rapidly growing breeds of dogs. It may also affect smaller breeds of dogs and cats. The term itself means abnormally formed hip. The condition causes a laxity of the hip joints that results in instability, secondary degenerative joint disease, and subluxation or luxation. Commonly affected breeds include the German Shepherd, the Labrador Retriever, and the Rottweiler. The racing Greyhound is rarely if ever affected, probably because breeding stock is selected solely on performance criteria related to good musculoskeletal development. The earliest detectable clinical sign is joint laxity.

Complex interactive genetic and environmental factors are involved in susceptibility to the development
of hip dysplasia. Puppies are born apparently normal but develop dysplasia as they grow. The development of the changes seen is variable and inconsistent. Much remains to be explained about the disorder, and the reader is referred to the copious literature on the subject.

Radiography may be required either to evaluate the hip joints in cases of lameness or to assess the hips as part of a breeding program. Efforts are made to limit its occurrence by controlled breeding programs in which only normal or minimally affected animals are bred. Currently radiography is the only method available for conclusively demonstrating the presence of anatomic changes associated with the disease in the living animal. A radiographically normal pelvis does not preclude the possibility of an animal transmitting the genes for the condition to its offspring.

In the United States, the Orthopedic Foundation for Animals (OFA; www.offa.org) maintains a database and issues certificates of freedom from hip dysplasia after examination of radiographs by a panel of veterinary radiologists. Dogs must be at least 2 years of age for OFA certification. A similar certification scheme is operated in Great Britain by the British Veterinary Association (www.bva.co.uk). Dogs must be at least 1 year old to be assessed under this scheme. Evaluation in the British system is carried out by a point-scoring system in which a score of zero indicates no radiographic evidence of hip dysplasia. Points are added for each grade of defect detected. Many European countries and Australia have similar schemes. If certification of an animal is required, application should be made to the appropriate organization for details of the required procedures.

It is advisable to wait until an animal is at least 1 year old before undergoing radiographic evaluation for hip dysplasia, although earlier examination may be useful if the disease is suspected from clinical signs. Animals found to be free from the condition at 1 year of age should be reexamined again 1 year later. It is inadvisable to certify animals younger than 2 years of age as being free of hip dysplasia. This is because some animals, even though free of radiologic signs at 1 year of age, later develop secondary degenerative changes in the hips.

Clinically, affected animals show varying degrees of lameness or an abnormal, swaying gait associated with one or both hindlimbs. The severity of the changes seen radiographically do not always correlate to the degree of clinical lameness.

Radiography

For radiography of the hip joint, deep sedation or general anesthesia is advisable to facilitate proper positioning. A grid should be used. The animal is placed in dorsal recumbency with the hindlimbs drawn caudally and as nearly parallel to each other and to the tabletop as possible. The extended hindlimbs are rotated inward so that the patellae overlie the femoral trochleas. The limbs may be strapped to the table in this position. Inward rotation of the stifles enables the femoral necks to be clearly seen. The pelvis should be parallel to the tabletop. The tail should not be allowed to tilt upward, and the pelvis must not be rotated. The examiner can check for rotation by feeling the distance between the wings of the ilia and the tabletop. The wings should be equidistant from the tabletop. Accurate positioning may be difficult or impossible if there is any deformity in the lumbosacral region such as lumbar transitional vertebrae or deformity caused by trauma. The use of sandbags or a V-shaped tray can assist in maintaining the required position.

The legs should be retained as nearly parallel to one another as possible. This position will result in the medial cortex of each femur overlying the corresponding ischial tuberosity. Maintaining the limbs actually parallel to one another is not usually possible in dogs with well-developed thigh muscles. The x-ray beam should be centered at the level of the coxofemoral articulations.

Another method of radiographic examination using the ventrodorsal view for hip dysplasia has been described: Penn-HIP (Hip Improvement Program). A distraction device placed between the femurs is used to assist in the diagnosis of the condition in animals younger than 2 years of age. Distraction attempts to force the femoral heads out of the acetabula and enables an estimation to be made of the degree of joint laxity present. A distraction index has been devised to permit prediction of the probability of an animal developing dysplasia. The method can be used in animals older than 4 months.

If the ventrodorsal radiograph has been correctly made, the following features can be noted:
1. The wings of the ilia appear symmetric.
2. The obturator foramina appear equal in size and symmetric in outline. If the obturator foramina are different in size, this is an indication that the pelvis was rotated when the exposure was made. The smaller appearing foramen is rotated down toward the cassette. As a result of the rotation, the hip joint on the side of the smaller appearing foramen will seem shallower than it really is. Conversely, the opposite hip joint will appear deeper than it actually is.
3. The dorsal acetabular edges should be visible through the femoral heads.
4. The patellae should overlie the femoral trochleas (Figures 4-17 and 4-18).

Normal Appearance. The normal coxofemoral (hip) joint has the following radiographic features:
1. The acetabulum is deep.
2. The femoral head is round and even, except at the fovea capitis, where it is slightly flattened.
3. The outline of the femoral head parallels the outline of the cranial acetabular edge from the cranial effective acetabular rim to the fovea capitis.
4. The femoral head fits snugly into the acetabulum, and at least half of the head should be within it. The center of the femoral head should lie to the inner (medial) side of the dorsal acetabular edge.
5. The cranial third of the joint space is even and regular and is not increased in width.
6. The femoral neck is smooth and not thickened.
7. There is no evidence of secondary degenerative joint changes (Figures 4-18 and 4-19).

Radiologic Signs. Many radiographic changes may be associated with hip dysplasia, depending on the severity of the condition when the examination is carried out. Not all possible changes are necessarily seen in any one animal. Care, judgment, and experience are required in the interpretation of radiographs. The changes seen are as follows:
1. The acetabulum is shallow.
2. The femoral head fits poorly in the acetabulum. The head may appear to be too small for the acetabulum, and the joint space is widened.
3. The outline of the femoral head deviates from the outline of the acetabulum along the cranial and caudal acetabular edges. Some care is necessary in assessing this sign.
4. Subluxation or luxation of the femoral head may be present. Subluxation is present when less than 50% of the head is within the acetabulum. In cases of doubt, subluxation can be assessed by Norberg’s method. This consists of measuring the angle formed between a line joining the centers of the femoral heads and a line joining the center of the head under examination with the cranial effective acetabular rim on the same side. This angle should be no less than 105 degrees (Figure 4-20).
5. Osteoarthrosis is a common sequel to hip dysplasia, and many of the changes seen are associated with secondary degeneration of the joint. As a result of the poor congruity between the femoral head and the acetabulum, secondary degenerative changes occur. These include the following:
   a. Irregular wear occurs on the femoral head, causing it to become misshapen and lose its rounded appearance.
   b. The acetabulum becomes flattened or shallow and irregular in outline.
   c. A line of increased opacity appears on the femoral neck along the line of attachment of the joint capsule. This finding is indicative of stress on the joint capsule (Figure 4-21).
   d. New bone is produced around the acetabulum and on the femoral head and neck.
   e. The angle formed at the cranial effective acetabular rim is worn away, producing a flattened area at that point. This effect is referred to as bilabiation.
   f. There is an increase in opacity (sclerosis) of the subchondral bone along the cranial acetabular edge.
   g. Coxa vara or coxa valga may develop, that is, changes in the angle between the femoral neck and the femoral shaft.

An early sign of coxofemoral degenerative joint disease has been described. This sign takes the form of a radiopaque line beginning at approximately the junction of the femoral head and neck and extending distally rather than encircling the femoral neck. The line of opacity represents new bone formation on the caudal aspect of the femoral neck. It is sometimes called the Morgan line.

Hip dysplasia is usually bilateral, but unilateral cases are seen. The incidence ranges from 3% to 30% depending on the breed and geographic population. It occurs more frequently unilaterally in the Newfoundland, Akita, and Golden and Labrador Retrievers. If only one hip is affected, trauma should be considered a possible cause of any abnormalities seen.

Minor deviations from normal can be difficult to assess. A more lenient view should be taken in interpreting radiographs of animals older than 2 years in the absence of evidence of secondary joint disease. The radiologist must also be aware of the conformational differences that exist among different breeds of dogs (Figure 4-22).

Ultrasoundography. Ultrasound has been used to examine the hip joints of neonatal puppies. Its usefulness has not been established.

Osteochondrodysplasia. Osteochondrodysplasia is the term used to describe a group of developmental disorders of the skeletal system seen in several breeds of dogs and often resulting in disproportionate dwarfism. In most cases the cause is genetic.

Chondrodysplasia. The features of chondrodysplasia are seen as normal anatomic variants in chondrodystrophic breeds such as the Dachshund and the Bassett Hound (Figure 4-23). Such features have also been reported in the appendicular skeleton of the Alaskan Malamute. Other breeds such as the Norwegian Elkhound may have a generalized skeletal involvement. Impaired endochondral ossification causes the diaphyses of the bones to be short, thickened, and abnormally curved, with prominent extremities. There is lateral deviation of the limbs (valgus deformity) below the carpus and carpal joint enlargement. There are varying degrees of shortening of the limbs. In some cases there are vertebral abnormalities. In
Figure 4-17  A, Good position of the pelvis on the ventrodorsal view. B, Lateral view of the pelvis. C, Pelvis of a Bassett Hound. D, Teat shadows (arrows) may overlie the hip joints and be mistaken for abnormalities.
Figure 4-18 A, Normal pelvis. B, Diagram of a normal pelvis.
achondroplasia, impaired endochondral ossification results in abnormally short limbs.

Multiple Epiphyseal Dysplasia (Dysplasia Epiphysialis Punctata). Multiple epiphyseal dysplasia has been described in Beagle puppies and miniature Poodles. Punctate, calcific, or bony opacities are seen in the epiphyses, which have a stippled appearance. There is failure of ossification at the epiphyseal centers. Affected puppies show a swaying hindlimb gait, sagging hocks, and forelimb lameness. Adult animals may show periodic lameness resulting from limb deformities or secondary degenerative joint disease.

Pseudoachondroplasia. Stippling of the epiphyses has been described in young Poodles and Scottish Deerhounds associated with dwarfism and locomotor incapacity. In adult animals the bones are short and malformed. There may be angular limb deformities (Figure 4-24).

Osteochondrodysplasia of Scottish Fold Cats. Scottish Fold cats are subject to a form of osteochondrodysplasia resulting in deformities of the metacarpus, metatarsus, and phalanges. The bones are short and deformed. The caudal vertebral end plates are widened and the vertebrae foreshortened. Secondary changes occur in associated joints, causing severe locomotor problems.

A similar condition has been described in Scottish Deerhounds and Bull Terriers.

Ocular-Skeletal Dysplasia. Labrador Retrievers and Samoyeds are subject to a form of dysplasia with shortened forelimbs, widening of the growth plates, and metaphyseal flaring, resulting in deviations of the elbow and carpus. There are concomitant ocular deformities, including cataract and retinal detachment.

Congenital Hypothyroidism. Congenital hypothyroidism has been reported in medium to large dog breeds such as the Boxer and the Great Dane. It results from aplasia or hypoplasia of the thyroid gland. Affected cats and dogs have thickened radial and ulnar cortices, bowing of the forelimbs, and short spines. Radiographically there is delayed or reduced ossification of cartilage, particularly in the limbs and vertebrae. The skull may be foreshortened.

Stunted and disproportionate growth with locomotor disability has been described associated with hypothyroidism in dogs and cats. Congenital hypothyroidism is rare and causes absence of or delayed appearance and development of epiphyseal growth centers. This results in a disproportionate dwarfism. Some cases are inherited. If diagnosed early, abnormalities may regress with treatment.

Miscellaneous Anomalies

Arteriovenous Fistula. An arteriovenous fistula is a communication between an artery and a vein that bypasses the normal capillary bed. It may be congenital or acquired as a result of trauma. It is rare in dogs and even rarer in cats. An arteriovenous fistula may affect bone, causing a mild periosteal reaction and some loss of bone opacity in the region of the fistula. A large fistula can cause pain in the limb, lameness, and ulceration. Pulsation may be felt in a peripheral vein. A small fistula may pass unnoticed. Angiography is required to demonstrate details of the lesion (Figure 4-25) (see Chapter 6, p. 543, and Figure 6-3).
Congenital Malformations. Various congenital anomalies, such as polydactyly (supernumerary digits) or the absence of one or more of the phalanges, are occasionally seen. Absence or malformation of diaphyseal bones is occasionally encountered (ectrodactyly); fusion of two or more digits (syndactyly) is occasionally seen (Figure 4-26).

Multiple Cartilaginous Exostoses (Multiple Osteochondromatosis, Hereditary Multiple Exostoses). Multiple cartilaginous exostoses have been reported in dogs. It is a developmental condition of young animals affecting bones that develop by endochondral ossification. It may be inherited in dogs. The abnormalities appear as protrusions in the metaphyses of affected bones. The exostoses grow with the developing skeleton and cease to grow at maturity. The cortex and the medullary cavity of the affected bone are continuous with those of the exostoses. Pressure on surrounding tissues may cause clinical signs of lameness, though they are usually of no clinical significance. Malignant transformation may occur. A single cartilaginous exostosis is called an osteochondroma (Figure 4-27).

In adult cats a similar condition is seen affecting the mandible, scapula, and vertebrae. It is probably of viral origin.

Premature Closure of Physes. Trauma may precipitate premature closure of a physis. The condition,
particularly in the distal radius and ulna, is not uncommon in dogs; the distal ulnar physis is commonly affected. Because of the conical shape of the distal ulnar physis, blunt external trauma to it causes crushing or partial crushing injuries rather than separation of the physis as tends to happen in the distal radius. Premature closure of the distal ulnar physis results in significant retardation of growth of the ulna because this physis is responsible for up to 80% of ulnar growth. Ulnar growth is retarded, yet the radius continues to grow at a normal rate. The distal radial growth plate accounts for some 75% of radial growth. The restriction imposed on growth of the limb as a result of reduced ulnar growth causes the radius to bow cranially. The distal limb is deviated laterally (valgus deformity), and the paw is rotated outward. Subluxation of the elbow joint and distortion of the radiocarpal joint may occur. Radiographs of the opposite limb should be made for comparison, especially in early cases. Infection in the physis may also disturb growth.

Radiologic Signs. The following signs are observed with premature closure of the distal ulnar physis:
1. The cartilaginous growth plate (physis) at the distal ulna is partially or completely ossified.
2. There are varying degrees of bowing of the radius.
3. The caudal radial cortex becomes thickened. The thickening is most marked in the area of greatest curvature.
4. The lower limb is deviated laterally on the cranio-caudal view, with outward rotation of the paw. The carpus may be deformed.
5. Subluxation of the elbow may be seen in more severe cases. The radial head is subluxated laterally and the humeroulnar joint space is widened.
6. Changes of secondary degenerative joint disease may be visible in the elbow and carpus.

The proximal and distal radial physes may also be sites of premature closure. If the proximal radial physis is affected, the radius is shortened, and there is caudal bowing of the ulna. The humeroradial joint is widened, and there may also be widening of the humeroulnar joint space. The radiocarpal joint may be subluxated. Involvement of the distal radial physis results in angulation of the distal limb. There may be subluxation of the humeroulnar articulation. Premature closure of the lateral side of the distal radial physis has been described. The medial side continues to grow normally, causing an angular deformity of the radial articular surface. There is a valgus deformity of the carpus and outward rotation of the paw (Figures 4-28 and 4-29).

Fractures
A fracture may be defined as a break or solution in the continuity of a bone. A break in continuity between the metaphysis and the epiphysis is often referred to as an epiphyseal or physeal separation and sometimes as an epiphyseal fracture. Fracture may be the result of trauma, or it may occur because the bone has been weakened by disease (pathologic fracture) (Figure 4-30).

Classification. For descriptive purposes, fractures may be classified as follows.

Complete or Incomplete. In a complete fracture there is a break through the entire substance or width of the bone. An incomplete fracture retains some degree of continuity between the fractured ends, such as occurs in a fissure or greenstick fracture. A greenstick fracture is one that occurs through the cortex on the convex side of a bone that has been bent while the opposite cortex remains intact. A torus fracture occurs through the cortex on the concave side of a bone that has been bent. In a fissure, or hairline fracture, there is a thin fracture line without any appreciable separation of the fractured ends; the full depth or width of the bone is not involved (see Figure 4-30, N).

Closed or Open (Compound). A closed fracture has no communication with the exterior. An open (compound) fracture is associated with a wound and is thus in communication with the exterior. On radiographs, air shadows can usually be seen in the soft tissues at the site of a compound fracture.
Simple or Comminuted. A simple fracture has only two fracture fragments; a comminuted or multiple fracture has three or more associated fragments. A “butterfly” fragment is a wedge-shaped piece of bone at a fracture site. A segmental fracture has two fracture lines resulting in the separation of a segment of bone between the fracture lines (Figure 4-30, O and P).

Transverse, Oblique, or Spiral. In a transverse fracture the fracture line is at right angles to the long axis of the bone. In an oblique fracture the fracture line is at an angle to the long axis of the bone. In a spiral fracture the fracture line winds along the long axis of the bone (see Figure 4-30, D).

Avulsion or Chip. In an avulsion fracture a bone fragment is pulled away from the bone at the point of attachment of a tendon or ligament. A chip fracture is a separation of a small piece of bone without disruption of its general continuity. Chip fractures occur at or near joint margins (see Figure 4-30, G, H, J, and L). Ultrasonography is useful in locating small bone fragments (Figure 4-30, W).

Impacted (Compression) or Overriding. An impacted fracture has the fracture fragments embedded in one another as a result of compression. It is most commonly seen in vertebral bodies. In an overriding fracture, one of the fracture fragments lies partially alongside the other (see Figure 4-30, A).

Pathologic or Stress. A pathologic fracture occurs at a site where a disease process has weakened the bone. An incomplete pathologic fracture is referred to as a folding fracture because the bone appears to fold in on itself. A stress fracture results from continued minor trauma to a bone when the repair processes, over a period of time, fail to keep pace with the repeated damage. Stress fractures can be difficult to demonstrate on conventional radiographs. Bone scintigraphy is useful when such fractures are suspected (see Figure 4-40, G).

Diaphyseal or Epiphyseal. A diaphyseal fracture occurs in the shaft of a long bone. An epiphyseal fracture or, perhaps more correctly, epiphyseal (or physeal) separation or slip, occurs when the epiphysis of a bone is displaced from its normal position. The movement takes place at the physis. An epiphysis
Figure 4-22, cont’d Hip dysplasia. C, Severe remodeling changes are seen in the acetabula and the femoral heads. The femoral necks are grossly thickened. The right femoral head is more than 50% luxated. D, The acetabula are flattened. The heads of the femurs are no longer within the acetabula. Inflammatory new bone formation is present, particularly in the acetabula and less obviously on the femoral necks. E and F, This 8-month-old Labrador Retriever had a history of abnormal gait and asymmetric development of the muscles over the hindquarters. E, On the extended ventrodorsal view both femora are subluxated. F, The frog-leg, or flexed, ventrodorsal view shows that the severity of this condition can be missed unless an extended ventrodorsal view is taken. Diagnosis: hip dysplasia.

may be the site of a separation with or without a concomitant fracture.

The Salter-Harris classification is often used to describe fractures in the region of the physis associated with an epiphyseal separation.

Type I: A simple epiphyseal separation. The epiphysis is separated from the metaphysis without any bone fracture (see Figure 4-30, I).

Type II: An epiphyseal separation with a fracture of a corner of the metaphysis (see Figure 4-7, J).
Type III: A fracture extending from the joint surface to the physeal plate with separation of the detached piece (see Figure 4-30, E).

Type IV: A fracture extending from the joint surface through the physeal plate and through a portion of the metaphysis (see Figure 4-30, C).

Type V: A condition in which the physeal plate is crushed between the epiphysis and the metaphysis. There is usually no displacement.

Eccentric physeal impaction is sometimes referred to as a type VI fracture.

In this classification, in general, the dog or cat with a type I physeal separation usually has the best prognosis and type V the poorest, with regard to the premature closure of a growth plate and development of a growth deformity (Figure 4-31, A).

Radiography. If a fracture is suspected, at least two radiographs, at right angles to one another, should be made of the affected area. The studies should include the joints proximal and distal to the suspected fracture site. Two views are required to relate the positions of the fracture fragments to one another three dimensionally. A fracture line may be missed if relying on one view alone. In fractures with little or no displacement, an oblique view may be required to demonstrate the fracture line.

Most fractures are readily recognized on radiographs because there is usually some separation of the fractured ends. The fracture line appears as a line of radiolucency between the fracture fragments. Physis and nutrient foramina must not be confused with fracture lines. In most cases, recent fractures have an associated soft tissue swelling.

When describing a fracture, the proximal fragment typically is considered as being fixed in position and the distal or caudal fragment as being displaced relative to the proximal. A selection of fractures is shown in Figure 4-30.

In the study of fractures, radiography may be required for one or more of the following reasons:
1. To confirm a clinical diagnosis.
2. To demonstrate the positions, relations, and nature of the fractured bone fragments, with a view to deciding on the best method of treatment.
3. To determine the age of a fracture.
4. To measure the length of a bone and the width of the medullary cavity, with a view to selecting the right size of prosthesis. This is often done by taking a radiograph of the corresponding intact bone of the opposite limb.
5. To visualize a suspected fracture not demonstrable clinically.
6. To assess the degree of healing.

If a fracture is suspected but is not demonstrable radiographically, the area should be reexamined after a few days, when bone resorption along the fracture edges may make it visible. Bone scintigraphy is useful.
Figure 4-24 A, This is an 11-year-old cross-bred Jack Russell Terrier. There is marked deformity of the hindlimb. The femur and tibial diaphyses are short with wide extremities. The metatarsals are the same length as the femur and tibia. Similar changes were evident in all four limbs. This is disproportionate dwarfism. B and C, This 3-month-old Poodle had walked abnormally since birth and had an abnormal splayed hindleg stance. B, The epiphyses of the stifle are stippled and irregular. C, This is the ventrodorsal view of the pelvis of the dam of the puppy pictured in B. It shows malformation of the femoral head and neck and enlargement of the distal femurs and proximal tibias. Diagnosis: pseudoachondrodysplasia.
Figure 4-25  Arteriovenous fistula. A, The trabecular pattern in the epiphyses of the femur and tibia is coarse, and there is loss of normal bone opacity. B, An angiogram shows a massive proliferation of vessels resulting from an arteriovenous fistula. C, The hock of the same animal showing loss of bone opacity and coarse trabeculation. A second fistula was present at the hock. There was pulsation in the saphenous vein.
Figure 4-26  A, Congenital anomalies of the tarsus and digits of a cat. The second metatarsal and digit are absent. B, This 4-month-old puppy had been abnormal since birth and had difficulty using its forelimb. The radius and ulna are completely separated from each other and from the carpus. The humeroradial joint is luxated. The ulna maintains a relatively normal alignment with the humerus. Only three metacarpal bones are present, and two phalanges are seen on each digit. The radius is displaced medially and cranially and is separately encased in a skinfold. Diagnosis: ectrodactyly. C and D, Syndactyly and ectrodactyly in an immature dog. The patient has a reduced number of metacarpal bones and phalanges. A normal first digit, the dew claw, is present. The split between the lateral and medial digits extends proximally between the metacarpal bones. This division between the metacarpal bones is referred to as a split hand deformity, or ectrodactyly. The metacarpal bones of the medial digit are fused. The proximal phalanges of the digits are also fused proximally. The fusion of the metacarpal bones and phalanges is termed syndactyly. E, Congenital ectrodactyly with severe hypoplasia of the ulna in a dog. The accessory carpal bone is markedly hypoplastic and positioned just distal to the elbow. (B, From Pratschke K: A case of ectrodactyly in a dog, Irish Vet J 49:412, 1996.)
Descriptions of fractures should be accurate and should give sufficient information to enable a decision as to the best method of treatment.

**Fracture Repair.** After a fracture occurs, there is hemorrhage, thrombosis, and death of the bone at the fractured ends. A hematoma is formed. Increased vascularity associated with vasodilation, changes in the pH of the tissue fluid, and osteoclastic activity result in resorption of bone along the fractured ends. The periosteum and endosteum are stimulated to initiate a repair process. Undifferentiated mesenchymal tissue arising from the periosteum and endosteum begins to form on either side of the fracture line. This tissue forms a bridge between the fractured ends, the periosteal bridge being the *external callus* and the endosteal bridge being the *internal callus*. Around the fracture site, cartilage is elaborated, and healing in this area then proceeds by endochondral ossification (*secondary bone healing*). Farther away, on either side, intramembranous ossification takes place beneath the periosteum. The extent of the callus formation will depend on the periosteal damage sustained at the time of injury. Ossification of the cartilage produces the first bony callus, which is large and irregular in outline. Subsequently, remodeling takes place, and the callus is incorporated into the general bone structure.

In cases in which apposition of the fractured ends has been accurately achieved and maintained by surgical methods, for example, by compression plating, repair takes place by intramembranous ossification (*primary bone healing*)—that is, by periosteal and endosteal extension rather than by organization of a hematoma. Little if any callus may then be seen.

From knowledge of repair processes, what the radiographic appearance will be like at various stages of bone repair can be deduced. It must be emphasized that not all bones heal in exactly the same way. Complicated processes are involved, and any time scale given for fracture healing is at best an approximation. The bones of young animals heal more rapidly than those of older ones. Disease processes, local or metabolic, and concurrent soft tissue injury may retard bone healing. The method of immobilization affects the rate of healing. Efficiently immobilized fractures heal more rapidly than those in which movement of the fractured ends is possible. Intramedullary pinning may slow bone healing as a result of interference with the endosteal blood supply.

The following time scale may be used as a rough guide to the changing radiographic appearance of a healing fracture:

1. **Recent fractures:** The fracture line is sharp and well defined. There is an associated soft tissue swelling.
2. **Fractures of 1 week to 10 days:** The fracture line is no longer sharp because of the resorption of bone along the fractured ends. Hairline fractures may be seen more clearly at this time than immediately after their occurrence. An early, indistinct periosteal reaction is in evidence. The soft tissue swelling has subsided. In young animals periosteal reaction becomes visible earlier than in mature animals.
3. **Fractures of 2 to 3 weeks:** Periosteal reaction is more marked, and the callus is being mineralized.
4. **Fractures of 4 to 8 weeks:** The fracture line becomes filled in with bony callus, and there is advanced bridging of the fracture site with new bone.
5. **Fractures of 8 to 12 weeks:** The callus is being remodeled, organized and incorporated into the general bone structure. The amount of visible callus is decreasing (Figure 4-31, B to D).

The process of reorganization and remodeling may take several months. The time scale of repair is extremely variable and depends on several factors, including the type of fracture, the degree of displacement and distortion originally present, the efficiency of immobilization, and the condition and age of the animal.
In assessing whether a fracture line has been bridged by callus, overlapping tongues of callus can be confused for actual union. Oblique views may be required to evaluate the degree of repair accurately. Little or no callus may be visible after compression plating (Figure 4-32, A).

**Radiologic Signs.** Fracture repair is associated with the following signs:
1. Bridging of the fracture line with a bony callus.
2. Obliteration of the fracture line. This feature should be demonstrated on more than one view.
3. Remodeling of the callus, with restoration of the cortex and medullary cavity.
4. Restoration of the normal trabecular pattern (Figure 4-32, B and C).

**Nonunion of Fracture.** Occasionally the fractured ends of a bone fail to unite. This nonunion of a fracture is most commonly seen in the smaller dog breeds. The distal radius and ulna and the distal tibia and fibula are common sites of nonunion, although other bones may be affected. The cause remains obscure, but movement of the fractured ends is probably a prime factor. Poor blood supply and infection also militate against a primary union. Nonunion is more common in dogs older than 1 year. Two categories of nonunion fracture have been recognized, viable and nonviable, and each includes several classifications.

Nonunion fractures may be viable or nonviable. *Viable fractures* display evidence of an ongoing but unsuccessful attempt to heal the fracture. There is an ineffectual callus. A *hypertrophic* viable nonunion fracture displays a large ("elephant’s foot") callus. It usually results from movement at the site of fracture. An *oligotrophic* nonunion shows scant callus formation and little evidence of an active repair process. The fractured ends are joined by fibrous tissue. Such fractures may be difficult to distinguish from delayed union. *Nonviable fractures* usually result from a severe disruption of the blood supply to the area and wide separation of the fractured ends, which are frequently rounded off. There is no evidence of an active repair process.

*Delayed union* is where the fracture is repairing but is taking much longer than normal to complete the
The classification of nonunion fractures is somewhat arbitrary, and it is often difficult to be certain about the exact status of any individual fracture. Bone scintigraphy will aid the differentiation in establishing the status of the bone healing.

Radiologic Signs

**Viable**
1. A clearly visible fracture line, long after the fracture has been sustained
2. A nonbridging callus that varies in size from small to large, the latter often being referred to as an “elephant foot” callus
3. A rounding off of the fractured ends, which become smooth and sclerotic

**Nonviable**
1. A clearly visible fracture line
2. Little if any callus formation
3. Fracture ends that tend to taper off, with sclerotic margins
4. Sclerotic medullary cavity

With either type, a pseudoarthrosis may develop, with fibrous tissue simulating a joint. Disuse osteopenia may develop in the bones distal to the fracture. Judgment must be exercised in correlating clinical and radiographic findings. There may be good clinical union with restoration of a considerable amount of function despite the fact that radiographically a fracture line has not been completely bridged. Some fractures show delayed union; that is, they take longer than usual to heal. With such fractures there will be still some evidence of repair activity. A diagnosis of nonunion should not be made too quickly (Figure 4-33).

**Malunion of Fracture.** Malunion is present when a fracture has healed in such a way that the fracture fragments are in abnormal alignment, resulting in distortion of the bone. The significance of malunion depends on its severity and the site. Remodeling processes may minimize its effects. Malunion can lead to secondary arthritic changes in joints above and below the fracture site because of abnormal stresses being placed on them as a result of the bone distortion (Figure 4-34, A).
Figure 4-30 A selection of fractures. A, Fracture of the scapula. B, Fracture of the capitulum of the distal humerus. C, Fractures of both the capitulum and trochlea of the distal humerus (“Y fracture”). D, Fissure fracture in the radius (arrows). Dorsopalmar (E1) and mediolateral (E2) views of the antibrachioarcopal joint in a dog that had been in a road traffic accident. Separation and fracture of the distal epiphysis of the radius are present. The separation is not readily seen on the lateral view. This illustrates the necessity for two views. This is not a recent injury because a periosteal reaction can be seen on the cranial aspect of the distal radius (Salter-Harris type III).
Figure 4-30, cont’d F, A fracture of the left femoral neck. The femoral head and neck have lost their normal opacity because of resorption of bone. This is common with intracapsular fractures because they usually interfere with the blood supply. G, Fracture of the accessory carpal bone. This is a common injury in the racing Greyhound. The most common site of fracture is the one illustrated, though fracture may occur at any of the angles of the bone. H, An avulsion fracture (arrow) of the distal extremity of a large metacarpal bone. This is seen, particularly in racing Greyhounds, as a result of tearing of the attachment of the collateral ligament of the adjacent joint. There is an associated soft tissue swelling. I, A physeal separation at the distal end of the femur (Salter-Harris type I). Note the smooth appearance of the end of the femoral diaphysis. A true fracture would have a more irregular appearance.
Figure 4-30, cont’d J, Fracture of the patella in a cat. K, Separation of the proximal epiphysis and crest of the tibia. L, Separation of the tibial tuberosity. M, Separation of the tibial tuberosity and cranial border of the tibia (crest).
Figure 4-30, cont’d Mediolateral (N1) and craniocaudal (N2) views of a greenstick (folding) fracture. Such fractures may appear as lines of increased opacity within a bone (arrows). Mediolateral (O1) and dorsoplantar (O2) views of a comminuted fracture of the central tarsal bone. This is a common injury in the racing Greyhound. The right leg is most commonly affected in dogs racing on left-hand tracks. The main fracture fragment is displaced medially and dorsally (arrows). Note that the hock has not collapsed.

Continued
Figure 4-30. cont’d Mediolateral (P1) and dorsoplantar (P2) views of a fracture of the central tarsal bone with collapse of the hock. The fracture is comminuted, and the talus is displaced distally (arrow). Such fractures carry a poorer prognosis than the type illustrated in Q1 and Q2. The fourth tarsal bone is also fractured. Q. Two views of a fracture of the os calcis or calcaneus. In Greyhounds this is frequently accompanied by a fracture of the central tarsal bone, as in this case.
Figure 4-30, cont'd R, Fracture of the femur. If the fractured diaphysis lies end-on to the x-ray beam, a peculiar "ring" effect is sometimes produced. This might be mistaken for a foreign body. S, Epiphysiolysis. This term is used to denote separation of an epiphysis, particularly at the femoral capital epiphysis. This pelvis has sustained multiple injuries, including bilateral separation of both femoral capital physes, a right sacroiliac subluxation, and fractures of both ischia. T, This Boxer had a history of slight lameness of the left forelimb that was exacerbated by exercise. An oblique radiolucent defect is seen in the radial carpal bone running from the proximolateral to the distomedial direction on the dorsopalmar view (T1). On the dorsolateral 45-degree palmaromedial oblique view (T2), there is some new bone formation on the dorsal aspect of the carpal bones and the fragment is seen more clearly. Diagnosis: fracture of the radial carpal bone; degenerative joint disease.

Continued
Incomplete Ossification of the Humeral Condyle.
This is an inherited condition seen in Spaniels and less commonly in other dog breeds. There is failure of fusion between the capitulum and trochlea of the humeral condyle, which normally unite by approximately the third month of age. This is seen as a sagittal radiolucent line at approximately the midpoint of the condyle. The lesion may not be visible on standard craniocaudal views. A 10-degree oblique craniocaudal view or a flexed craniocaudal view may be necessary to demonstrate it. The condition is often bilateral. In adults it predisposes to fracture. Complete fracture may occur with or without a history of trauma. Animals present with elbow lameness. Computed tomography is useful (Figure 4-34, B and C).
Figure 4-30, cont’d X and Y, Articular fracture of the medial condyle of the distal femur in a puppy. X, The mediolateral study shows a slight distension of the caudal joint capsule. Y, On the craniocaudal projection there is a type IV Salter-Harris fracture that is only visible on this projection. This case emphasizes the importance of obtaining two views at right angles to each other. Z, This close-up radiograph of the distal tibia shows endosteal thickening (arrows). This is probably caused by stress remodeling in the area as a result of a trauma.
Figure 4-31 A, Salter-Harris classification of epiphyseal plate injuries. B to D, Three stages in the repair of an untreated fracture. B, Recent fracture. C, Three weeks after occurrence, callus formation is evident. D, Ten weeks after occurrence, there is excessive callus formation incorporating the fragments. The fracture line is not yet completely bridged. The delayed union is probably the result of the comminution and ineffective immobilization.
Figure 4-32  A, No callus formation is visible at the site of injury in this healed fracture of the radius (arrow). There is some callus associated with the ulnar fracture. B, An oblique overriding fracture of the femur. The distal femur is rotated. C, Five weeks later, remodeling is evident and the distal fragment is no longer rotated. D, This is a dorsopalmar projection of the left antebrachio-carpal joint of a racing Greyhound that had been lame for several weeks. A nondisplaced transverse fissure fracture (arrow) is visible in the proximal second metacarpal bone. Smooth periosteal reaction is evident bridging the fracture site, and sclerosis is present in the adjacent fracture ends. The first digit is superimposed on the area. Oblique projections are often required to fully examine this area in racing and working dogs. This is a common injury in this type of dog.
Metabolic Bone Disease

Bone is affected by changes in the composition of the circulating blood. Abnormalities of the body's metabolic processes may be reflected in bone. Changes in bone usually reflect severe rather than mild metabolic disturbances. The calcium content of bone must be reduced by approximately 50% before radiographic changes become evident. Metabolic disease should be suspected when changes are seen in several bones. Solitary bone lesions are not likely to be the result of metabolic causes.

Nutritional Secondary Hyperparathyroidism (Juvenile Osteodystrophy, Nutritional Osteodystrophy, Nutritional Osteoporosis, Osteodystrophia Fibrosa). Nutritional secondary hyperparathyroidism is occasionally seen in young dogs and cats. It affects animals fed exclusively, or almost exclusively, on meat, which has a low calcium and high phosphorus content. Excessive intake of phosphorus will produce hyperparathyroidism, even in the presence of a normal calcium intake. The excessive phosphorus intake causes a hyperphosphatemia that in turn depresses calcium levels. The resulting hypocalcemia stimulates increased production of parathyroid hormone. This hormone causes a decreased renal reabsorption of phosphate and increased reabsorption of calcium. The calcium deficiency also results in a deficiency of matrix. Furthermore, there is increased resorption of bone by osteoclasts, causing a release of calcium into the bloodstream. The bone resorption results in generalized decreased bone opacity.

Clinically, the condition is seen in young animals that appear to be well nourished but present with signs of locomotor impairment. The severity of the clinical signs varies from lameness on one limb to complete inability to rise. There may be reluctance to stand or move. If capable of movement, the animal does so tentatively and with difficulty. The bones are painful on palpation, and folding fractures are common. Feeding a balanced diet results in rapid remineralization of the bones and healing of any fractures. Deformities that are caused by fractures, however, may persist (see also Renal Secondary Hyperparathyroidism, Chapter 5, p. 463).

Radiologic Signs
1. There is a generalized skeletal demineralization (osteoporosis) in which contrast between the bones and the soft tissues is drastically reduced.
2. The cortices of the bones are extremely thin and shell-like.
3. There is a thin zone of increased opacity along the physeal edges of the metaphyses.
4. Trabeculae become coarse and prominent.
5. Physes are normal in width.

Figure 4-33 Examples of nonunion fracture. A, An old femoral fracture. Although there is considerable callus formation, the fracture line has not been bridged. The fractured ends have become rounded off. B, An 8-month-old fracture of the humerus. The fracture line is still obvious, and there is no callus formation. The fractured ends are sclerotic. C, Nonunion fractures of the radius and ulna. The fractured end of the proximal radial fragment is rounded and well margined.
6. Pathologic fractures are regularly seen. They are often of the folding (torus) or greenstick type. There is practically no separation of the fractured ends, but the bones are bent, with one cortex usually remaining intact. Old fractures appear as lines of increased opacity in the diaphyses of the bones.

7. Some long bones have an abnormal shape as a result of malunion of earlier healed fractures.

8. The spine may be abnormal in shape, with ventral curvature (lordosis) in the lumbar region being common, particularly in cats.

9. Compression fractures of the vertebrae may occur (Figure 4-35).
Osteogenesis imperfecta is a rare heritable condition in dogs and cats caused by a disturbance in collagen metabolism. The radiologic signs are similar to those of secondary hyperparathyroidism.

**Rickets.** Rickets is rarely seen nowadays as a clinical entity in the dog and cat. The disease is characterized by a failure of mineralization, particularly of the cartilaginous matrix at the physis. It may be the result of a deficiency of calcium, phosphorus, or vitamin D.

**Radiologic Signs**

1. In normal animals, the physes are but a few millimeters deep in the proximodistal direction. In animals with rickets, the physis become deeper in that direction and are irregular in outline.
2. The metaphyseal edge of the bone at the physis becomes wide, irregular in outline, and concave, giving a “mushroom” (flared) effect to the bone in that area (Figure 4-36).
3. Long bones may show some degree of demineralization, and bending or bowing may be present. Variations in the appearance of the metaphyses occur in some dogs that are young and rapidly growing, particularly larger breeds. They show a wide metaphyseal edge at the physis (flared metaphysis). The metaphysis is increased in opacity. The bone edges adjacent to the metaphysis may be irregular in outline. The epiphysis and physis are normal. The radius and the ulna are more commonly affected. The significance of such changes is questionable. It is probable that they do not constitute a clinical entity. The changes may be part of a normal growth process and should not be mistaken for rickets. These changes have been referred to as idiopathic osteodystrophy (Figure 4-37).

**Renal Secondary Hyperparathyroidism.** Renal secondary hyperparathyroidism may cause dystrophic calcification in soft tissues (see Chapter 5, p. 463).

**Neoplasia.** Bone neoplasia, although uncommon in dogs and cats, is nonetheless seen from time to time, particularly in larger dogs. It is often impossible to diagnose the type of tumor present from a radiographic study alone. Usually, however, a reasoned opinion can be given regarding whether a neoplasm is malignant or benign. Malignant tumors may be difficult to differentiate from osteomyelitis. Radiologically, the primary problem remains one of differentiating bone malignancy from osteomyelitis. Biopsy is almost always required. Neoplasms are usually painful. Occasionally on the ventrodorsal projection of the pelvis, focal radiolucent areas are seen in the area of the ischial bones. Air in the anal sacs—unilateral or bilateral—can simulate osteolysis in this area (see Figure 4-40, I).

**Radiologic Signs**

1. **Bone destruction:** Osteolysis is a more or less consistent feature of malignancy. Loss of the normal trabecular pattern in the metaphysis of a bone may be the first sign of disease. The cortex at the site of the tumor is destroyed, or at least expanded and thinned, as a result of the growing neoplasm.
2. **New bone formation:** Disorganized new bone formation often accompanies bone destruction. The new bone may extend into and invade the surrounding soft tissues.
3. **Indefinite outline:** No clearly demarcated division exists between affected and normal bone because there is a failure of the body defenses to confine the lesion. The lesion fades imperceptibly into the adjacent normal bone, with an ill-defined transitional zone. Sclerosis, if present, is disorganized in distribution.
4. **Periosteal reaction:** The periosteum becomes elevated at the site of the lesion, and subperiosteal new bone formation occurs. Often a triangle of new bone is formed between the elevated periosteum, the diaphysis of the bone, and the lesion (Codman’s triangle). This sign may also be seen occasionally in other conditions, such as osteomyelitis.
5. **Soft tissue swelling:** There is usually an associated large soft tissue swelling that may be caused by the tumor locally. Calcification of adjacent soft tissues is common.
6. **Pathologic fracture:** Neoplastic bone fractures easily. A pathologic fracture may be the first evidence of disease.
7. **Metastases:** Metastatic lesions may be found elsewhere in the body.
8. **Progression:** The disease progresses despite treatment.
9. **Origin:** Primary bone tumors commonly arise at the ends of the bones. Not all the preceding signs are seen in any individual case. “Aggressive” is sometimes used to denote a very invasive process in bone. Such a process may or may not be malignant. Soft tissue tumors may invade bone (Figures 4-38 to 4-41).

Distinguishing between malignant and benign lesions is not always easy. In general, malignant lesions are aggressive, destructive, and poorly defined. Reaction to a malignant process is not well organized. There is an ill-defined zone of transition between normal and abnormal bone. Calcification in adjacent soft tissues is common. Soft tissue tumors may invade bone. Polyostotic lesions are likely to be malignant. Metastatic lesions may be single or multiple in location and are usually destructive. Benign tumors are more clearly defined with a more organized reaction. There is usually a clearly defined margin between normal and abnormal bone, and the zone of transition is sharply margined. Benign bone neoplasms are much less common than malignant ones.

**Ultrasonography.** The echogenicity of bone neoplasms depends on the degree of production or destruction of bone. Hence, the echogenicity is variable. The normal hyperechoic cortical margins may be disrupted. Periosteal proliferation in the form of undulating hyperechoic edges is seen. Dystrophic calcification in the form of multiple hyperechoic foci scattered throughout the soft tissues casting acoustic shadows is visible. Disruption of fascial planes and soft tissue
Figure 4-35 Nutritional secondary hyperparathyroidism. A, This radiograph is of a 3-month-old domestic cat. There was splaying of the legs and hindquarter pain. The bones are poorly mineralized. There is little contrast between bones and soft tissues. There are folding fractures in both proximal femora and in the left distal femur. B, In this puppy the cortices are extremely thin, and there is a fracture in the proximal third of the tibia (arrow). C, This cat shows bowing of the tibia, and the femur is fractured in two places (arrows). The tibia is also fractured. D, This is a 4-month-old Irish Wolfhound showing healing fractures of the radius and ulna after treatment for nutritional secondary hyperparathyroidism.
swelling are also features. Ultrasound-guided fine-needle aspirates of the mass and the bone through a cortical defect are invaluable (see Figure 4-41, K). Bone scintigraphy is sometimes used to localize and stage neoplasms and to assess the skeleton for metastases.

**Osteosarcoma.** Osteosarcoma is the most common malignant bone tumor in the dog. More than 80% of all bone malignancies in dogs are osteosarcomas. Although it may be seen in dogs as young as 1 year of age, incidence is highest in dogs aged 5 to 9 years, with a peak at around 7 years. Large breeds such as the Great Dane, Saint Bernard, Irish Setter, German Shepherd, and Greyhound are particularly susceptible. Both sexes are equally affected. The prognosis is grave because metastases occur rapidly.

Clinically affected animals typically present with lameness and with a large, painful swelling at the site of the tumor. The condition is often first noticed after minor trauma.

Skeletal and soft tissue osteosarcoma occurs also in cats, but it is much less common than in dogs, and metastatic development is slower.

Three types of osteosarcoma can be distinguished:
1. **Lytic type (osteoclastic):** This is characterized by lysis, or destruction, of bone with little or no defensive response. There is early destruction of the cortex with invasion of the surrounding soft tissues. Early metastatic spread is typical.
2. **Sclerosing type (osteoblastic):** The principal feature of this type is new bone formation with increased radiographic opacity of the affected bone.
3. **Mixed type**: Areas of bone destruction and bone production are intermixed with one another. The tumor has a disorganized and aggressive appearance. This is the most common type.

*Multicentric (polyostotic) osteosarcoma* (arising in more than one bone at the same time) has been reported but is rare. Osteosarcoma may also arise in soft tissue. It is occasionally seen in degeneration of mixed mammary tumors in the bitch. It may also arise after esophageal infestation with *Spirocerca lupi*. Other sites may also be affected (see Figures 4-38 and 4-39).

**Radiologic Signs**
1. Many or all of the radiographic features of osteosarcoma will be those of a malignant bone tumor.
2. Osteosarcoma occurs most commonly at predilection sites. These are the distal extremities of the radius and femur and the proximal extremities of the humerus and tibia—"away from the elbow and around the stifle."
3. The lesion begins in the metaphysis of the bone but rarely crosses a joint space. The subchondral bone is usually spared.
4. Some cases show a so-called "sunburst" type of periosteal reaction. Spicules of periosteal new bone radiate outward from the tumor. Periosteal reaction without invasion is often seen on adjacent bones, such as on the ulna if the radius is affected.
5. Most animals presenting with a malignant bone tumor do not have macroscopic metastases at the time of presentation. The lungs are the most
common metastatic site, and thoracic radiographs should be taken in any case of suspected bone malignancy. Failure to demonstrate metastases on thoracic radiographs does not mean that the lungs are free of the disease. Pulmonary metastases are common late in the disease. Pulmonary metastatic foci appear as rounded, discrete opacities ("cannonball" metastases). Metastatic foci less than 5 to 10 mm in diameter may not be visible radiographically. Radiographs should be taken of the thorax with the animal in both left and right lateral recumbency because lesions not visible in the dependent lung may be seen when that lung is placed uppermost. Metastases to other bones are rare but are seen more often in dogs treated by chemotherapy or radiation (see Figures 4-38 to 4-40).
Figure 4-40, cont’d D and E, A mixed type of osteosarcoma of the left distal radius. Areas of lysis and areas of sclerosis are intermixed. There is a palisade-type of periosteal reaction and a well-marked Codman’s triangle. F, An osteosarcoma arising in the soft tissues of the right thigh. G, Pathologic fracture of the humerus associated with osteosarcoma. H, An osteosarcoma affecting the left femoral head. This is an unusual site for this type of tumor. The right hip has osteoarthritis. I, This is a ventrodorsal projection of the pelvis of a dog that was taken for assessment of hip dysplasia as part of a breeding program. Two oval radiolucent shadows (arrows) are seen superimposed on both ischial bones. These shadows are the result of air in the anal sacs and should not be mistaken for an osteolytic destructive process.
Figure 4-41 A, An undifferentiated sarcoma affecting the metatarsal bones. B and C, A reticulum cell sarcoma affecting the ulna. There is loss of bone opacity in the olecranon on the craniocaudal view. D and E, A fibrosarcoma in the tibia. A “window” effect is produced by bone lysis. The periosteal reaction is relatively mild.
Parosteal Sarcoma. Parosteal sarcoma is an uncommon and slow-growing tumor that arises in the periosteum or parosteal connective tissue. Masses of periosteal new bone surround the site. The cortex remains intact until late in the disease, and metastatic spread is slow. An affected animal may survive for up to 2 years.

Chondrosarcoma. Chondrosarcoma, the second most common tumor to affect the skeleton in the dog, is a neoplasm of cartilage. It is seen most frequently in the ribs but may also arise in the scapula, pelvis, or skull. When a rib is involved, chondrosarcoma presents as a hard, painless swelling at the costochondral junction (see Chapter 3, p. 279). Large and medium-sized dogs in middle age are usually the ones affected. Radiographically, there is osteolysis with periosteal reaction, which is often minimal in relation to the size of the tumor. Calcification may occur within the tumor mass. Surgical excision is often successful because the tumor is slow to metastasize (see Figure 4-41, N and O).

Fibrosarcoma. Fibrosarcoma is primarily lytic in nature and occurs in the metaphysis of a long bone. It results in widespread bone destruction. It is slow growing and frequently invades an adjacent joint space. There is a minimal periosteal reaction (see Figure 4-41, D, E, P, and Q).

Multiple Myeloma (Plasma Cell Myeloma, Plasmacytoma). Multiple myeloma, a tumor of the plasma
Figure 4-41, cont’d I, This is a Rottweiler with a history of hindleg lameness. There are osteolytic defects (arrows) on the distocranial femur, proximal cranial tibia, and both poles of the patella. This was a histiocytic sarcoma. There is intraarticular soft tissue swelling. J, Multiple metastatic lesions seen as radiopaque areas in the medullary cavity of the femur. K, This dog had a firm mass in the muscle region of the caudal thigh. Clinically it appeared to be attached to the underlying bone. On radiography a faint periosteal reaction was visible on the femoral diaphysis. The sonogram of the area shows that the hyperechoic margin (B) represents a bone/soft tissue interface. There is an echogenic mass (M) invading bone and elevating the periosteum (P) proximally (arrows). Fine-needle aspiration confirmed the mass was a soft tissue tumor invading bone.
Figure 4-41, cont’d L, A 7-year-old Labrador Retriever had a swelling on the foot. A dorsoplantar view of the phalanges shows a lytic process at the proximal aspect of the first phalanx of the fifth digit. Reactive new bone is present that involves the fifth metatarsal bone. This was a spindle cell tumor. M, A large cystic lesion in the ulna. The lesion is expansile and has caused marked thinning of the cortex. N and O, This 15-year-old cat presented with a right hindlimb lameness and swelling around the stifle joint. Mediolateral (N) and craniocaudal (O) projections of the distal femur show an expanding mineralized mass in the distolateral femur. It has a smooth undulating margin. The distolateral femoral cortex is interrupted. A less well-marginated proliferative lesion is present on the distomedical femur. Mineralization is present in the soft tissues medially. Histopathological diagnosis: chondrosarcoma.

Continued
cells, may occur as a solitary lesion (plasmacytoma) or as multicentric or generalized disease. Lesions appear as sharply defined “punched out” areas of lysis without any surrounding reaction. Flat bones and the ends of long bones are the usual sites (see Figure 5-42, G).

**Synovial Neoplasia-Joint Tumors.** Many joint-associated tumors have recently been classified as malignant histiocytic sarcomas. Malignant synovioma arises from the synovial lining of a joint or tendon sheath. It is seen most commonly in the elbow and stifle of medium-sized to large dogs. It is primarily destructive, or osteolytic, in nature and may affect the bones on either side of a joint. Mineralized deposits may be seen within the tumor mass. Periosteal reaction is minimal. This is an uncommon tumor in dogs, and it is even rarer in cats (see Figure 4-41, I).

**Other Bone Malignancies**

Other bone neoplasms (e.g., reticulum cell sarcoma, giant cell tumor, hemangiosarcoma) are occasionally seen. Except perhaps for osteosarcoma, attempts to differentiate one type of bone malignancy from another on radiographic evidence alone are not likely to be successful (see Figure 4-41, A to I).

Feline leukemia virus in cats may induce a medullary osteosclerosis in various bones, giving an increased opacity to the medulla.

**Metastatic Lesions.** Metastases of neoplasms to bone appear to be much rarer in the dog and cat than in humans. Metastatic disease should be considered in the differential diagnosis of solitary destructive lesions, especially if they occur at sites where primary bone tumors rarely occur. It is impossible, however, to

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Figure 4-41, cont’d P and Q. This dog had a firm soft tissue swelling affecting the right forelimb. There is a proliferative periosteal reaction (arrows) along the radius and ulnar diaphyses. The soft tissue swelling encircles the radius and ulna. This soft tissue mass was a fibrosarcoma invading bone.
Figure 4-42 Some examples of osteomyelitis. A and B, These craniocaudal and lateral views of the distal radius show a case of osteomyelitis. There is a central area of bone destruction surrounded by a well-defined sclerotic border. There is a sharp demarcation between normal and abnormal bone. There is a palisade-type periosteal reaction. Because of the site and degree of bone lysis, this might be interpreted as an osteosarcoma.

Benign Bone Tumors. Benign bone tumors are rare in the dog and cat. The benign tumor has well-demarcated edges, with a short transitional zone between normal and abnormal bone. It provokes no periosteal reaction and does not invade the surrounding soft tissues, although it may displace them. Osteomas have a smooth, rounded, radiopaque appearance. They are frequently seen in the skull or in the lungs (see Figure 5-6, D).

Other Bone Diseases

Osteomyelitis. Osteomyelitis is defined as inflammation of the bone marrow and adjacent bone, usually the result of infection. Suppurative osteomyelitis occurs when bacteria invade the bone. It may arise as a result of infection in a wound, whether traumatic or surgical, or it may be blood borne. Osteomyelitis may be localized if the defensive reaction contains it, or it may be disseminated throughout the bone if the inflammatory process is inadequate. A sequestrum is an area of dead bone. It has an increased radiopacity because of trabecular collapse. An involucrum is a radiolucent depression or recess in a bone lined by granulation tissue within which there is a sequestrum. Osteomyelitis may be acute or chronic. The clinical signs include pain, swelling at the site of infection, an elevated temperature in acute cases, and one or more discharging tracts in chronic cases.

Radiologic Signs
1. Loss of the normal trabecular pattern may be the first sign of osteomyelitis. This sign is often seen in the metaphysis of the bone, which is a predilection site of infection in young animals.
2. Lysis, or destruction, of bone appears as an area of radiolucency within the bone.
3. There is a periosteal reaction that may take various forms. It usually becomes apparent 7 to 14 days after the infection occurred. The reaction may extend for a considerable distance on either side of the area of infection. The periosteum often becomes elevated, and there is subperiosteal new bone formation. A Codman's triangle may develop.
4. The lesion may have a sclerotic margin that defines the limit of the infection. This margin represents an apparent attempt by the body to confine the infection. It usually indicates chronicity of disease.
5. A sequestrum may be seen as a fragment of well-defined cortical bone of normal opacity. It may
Figure 4-42, cont'd  C and D, Osteomyelitis secondary to coccidioidomycosis in the third metacarpal bone. The lesion is primarily sclerotic in nature.  E, Osteomyelitis provoking a profuse periosteal reaction.  F, Periostitis associated with osteomyelitis.  G, Coccidioidomycosis in the humerus.
Figure 4-42, cont’d H, Blastomycosis in the ulna. I to K, Osteomyelitis in the humerus. I, Two weeks after a dog bite. J, The healing phase 6 weeks later. K, Twelve weeks later.

Continued
Figure 4-42, cont’d L, Osteomyelitis in the radius. There is erosion of the cortex (arrows). M, This 10-month-old dog had a road traffic accident some months earlier. An old fracture site is evident at the junction of the middle and distal thirds of the bone diaphysis. The distal radial fracture fragment has been incorporated into the ulnar callus. The proximal radial fragment is isolated. There is a radiolucent circular area within the distal physeal region (arrow). A discrete opacity (a sequestrum) lies within this lucent area. Diagnosis: malunion fracture of the radius and ulna; bone sequestrum. N, This 4-month-old German Shepherd had a deviation of the right elbow and pain on movement for 3 weeks. A mediolateral view of the shoulder shows there is complete disruption of the normal shoulder joint. Radiolucent defects are seen in the distal aspect of the scapula, and a large cuboidal defect is present at the proximocaudal aspect of the humerus. Multiple separate opacities lie within the lesion in the proximal humerus. The articular margins are nonexistent. The proximal humeral epiphysis is not discernible. A soft tissue swelling was present. Diagnosis: infectious osteoarthritis. O, This mediolateral projection of the stifle of a dog demonstrates a multifocal osteolysis (arrow) in the proximal tibia. Diagnosis: leishmaniasis. P, This young cat has an exuberant proliferative periosteal reaction enveloping the humeral diaphysis. The reaction has a palisade-like conformation with columnar-like projections from the bone surface. The proximal metaphyseal region has multiple septated osteolytic areas within it. Histopathological diagnosis: pyogranulomatous osteomyelitis. (O, Courtesy Dr. A. Agut. P, Courtesy Dr. N. Sayyah.)
appear more opaque than normal because of the contrast with the surrounding lucent zone. Living and dead bone cannot be distinguished radiographically unless there has been collapse of bone trabeculae, in which case the dead bone appears more radiopaque than normal. Sequestrum formation suggests chronicity of disease.

6. An involucrum is seen as an area of decreased bone opacity surrounding the sequestrum.

7. There is often cortical destruction. The cortex becomes thinned and eventually eroded at the site of infection.

8. Involvement of a joint is unusual.

9. A soft tissue swelling is present, but this swelling usually is not as marked as that encountered with tumor formation. Sinus tracts or subcutaneous emphysema may develop.

10. There may be disuse osteopenia of the affected limb.

11. The more virulent the invading organism, the more aggressive is the reaction. Low-grade infections provoke bone sclerosis (Figure 4-42).

If serial radiographs are made during the course of treatment, the condition may be seen to be progressing or regressing. Normal bone structure begins to reappear in cases that are responding satisfactorily to treatment. The radiographic appearance of osteomyelitis is extremely variable. It is often difficult, if not impossible, to distinguish with certainty between it and neoplasia; both cause bone destruction and reactive processes within the bone.

Mycotic infections frequently involve bones in a nonsuppurative type of osteomyelitis, which may be multifocal. In the United States, coccidioidomycosis is seen in the Southwest and West, blastomycosis in the Midwest, and histoplasmosis in the Midwest. Systemic Aspergillus infection is uncommon and is seen sporadically throughout North America. Blastomycosis may produce aggressively destructive lesions in the early stages of infection. Coccidioidomycosis and blastomycosis produce proliferative, sclerotic bone changes with small lytic areas. Histoplasmosis produces a more destructive type of lesion. Mycotic infections frequently produce a mottled appearance in bone. Polyostotic osteomyelitis is more likely to be fungal than bacterial in origin (see Figure 3-15).

Metallosis is a term that has been applied to a non-suppurative osteomyelitis resulting from various reactions to metal implants in bones. The condition is noninfectious, even though sinus tracts may be present. Areas of radiolucency are seen around bone screws or other implants.

Bone scintigraphy is useful in localizing lesions that may not be discernible on clinical examination or visible on radiographs.

Paronychia. Paronychia is an infection of the nail bed. It is characterized by lysis of the third phalanx, a profuse periosteal reaction, and soft tissue swelling. It may be difficult to differentiate from neoplasia or intraosseous epidermoid cysts, which also affect the third phalanx in dogs.

Bone Cyst. Bone cysts are rare and usually benign. Young dogs are more likely to be affected. A cyst appears as a circumscribed area of decreased bone opacity. It originates in the metaphysis, causing expansion of the bone. There is loss of the normal trabecular pattern. Septa are frequently seen within it. The cyst is sharply demarcated from the surrounding healthy bone. There is cortical thinning but no associated inflammatory reaction. Pathologic fracture may occur at the site of a bone cyst because the cyst weakens the bone. Rarely, cyst formation affects several bones (see Figure 4-41).

An unusual form of cyst is the aneurysmal bone cyst, which is associated with vascular abnormalities and is indistinguishable radiologically from other types of cyst. Fibrous dysplasia is a developmental anomaly of bone that may have the appearance of a cyst.

Subchondral bone cyst is located in the subchondral bone of joints and may be associated with arthritis or osteochondrosis.

Hypertrophic Osteodystrophy (Metaphyseal Osteopathy, Skeletal Scurvy, Juvenile Scurvy, Barlow's Disease). Hypertrophic osteodystrophy is a disease of bone seen in young (2 to 8 months old), rapidly growing larger dog breeds. The etiology remains uncertain. Weimaraners are reported to have a breed susceptibility. Weimaraners are reported to have a breed susceptibility. The pathologic changes are seen in the metaphysis of an affected bone, where an area of necrotic bone appears in the metaphysis adjacent to an open physeal line. This appears as a lucent band in the metaphysis, creating an appearance that is sometimes termed a double physeal line. There is moderate localized soft tissue swelling, and a collar of parosteal mineralization surrounds the metaphysis. This is eventually incorporated into periosteal new bone formed around the metaphysis. The affected metaphyseal bone is eventually replaced by new bone, and the surrounding periosteal cuff becomes incorporated into the general structure of the bone. There may be some residual thickening of affected bones. All limbs may be affected, and in severe cases lesions may develop at the distal end of the ribs. Acute cases may present before radiological signs are evident. They usually appear within 48 to 72 hours.

Clinically, affected animals present with painful swellings at the metaphyses. Most commonly affected are the distal radius, ulna, and tibia. The animal is reluctant to move and has a high temperature, often as high as 106º F (41º C). Anorexia is common. The highest incidence is between 3 and 7 months of age. Males are more frequently affected than females. The condition is usually bilateral and self-limiting.

Radiologic Signs
1. A radiolucent band appears at the metaphysis of an affected bone (Trümmerfeld zone). It simulates a second physeal line.
2. Within 1 week to 10 days, an irregular collar of bone or calcification forms around the metaphysis outside the cortex. This area may extend to involve the entire diaphysis.
3. As the disease progresses, the metaphysis appears more opaque than normal because of the surrounding collar. The trabecular pattern is lost.
4. The physis remain normal in depth.
5. There is a diffuse soft tissue swelling about the metaphysis.
6. As the changes progress, the mineralized collar surrounding the metaphysis fuses with the bone. The metaphysis may appear thickened as a result.
7. Over a period of months, remodeling of the bone occurs and the abnormalities gradually disappear. There may be some residual thickening of the diaphysis of the bone in the metaphyseal region.
8. The changes are bilaterally symmetric. The disease is apparently self-limiting, and eventual full recovery is typical. However, it may recur and some patients may suffer multiple episodes. In rare cases, there may be mandibular lesions that resemble craniomandibular osteopathy. If the reaction is severe, growth retardation and limb deformities may occur (Figure 4-43).

**Canine Leukocyte Adhesion Deficiency.** Canine leukocyte adhesion deficiency has been reported in the Irish Setter, in which it is inherited. Radiologic changes are seen in the metaphyseal regions of the distal radius and ulna. There is osteolysis or mixed lytic and productive lesions. Changes are also present on the skull resembling craniomandibular osteopathy. If the reaction is severe, growth retardation and limb deformities may occur (Figure 4-43).

**Hypertrophic Osteopathy (Hypertrophic Pulmonary Osteoarthropathy, Hypertrophic Pulmonary Osteopathy, Marie’s Disease).** Hypertrophic osteopathy is a periosteal response to bone to chronic disease, usually within the thorax. It has also been reported associated with tumors of the bladder, liver, and ovary without thoracic involvement. It may be the result of primary or secondary neoplasia, chronic infectious diseases, parasitic infestation, or lung abscess. The etiology is unknown. It may be associated with circulatory disturbances. Vascular endothelial growth factor and abnormal platelet fragments have been implicated in the pathophysiology of this condition. Periosteal new bone develops around affected bones. The clinical signs include bilateral swellings around the distal limbs, which are tender to palpation. Lameness is common.

**Radiologic Signs**

1. Periosteal new bone formation is distributed symmetrically along the diaphyses of the long bones and the phalanges. The earliest changes are usually seen in the metacarpal and metatarsal bones, often first affecting the medial aspects of the second and the lateral aspects of the fifth digits. The bones of the carpus and tarsus are less severely affected.
2. The new bone is laid down in smooth or in irregular fashion. New bone is frequently laid down at right angles to the long axis of the bone in “palisade” fashion. This gives the bone an irregular appearance. Individual areas of a bone may be more severely affected than other areas (Figure 4-44).
3. As the disease progresses, the new bone tends to become smooth.
4. If the underlying primary disease is successfully treated, the bony lesions rapidly regress. Intrathoracic vagotomy on the side of the thoracic lesion may result in regression of the bone changes but will not influence the underlying condition.

**Hypervitaminosis A.** Hypervitaminosis A occurs in cats fed a diet with excessive vitamin A, usually large amounts of raw liver. It is rare in dogs. In cats, hypervitaminosis A usually affects primarily the vertebrae (see Chapter 5, p. 530). It can also cause new bone formation on the metaphyses of long bones and around joints. Long bones often show a periosteal reaction and sometimes osteoporosis. Joints only may be affected (Figure 4-45).

**Bone Infarcts.** Infarcts in bone are not common. They cause areas of necrosis within a bone. They produce irregular areas of increased opacity in the medullary cavity and are often associated with tumor formation. Infarcts mainly affect the smaller breeds.

**Lead Poisoning.** In lead poisoning, transverse sclerotic lines are seen in the metaphyses of the long bones and in the vertebral bodies. There is a generalized reduction in opacity of all bones.

**Osteopetrosis (Osteosclerosis Fragilis).** This is a rare condition in dogs and cats in which there is failure of bone modeling as a result of defective osteoclastic resorption. This results in radiopaque, thickened cortices but brittle bones. It may be congenital or acquired.

**Mucopolysaccharidosis.** The mucopolysaccharidoses are a series of hereditary conditions associated with storage disorders. Clinically affected animals are lame, and manipulation of the vertebrae or limb joints elicits pain.

The condition includes degenerative joint disease, osteopenia, and ankylosis of joints. There are also changes in the vertebrae. The condition resembles hypervitaminosis A (see Chapter 5, p. 530).

**Aseptic Necrosis of the Femoral Head (Legg-Perthes Disease, Legg-Calvé-Perthes Disease, Ischemic [Avascular] Necrosis of the Femoral Head, Osteochondritis Deformans Juvenilis, Osteonecrosis, Coxa Planus).** Young, growing toy and small-breed dogs may be affected by necrosis of the femoral head. The condition is degenerative rather than inflammatory. The etiology is uncertain. It is suggested that there is a hereditary factor. A portion of the femoral capital epiphysis loses its blood supply, and the affected area undergoes necrosis. The articular cartilage is unaffected. Attempts to replace the damaged bone with granulation tissue and new bone formation are usually unsuccessful, and the femoral head collapses. Varying degrees of deformity and secondary degenerative joint disease result. The condition is usually unilateral, but some cases are bilateral. It is most often
Figure 4-43 Hypertrophic osteodystrophy (metaphyseal osteopathy). A, Radiolucent bands (arrows) are seen in the radial and ulnar metaphyses. B, A cuff of mineralized tissue is developing outside the cortex of an affected tibia. C, The healing phase. Mineralized cuffs are being incorporated into the bones, resulting in widening of the metaphyses. D, This Doberman Pinscher had a recurrent history of lameness since it was 12 weeks of age. This radiograph was taken at 5 months of age. Extensive collars of new bone encircle the distal radius and ulna, resulting in marked thickening of the diaphyses. The physes are not clearly discernible, and growth retardation was clinically evident. This type of deformity is not a common sequel to hypertrophic osteodystrophy.
seen in West Highland White, Cairn, and Yorkshire Terriers. Clinically, affected animals present with a hindlimb lameness. Radiology is required for a definitive diagnosis.

**Radiologic Signs**

1. The joint space becomes wider than normal, which may be the earliest sign.
2. Areas of decreased bone opacity resulting from bone lysis are seen in the femoral head and sometimes the femoral neck. In early cases, areas of increased opacity resulting from trabecular collapse may be seen. The areas of decreased opacity become more marked as the disease progresses.
3. The femoral head loses its rounded contour and becomes flattened cranially.
4. The acetabulum becomes shallow, and its cranial edge is flattened to accommodate the changing shape of the femoral head. Subluxation may occur.
5. Fragmentation of the femoral head may occur, with discontinuity of the subchondral bone beneath the articular surface.
6. The femoral neck becomes thicker, and secondary degenerative joint changes develop with periarticular new bone formation.
7. A varus deformity often develops; that is, the angle between the femoral neck and femoral shaft becomes more acute.
Figure 4-45  A and B. Hypervitaminosis A. Radiographs of an adult cat fed almost exclusively on liver and heart. The animal became progressively lame in all limbs. The trabecular patterns are coarse. The cortices are thickened, and there is calcification in the soft tissues around the stifle and elbow. C, Early hypervitaminosis A (feline osteodystrophy) in a mature cat. The earliest radiographic abnormality was spongy bone formation in the infrapatellar fat pad region (arrows). In this same cat a similar bone formation was observed in the soft tissues adjacent to both elbows (not shown). (A and B, Courtesy Dr. Wayne Riser; C, Courtesy Dr. W. H. Rhodes.)
All these changes are not necessarily seen in any individual patient (Figure 4-46).

Panosteitis (Canine Panosteitis, Eosinophilic Panosteitis, Enostosis). Panosteitis is an inflammatory disease of the long bones that affects the larger dog breeds, notably the German Shepherd. Most cases occur in animals from 5 to 18 months of age, but animals up to 7 years of age may occasionally be affected. There is increased osteoblastic and fibroblastic activity primarily in the endosteum and medullary cavity of the diaphyses of the humerus, radius, ulna, femur, and tibia. The etiology is unknown, and the disease is self-limiting.

The presenting clinical sign is lameness without any history of injury. The lameness may disappear from one limb only to reappear in another. This phenomenon has been termed a “shifting leg” lameness. Affected bone shafts are painful on deep palpation. The condition may be mistaken clinically for a joint problem because manipulation of joints requires pressure on adjacent diaphyses, which are tender. The most obvious radiographic lesions may be seen in limbs that were affected earlier and are not the site of the presenting lameness.

Radiologic Signs
1. Areas of increased opacity appear within the medullary cavity of an affected bone, particularly in the region of the nutrient foramen. They may be discrete or ill defined. The term “thumbprints” is sometimes used to describe the changes.
2. Loss of the normal trabecular pattern and accentuation of the areas of increased opacity give a mottled, or patchy, appearance to the medullary cavity. There may be more than one discrete area of increased opacity within a bone.
3. The endosteum increases in opacity and becomes visibly thickened.

Figure 4-46 Legg-Perthes disease. A, Areas of decreased opacity are seen in the right femoral head and neck. The femoral head is misshapen. The acetabulum is widened and flattened and the joint space is uneven. B, A more advanced case. The right femoral head has lost its rounded contour. The neck is thickened. The cranial acetabular edge is flattened. The joint space is widened, and the head does not sit well into the acetabulum.
Figure 4-47 Panosteitis. A, Areas of increased opacity can be seen in the medullary cavities of the proximal extremities of both the radius and ulna. B, Patchy areas of increased opacity are seen in the proximal half of the tibial diaphysis extending into the distal third of the tibia. C, A lesion in the midhumeral diaphysis that has almost healed. The trabecular pattern is coarse, and the endosteum appears irregular. D, This 8-month-old Bassett Hound was lame in the right forelimb. This mediolateral radiograph shows patchy areas of increased opacity (arrows) within the medullary cavities of the radius and ulna. Diagnosis: panosteitis.
4. Several lesions may coalesce to fill the entire medullary cavity.
5. As the disease progresses, a smooth type of periosteal reaction develops. A careful examination is often necessary to perceive this change because the reaction is not prolific and is not seen in all cases.
6. Eventually the abnormal opacities gradually disappear. As they do, the endosteal face of the cortex appears irregular and coarse trabeculation becomes evident.
7. The medullary cavity seems more radiolucent than normal, and the cortex may be thickened.
8. After a full recovery, which is typical, affected bones usually become radiologically normal. In some cases, however, medullary opacities persist (Figure 4-47).

Craniofacial Osteopathy. This condition is usually associated with changes in the skull. Symmetrical proliferative periosteal reactions are occasionally seen along the metaphyses of the long bones. These should not be mistaken for lesions of metaphyseal osteopathy (see Chapter 5, p. 461).

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Chapter 4  ■  Bones and Joints 445


**Ultrasonography**


The Skull and Vertebral Column

The Skull

Radiography is commonly used to study the bone structure of the skull. Contrast techniques are available to demonstrate associated soft tissue structures. Generalized or diffuse diseases of the central nervous system are usually diagnosed by methods other than radiography.

The skull is a difficult area to study radiologically. Its bone structure is very complex, and superimposition of important structures makes detailed examination of individual parts difficult. The radiographic examination should be considered supplemental to a thorough physical and neurologic examination as appropriate for the clinical signs. The shape of the skull varies widely in different breeds of dogs; there is less variation in the cat.

Anatomy

Three types of head shapes are recognized in dogs: the long, narrow type of head as seen in Collies is called dolicocephalic (dolichocephalic); a head of medium shape, such as that of the Labrador Retriever, is called mesaticephalic; and a short, wide head like that of the Pekinese or Boston Terrier is called brachycephalic. Some breeds of cat are brachycephalic. The brachycephalic type presents most problems for the radiologist both radiographically and radiologically.

The skull is made up of some 50 bones, and a detailed anatomic description of them is not helpful for the purposes of this book. Attention is instead concentrated on the radiographic anatomy.

Radiography. Many different radiographic views are used to demonstrate individual structures or regions within the skull. The basic views are the lateral, dorsoventral or ventrodorsal, left and right lateral oblique, rostrocaudal, and occlusal (intraoral). General anesthesia is recommended for all skull radiographs. Obtaining well-positioned radiographs of diagnostic quality is difficult or impossible with sedation only. For intraoral, rostrocaudal, and open-mouth views, anesthesia is required.

Cross-sectional imaging in three planes using computed tomography (CT) and magnetic resonance imaging (MRI), where available, is a superior technique in localizing and defining bone and soft tissue pathology.

Lateral View. The patient is placed in lateral recumbency. A foam wedge is placed under the animal’s nose and mandible so that the sagittal plane of the skull is parallel to the tabletop. The beam is centered midway between the ear and the eye, dorsal to the zygomatic arch (LeRtL or RtLeL). The jaws should be opened if the temporomandibular joints are the areas of interest (Figure 5-1, A, B, and f).

Ventrodorsal View. The animal is placed in dorsal recumbency. A radiolucent block is placed under the neck behind the skull. The occipitoatlantal articulation is extended so that the hard palate lies parallel to the film. The x-ray beam is centered between the eyes and the ears on the midline. The sinuses are more clearly seen on this view than on the dorsoventral view, although it is more difficult to achieve symmetry in the ventrodorsal position. This view is best for demonstrating the cranium because the calvarium is closer to the film (Figure 5-1, C and D).

Intraoral film or a film-screen combination in a flexible envelope can be used to demonstrate the mandibles. The ventrodorsal position can be used with an intraoral film to demonstrate the mandibular incisor teeth. The x-ray beam is directed rostrocaudally at an angle of 20 degrees (V20°R-DCdO). With the animal’s mouth opened wide, the maxilla parallel to the tabletop, and the same beam angle centered on the maxilla, the nasal and ethmoid regions can be demonstrated.

Dorsoventral View. The animal is placed in sternal recumbency with the head resting on the cassette so that the hard palate lies parallel to the tabletop. This position can be maintained by a bandage passed across the neck, behind the skull, and fixed to the table. On occasion it may be easier to position the head if the cassette is raised off the tabletop on a support. The x-ray beam is centered between the eyes and the ears on the midline. It is easier to achieve symmetry in this position than it is in the ventrodorsal position, but the calvarium is farther from the film and is therefore more distorted on this view. However, this is of no practical significance (Figure 5-1, E).

The maxillary nasal turbinates can also be examined in this position by introducing the intraoral film corner first and placing it as far back in the mouth as possible. Alternatively, a high-detail single-screen film combination in a plastic lightproof envelope can be
used (Figure 5-1, L). The x-ray beam is centered over the nasal septum. This position can be used with intraoral film to demonstrate the maxillary incisor teeth. The x-ray beam is directed rostrocaudally at an angle of 20 degrees (D20°R-VCdO).

**Oblique Views.** Oblique views enable some structures to be demonstrated without superimposition of the contralateral side. Oblique views are used to study the temporomandibular joints, the osseous bullae, the frontal sinuses, and the dorsal edge of the orbit. In the open-mouth position, the maxillary and mandibular dental arcades are profiled by using oblique views. The structure profiled varies with the oblique study selected (Figure 5-1, F and K).

Specific oblique views for various anatomic and pathologic abnormalities are discussed in subsequent sections.
Figure 5-1, cont'd Normal skull. C and D, Ventrodorsal view. E, Dorsoventral view. F, Oblique. Made in right lateral recumbency, the oblique view demonstrates the right temporomandibular joint (black arrow). The osseous bulla (open arrow) is more clearly visible than on the true lateral view.

Continued
Rostrocaudal (Frontal) View. The patient is placed in dorsal recumbency, and the neck is flexed so that the hard palate lies perpendicular to the film. The patient’s head is held in position with a bandage or tape around its nose. The beam is directed at right angles to the tabletop, along the line of the hard palate and centered between the eyes (RCd). The frontal sinuses, the odontoid process or dens, and the foramen magnum can be demonstrated on this view. In cats, a similar technique can be used to demonstrate the tympanic bullae, which lie ventral to the mandibles. The patient is placed in dorsal recumbency, and the head is tilted slightly dorsal so that the hard palate is at an angle of approximately 70 to 80 degrees to the tabletop and the beam centered just ventral to the mandibular symphysis (Figure 5-1, N). This frontal view, with the animal’s mouth opened, can be modified to demonstrate the osseous bullae and temporomandibular joints, in which case the beam is directed rostrocaudally at an angle of 20 to 30 degrees to the hard palate (Ro20°V-CdDO). By varying the angles of the hard palate to the tabletop, the frontal view can also be used to outline the calvarium (Figure 5-1, G and M; also see Figure 5-13, C and F).

Caudorostral View. With the animal in sternal recumbency, the head is supported above the level of the neck with the hard palate parallel to the tabletop. A horizontal beam, directed caudorostrally, is used parallel to the tabletop and centered on the skull with the cassette placed in front of the animal’s nose. The frontal sinuses are profiled. An advantage of the caudorostral view is that it will demonstrate fluid levels in the frontal sinuses.

Normal Appearance
The appearance of the normal skull is best demonstrated by illustrations (see Figure 5-1).

Abnormalities
Because the bone structures are bilaterally symmetric, a skull examination frequently makes it possible to compare a unilateral abnormality with the corresponding normal structure on the opposite side.
Figure 5-1, cont’d Normal skull. K, Normal tympanic bulla—oblique view. Note the thin wall and the air-filled cavity (arrow). L, An occlusal view of the maxilla. M, Normal tympanic bullae in a cat. This is a rostrocaudal open-mouth view. The bullae have thin, well-defined, bony walls. Feline bullae have medial and lateral compartments that are separated by a thin wall of bone. An endotracheal tube is seen superimposed on the skull between the two bullae.

Continued
Fractures. Skull fractures in dogs are not very common except for fractures of the mandibles. The superimposition of bones makes fractures difficult to demonstrate. Lateral oblique views are useful in outlining the mandibular rami. The mandibular symphysis is frequently the site of a separation injury in cats that have fallen from a height (Figure 5-2, G). Fractures involving the calvarium, frontal bones, or nasal bones are often depression fractures, and lesion-oriented oblique (tangential) views of the area may be necessary to demonstrate them. Overriding of fracture fragments may cause a linear opacity, whereas a fracture with displaced ends causes a linear radiolucent defect. Soft tissue swelling is often present. Fractures may be the cause of focal cranial nerve dysfunction. Fractures involving the nasal or frontal bones may be accompanied by hemorrhage into the frontal sinus or nasal cavity. The hemorrhage causes a soft tissue opacity within the air-filled cavity (Figure 5-2).

Suture lines should not be mistaken for fractures. In the dog and cat, suture lines close within a few weeks after birth, although in some small breeds the suture lines may remain open permanently, as may the fontanelles (areas of unossified tissue found at the junction of several suture lines). In these breeds, such as the Maltese and Chihuahua, no frontal sinus may be evident.

Temporomandibular Dislocation. The temporomandibular joint is formed by the articulation between the condyle of the mandible and the mandibular fossa of the squamous part of the temporal bone. The rostral surface of the retroglenoid process forms part of the mandibular fossa.

Diagnosis of dislocation of the temporomandibular joint can be problematic radiologically. The following views are useful:
1. Ventrodorsal.
2. Lateral view with the mouth open.
3. Two lateral oblique views (Le20°V-RtDO or Rt20°V-LeDO). Two oblique views are obtained. With the animal in right lateral recumbency, the skull is rotated axially 20 degrees to the right from the true lateral position. This projects the left temporomandibular joint onto the cranium, and the right joint will be seen more clearly ventrally. For the left temporomandibular joint, the animal is placed in left lateral recumbency and the procedure is repeated, rotating the skull axially to the left. An alternative technique for obtaining oblique views is to elevate the nose with the animal in lateral recumbency. In right lateral recumbency the right temporomandibular joint is projected rostral to the left, and in left lateral recumbency the left joint is projected rostral to the right. The angle of elevation varies with the breed type. A dolicocephalic skull requires a 10-degree elevation, whereas a brachycephalic skull requires an elevation of 30 degrees. The open and closed views are particularly useful to demonstrate subluxation or fracture of the retroglenoid process (Figure 5-3, E and F).
4. An open-mouth rostrocaudal view with the x-ray beam bisecting the angle of the temporomandibular joint.

Traumatic luxation (Figure 5-3, D) of the temporomandibular joint is not very common in dogs. It may be associated with mandibular fracture, particularly in cats. Clinically, affected animals hold the mouth...
open, and manipulation of the mandible is painful. The dislocation is usually unilateral. The displaced mandibular condyle can be seen radiographically on the appropriate view. It is seen to be displaced ros-trally and dorsally from the retroglenoid (retroarticu-lar) process. If the dislocation is unilateral, comparison with the opposite side is helpful. The mandibles are displaced toward the normal side. There may be an associated fracture. If the retroglenoid process is fractured, the condyle may displace caudally.

**Temporomandibular Dysplasia.** Temporomandibu-lar dysplasia is a congenital condition described in young red Irish Setters and Bassett Hounds and some other breeds. The mandibular fossa is shallow. If the mouth is fully opened, subluxation of the temporomandibular joint may occur. The coronoid process of the mandible on one side becomes fixed lateral to the zygomatic arch, resulting in an open-mouth locked jaw. Clinically this occurs when the animal yawns or grabs a moving object. In some cases the condition resolves spontaneously. Other patients are treated surgically by removing part of the zygomatic arch or part of the coronoid process of the mandible. The condition is best demonstrated on open- and closed-mouth oblique studies.

**Temporomandibular Arthrosis.** Osteoarthrosis of the temporomandibular joint is occasionally seen. It may be the result of trauma, or it may be a sequela to conditions such as craniomandibular osteopathy, otitis media, or temporomandibular dysplasia. Periarticular osteophytes are seen on lateral oblique and dorsoventral views. Narrowing of the joint space may also be seen.

**Foreign Bodies.** Radiopaque foreign bodies are readily seen within the skull. They are usually located in the mouth, pharynx, or nasal chambers. Radiolucent bodies may require contrast medium to outline them (Figures 5-4 and 5-5; see Figure 5-11).

**Infection.** Any of the bones of the skull may become infected. However, infection is uncommon except as an extension from infection in a nasal chamber, frontal sinus, or tooth root or as a result of direct trauma.

**Radiologic Signs**
1. Infection causes destruction of bone, and the bone in the affected area loses its normal opacity.
2. Surrounding the area of destruction, there is often an area of increased opacity (sclerosis) that sharply demarcates the affected area from normal bone.
3. A sequestrum may form (see Chapter 4, p. 433).
4. Periosteal reaction is usually in evidence.
5. Fungal infection may simulate neoplastic changes. However, fungal lesions are usually multifocal.
6. Inflammation of the bone (osteitis) may cause thickening of the walls of the tympanic bullae, with a resultant reduction in their air content.
7. Local soft tissue swelling is often present.

**Neoplasia.** Primary neoplasia of skull bones is not common. The dog is more often affected than the cat. Osteosarcoma may affect any of the bones of the skull. Its appearance is that of a destructive lesion, usually accompanied by a profuse and aggressive periosteal reaction. If the tumor is superficial, there will be an associated soft tissue swelling. Proliferative changes and sclerosis are more prominent than are erosive changes when the cranial vault is involved. Other
Figure 5-2, cont’d B and C, Fracture of the horizontal ramus of the mandible. The displacement in the lateral plane is seen as a step defect (arrow) on the ventrodorsal view. D, Fracture of the right zygomatic arch. The temporozygomatic suture, which is a late-closing suture, should not be mistaken for a fracture line.
neoplasms, such as fibrosarcoma, chondrosarcoma, and osteochondroma, are occasionally seen.

Differentiation of primary bone tumors is not easy. Osteomas are occasionally seen and are benign. They appear as dense and circumscribed areas provoking little if any adjacent reaction. Multiple myeloma has been reported in the dog, showing the typical punched-out lesions described in human patients. Soft tissue tumors, such as squamous cell carcinoma, malignant melanoma, and fibrosarcoma, frequently invade and destroy adjacent skull bones. Metastases to regional lymph nodes are common with squamous cell carcinoma. Malignant melanoma may metastasize early to lymph nodes and the lungs.

Fibrosarcoma rarely metastasizes. Exophthalmos may occur as a result of displacement by a neoplasm when it is in the vicinity of the orbit. Teeth may be lost or displaced. Biopsy is needed for a definitive diagnosis.

An effort should be made to rotate the skull for a lesion-orientated view so that the mass lesion is as near to the film as possible and there are few superimposed structures (Figure 5-6).
Figure 5-3  A, Normal temporomandibular joint. B and C, Dislocation of the right temporomandibular joint. The displaced mandibular condyle (straight arrows) can be seen both on the oblique and ventrodorsal views. The right external auditory canal is almost obliterated because of swelling in that area (curved arrow). The left mandible is fractured (open arrow). D, Temporomandibular luxation in a cat. The right mandible is luxated rostrally. The right mandibular condyle is rostral to the mandibular fossa of the temporal bone (arrows), with which it should articulate. The left temporomandibular joint appears normal. (D, Courtesy Dr. W. H. Rhodes.)
Ultrasonography. Ultrasonographic examination of the eye is useful if a neoplasm is located in the immediate area. If the tumor extends from the turbinates or frontal sinus, the site of associated bone disruption can be identified. Ultrasound-guided fine-needle aspiration is valuable.

Caudal Occipital Malformation Syndrome: Congenital Malformation of the Foramen Magnum (Occipital Dysplasia, Chiari Malformation). Caudal occipital malformation syndrome is a congenital anomaly of the occipital bone. The foramen magnum is formed in the occipital bone. Congenital malformation of the

Figure 5-3, cont'd E and F, A 3-year-old Golden Retriever presented with pain on opening its jaw. Lateral oblique radiographs of the right temporomandibular joint (arrows) in the open- and closed-mouth positions. E, The temporomandibular joint is normal on the closed study. F, On the open-mouth study the joint is subluxated. Diagnosis: temporomandibular subluxation.

Figure 5-4 A and B, Foreign body. A needle in the pharyngeal region of a cat.
foramen magnum occurs in small and toy dog breeds. The foramen magnum is enlarged dorsally and is abnormal in shape. It has been described as having a “keyhole” appearance. In the normal animal the shape of the foramen magnum varies, making it difficult to evaluate the exact shape of the foramen without the use of CT or MRI. The thin plate of bone at the dorsal aspect of the foramen is virtually radiolucent. Radiographically, this may give the appearance of an enlarged foramen. The condition is believed to occur as a result of mismatch of the cerebellar and caudal fossa volumes, which leads to increased intracranial pressure. This causes part of the cerebellum to be herniated through the foramen magnum. The cerebellar herniation obstructs flow of cerebrospinal fluid (CSF) to the subarachnoid space of the spinal cord, resulting in reduced pressure in this space. High-velocity pulsatile flow of CSF into the central canal of the spinal cord leads to hydromyelia or syringomyelia. Hydromyelia is dilation of the central canal of the spinal cord. Syrinxes are fluid-filled cavities that may be continuous or segmental, tubular or saccular, and are seen in the cervical and sometimes in the cranial part of the thoracic spinal cord. There may also be dilation of the lateral and third ventricles.

Clinical signs are variable. Some dogs are apparently normal; others may show pain, obsessive scratching, ataxia, and quadripareisis. Ataxia has been
reported in approximately 25% of cases with enlarged foramen magnum. The brainstem and cerebellum can herniate through the enlarged foramen, giving rise to neurologic signs. There may be an associated hydrocephalus with open suture lines. Cisternal puncture for CSF collection or myelography is contraindicated in dogs in which cerebellar herniation may occur. MRI is the imaging method of choice. Sagittal plane T1- and T2-weighted images are most helpful. The caudal border of the cerebellum appears flattened,

Figure 5-6, cont’d C, The right fourth premolar and the first molar tooth of the upper jaw are displaced as a result of invasion of the maxilla by a carcinoma originating in the mouth. D, This 8-year-old cross-bred Terrier had a hard, painless swelling on the dorsal aspect of the cranium. It was slow growing and had been present for 1 year. The lateral radiograph shows a well-circumscribed radiopaque mass on the dorsal aspect of the cranium. There is no periosteal reaction on adjacent bones. Diagnosis: osteoma. E, This old male Labrador Retriever had a swelling on the left mandible. A ventrodorsal occlusal study demonstrates a discrete, osteolytic, expansile lesion (arrows) enveloping the roots of the fourth premolar and first molar teeth in the middle third of the horizontal ramus. A proliferative periosteal reaction is seen medially. Diagnosis: soft tissue tumor invading bone. This was a melanoma.

Continued
and part of the cerebellum is herniated through the foramen. Syringomyelia and hydromyelia appear as tubular hypointense structures within the spinal cord on T1-weighted images and hyperintense structures on T2-weighted images (see Figure 5-32 and p. 510).

The foramen magnum is best shown on a rostrocaudal view of the skull. The animal is placed in dorsal recumbency, and the occipitoatlantal articulation is flexed so that the hard palate is at an angle of approximately 70 degrees to the tabletop. The x-ray beam is directed perpendicular to the tabletop (R30°V-CdDO). It may also be demonstrated on an open-mouth rostrocaudal view. Care should be exercised in positioning animals for radiography of this area if anomalies are suspected. A seizure can be induced in an apparently normal animal by extremes of manipulation of the occipitoatlantal articulation if an abnormality is present.

A number of other abnormalities are encountered in this area. The first cervical vertebra may be shortened, and there may be hypoplasia and nonfusion of the odontoid process (dens). The significance of anatomic changes seen in this region is often uncertain. A lateral view of the cervical spine is required to demonstrate these changes (Figure 5-7).
There may be an accompanying hydrocephalus and syringomyelia or hydromyelia.

**Craniomandibular Osteopathy (Craniomandibular Osteoarthropathy, Mandibular Periostitis, Craniomandibular Osteodystrophy, "Lion Jaw")**. Craniomandibular osteopathy is a disease seen in young West Highland White Terriers. Also affected are the Boston, Scottish, and Cairn Terriers and, more rarely, other small breeds. There have been isolated reports of this disease in Labrador Retrievers and Doberman Pinschers. The condition is of uncertain etiology except in the West Highland White Terrier, where it is known to be hereditary. The condition is first noticed between 3 and 10 months of age. Affected animals present with difficulty and pain when opening the mouth or chewing food. The pain may be intense. Palpation of the skull reveals bilateral or sometimes unilateral swelling on the horizontal rami and perhaps on the vertical rami. These areas are tender on palpation. There may be atrophy of the temporal and masseter muscles. Some animals recover with supportive treatment after a period of months, at least to the stage at which nutrition can be maintained. More severely affected patients may require placement of a feeding tube. Some have to be euthanized because of the inability to eat.

Craniomandibular osteopathy produces proliferative changes, particularly on the mandible and in the areas of the osseous bullae. The calvarium may be thickened. New bone formation at the distal metaphyses and along the diaphyses of the radius and ulna has been reported, although this is rare.

**Figure 5-7** A, Normal foramen magnum. Suture lines can be seen in this young dog's skull. B, Malformation of the foramen magnum. The horizontal arrows indicate the dorsal limits of the foramen magnum. The area of radiolucency above the black arrows, the dorsal limit of which is indicated by the open arrow, is the central sulcus of the caudal fossa. The bone of the central sulcus, called the vellum, may be very thin and almost radiolucent. As a result, the extent of the deformity of the foramen magnum may be overestimated. C, Shortening of the first cervical vertebra (arrow). The space between the axis and the atlas, dorsally, is increased.
Clinically, the condition has to be distinguished from eosinophilic myositis of the head muscles, although that condition is more common in larger dogs.

Radiologic Signs
1. Periosteal new bone formation and sclerosis are seen, usually affecting both mandibles, which are thickened and irregular in appearance.
2. Masses of new bone are seen in the area of the tympanic bullae and on the petrosal part of the temporal bone.
3. The occipital bones may be similarly affected, with thickening of the calvarium.
4. In rare cases, periosteal changes appear on the limbs similar to those seen in hypertrophic osteodystrophy (metaphyseal osteopathy) (see Chapter 4, p. 437).

Figure 5-8 A to C, Craniomandibular osteopathy. A and B, Thickening of the calvarium associated with craniomandibular osteopathy. There is extensive new bone formation on the mandibles and around the osseous bullae. C, Masses of periosteal new bone are seen along the horizontal rami. The calvarium is thickened.
The temporomandibular joints are rarely directly involved in the new bone growth, but their movement may be inhibited because of the bony masses around them (Figure 5-8, A to E).

Calvarial hyperostosis has been described in Bullmastiff puppies and affects the frontal and parietal bones. It is of unknown etiology and regresses with age.

Renal Secondary Hyperparathyroidism ("Rubber Jaw," Renal Osteodystrophy, Renal Rickets, Renal Osteitis Fibrosa). A secondary hyperparathyroidism in older animals may result from renal insufficiency caused by chronic renal disease. It is occasionally seen in young animals with congenital nephropathies. In short, if the glomerular filtration rate is reduced, there is retention of phosphorus and resulting progressive hyperphosphatemia. The hyperphosphatemia causes a lowering of the blood calcium level, which provokes hyperparathyroidism. The resulting increase in parathyroid hormone levels causes a resorption of bone and a release of calcium. The skull is primarily involved with demineralization of the mandible and the maxilla. Demineralization elsewhere is slower. Clinically, the mandible becomes softened (rubbery),

Figure 5-8, cont’d D and E, Craniomandibular osteopathy. New bone formation on the temporal bones. E, A 6-month-old West Highland White Terrier presented with recurrent pain around the mouth. A lateral study of the skull shows extensive new bone formation in the region of the temporal bones, tympanic bullae, and mandibles. The calvarium is thickened. F and G, Rubber jaw. Gross demineralization of the skull caused by renal secondary hyperparathyroidism. The zygomatic arches have virtually disappeared, and the mandibles are abnormally radiolucent. The teeth stand out prominently because of lack of bone opacity in the skull.
teeth become loose, and breathing may be impaired because of collapse of bones around the nasal cavity. The face may appear swollen as a result of proliferation of fibrous tissue. Salivation is common.

Radiologic Signs
1. There is a marked decrease in opacity of the bones of the skull. The teeth consequently stand out very prominently. This gives an appearance of “floating teeth.” Loss of the lamina dura, the line of opaque bone around the periodontal membrane, is first noted in early cases. The radiographs may seem overexposed.
2. In advanced cases, the mandibles appear to be grossly thinned and in places may be radiographically absent.
3. The normal trabecular pattern of the affected skull bones is lost.
4. Elsewhere some demineralization of bone may be noted—subperiosteal bone resorption in particular. This gives a flat, reticulated, or lacelike appearance to the bone in an affected area. This sign is not always detectable.
5. Metastatic calcification in the soft tissues is occasionally seen (Figure 5-8, F and G).

Primary hyperparathyroidism has been reported but causes hypercalcemia rather than skeletal lesions. It is the result of hyperplasia or neoplasia of one or more of the parathyroid glands.

Nutritional Secondary Hyperparathyroidism (Juvenile Osteodystrophy). Nutritional secondary hyperparathyroidism may cause changes in the skull similar to those seen in the skeleton. However, changes are usually seen concurrently in the appendicular skeleton and spine (see Chapter 4, p. 420).

THE NASAL CHAMBERS

Anatomy
The nasal cavity, which extends from the external nares to the pharynx, is divided into two symmetric halves (chambers, or fossae) by the nasal septum, which is cartilaginous rostrally and osseous caudally. The septum is composed of the septal cartilages, the sagittal portion of the vomer bone, the septal processes of the frontal and nasal bones, and the perpendicular plate of the ethmoid. The septal cartilages are radiolucent. The linear opacity seen on radiographs dividing the nasal cavity is the nasal septum. The major portion of each nasal chamber is occupied by the dorsal (dorsal nasoturbinates), ventral (maxilloturbinates), and ethmoidal (ethmoturbinates) conchae, which are cartilaginous or slightly ossified scrolls covered by mucosa. The ethmoidal conchae are outgrowths of the ethmoid bone. They partially extend into the frontal sinus. The conchae divide the nasal chamber into passages, or meati: dorsal, middle, and ventral. The passage on either side of the nasal septum is called the common meatus. The passageway from the back of one side of the nasal cavity to the pharynx is called the choana. There are two choanae, one on either side.

The cribiform plate of the ethmoid bone separates the caudal nasal cavity from the brain. The palatine fissures are two oval spaces in the rostral portion of the hard palate just caudal to the incisor teeth.

Radiography
Standard lateral and ventrodorsal or dorsoventral views of the skull show a large part of the nasal chambers. However, the mandibles are superimposed on the chambers except on the lateral view. Unilateral changes may be obscured on a lateral study. A full examination should include an occlusal view using intraoral film, with the dog in the dorsoventral position, and a frontal sinus view. Oblique views are useful to separate individual structures. The nasal chambers can also be demonstrated with an open-mouth view in the ventrodorsal position, with the x-ray beam directed rostrocaudally at an angle of 20 degrees; that is, parallel to the mandibles and with the animal’s mouth fully opened (V20°R-DCdO). Accurate positioning is important to ensure that radiographic details are bilaterally symmetric. High-detail screen-film combinations give good results.

Normal Appearance
The nasal chambers normally project a fine, bony, trabecular, or turbinate pattern surrounded by lucent nasal cavities. The nasal septum divides the nasal cavity into two symmetric halves (Figure 5-9).

Abnormalities
Infection. Unilateral infection in the conchae causes an increased radiographic opacity on the affected side compared with the normal side. This is caused by elimination of air around the conchae as a result of the presence of inflammatory exudate. The nasal septum provides a sharp line of demarcation between affected and unaffected sides. If the condition is bilateral, there will be increased radiographic opacity on both sides. Destruction of the septal cartilages is not visible radiographically. Animals with acute rhinitis may be normal radiographically. The frontal sinus may be affected secondarily. A fluid or soft tissue opacity will be seen within it. Clinically there is nasal discharge, which may be serous, mucopurulent, or bloodstained.

Chronic hyperplastic rhinitis is a condition of increased radiographic opacity without evidence of destruction of the conchal pattern. In early cases of infection, it is often possible to distinguish the underlying scroll pattern through the increased opacity. As the mucous membrane swells and exudates accumulate within the affected chamber, the scroll pattern is masked. Severe infections may erode the conchae, disrupting their normal linear pattern. Chronic hyperplastic rhinitis is usually bilateral.

Aspergillosis. Areas of decreased opacity within the nasal chambers have been reported in association with aspergillosis. This is a destructive rhinitis seen mainly in young doliocephalic types of dog. The nasal septum may be destroyed. The lesions often start rostrally in the nasal cavity. The infection causes necrosis...
and sloughing of the conchae and the nasal mucous membrane. In chronic cases, punctate lytic lesions are sometimes seen in the maxillae and nasal bones, but they are not pathognomonic for aspergillosis. If there is extension into a frontal sinus, it acquires a granular, mottled opacity. Destructive rhinitis may disrupt the vomer bone. It can be difficult to differentiate destructive rhinitis from neoplasia when there is mucosal thickening, accumulated exudate, and hemorrhage and fungal granulomas. However, some cases have complete turbinate destruction and marked hyperlucency of the nasal chambers, which are characteristic of the condition. Less commonly, other organisms, notably Penicillium spp., may cause destructive rhinitis.

Cryptococcosis. This fungal infection occurs most commonly in cats, although other species may be affected. The nasal cavities, the paranasal sinuses, and occasionally the lungs are involved. The pigeon is a common vector. Clinical signs include sniffing and sneezing, with a unilateral or bilateral nasal discharge. Oral ulceration is occasionally present. Skin nodules with or without ulceration are common. The central nervous system may be involved through spread from the nose through the cribiform plate of the ethmoid bone. Radiographically, there is an increased opacity within the nasal chambers with occasional bone erosion and involvement of the frontal sinuses. Cryptococcosis usually results in a hyperplastic reaction rather than a destructive one.

Figure 5-9 A and B, Normal turbinate pattern as seen on standard lateral and ventrodorsal views of the skull. C, The turbinate pattern is more obvious when demonstrated on this open-mouth (ventro 20 degrees rostral-dorsocaudal) view.
Linguatula spp. infestation in cats and dogs may cause rhinitis with erosion of the vomer bone. It can mimic neoplasia.

Rhinitis may be caused by dental disorders. Rhinitis and sinusitis in the cat may occur from viral infection. Otitis media has been reported as a sequela (Figure 5-10).

**Foreign Body.** Radiopaque foreign bodies are readily recognized on radiographs. The skull should be examined as far caudally as the pharynx. Clinically, there may be sneezing and a nasal discharge. Radiolucent foreign bodies are not seen. However, there may be increased opacity within the affected chamber as a result of inflammatory exudate. The introduction of contrast medium into the nasal chamber (contrast rhinography) is seldom informative, except perhaps in the case of a large radiolucent foreign body (Figure 5-11).

**Neoplasia.** The most common nasal neoplasms are adenocarcinoma, squamous cell carcinoma, undifferentiated carcinoma, fibrosarcoma, chondrosarcoma, and undifferentiated sarcoma. Lymphoma may occur but is more common in cats. Neoplasia is more common in older animals. In general, neoplasms are more destructive and aggressive than infection and may invade the conchae, nasal septum, and walls of the nasal chambers.

Clinically there is a nasal discharge, which is often blood stained. There may be swelling of the face, which is usually unilateral.

**Radiologic Signs**

1. There is increased radiographic opacity in the affected chamber as a result of the tumor mass and associated exudation.
2. The nasal septum is frequently displaced or eroded by the growing tumor.
3. The nasal scroll pattern is destroyed.
4. The tumor frequently invades and surrounds adjacent bones, the vomer bone, and bones of the nasal cavity.
5. The facial bones may show a periosteal reaction, and there may be an associated soft tissue mass or facial deformities.
6. The tumor mass may invade the frontal sinus and cause erosion or deformity.

Because the radiologic signs of infection and neoplasia are similar in many respects, it is usually impossible to be sure on radiographic evidence alone whether the cause is infection or a neoplasm. This is particularly true in cats. Some infections can be very destructive, such as aspergillosis. If there is an associated soft tissue mass, there is a strong presumption that the lesion is neoplastic. CT and MRI are useful to evaluate fully the precise area and extent of the lesion (Figure 5-12).

**Hemorrhage.** Hemorrhage within a nasal chamber produces an increase in opacity that may cause blurring or obliteration of the nasal turbinate pattern. The cause may be trauma, infection, or neoplasia. Fracture lines can be difficult to demonstrate radiographically unless there is displacement.
THE PARANASAL SINUSES
Anatomy
Paired paranasal sinuses are located in the maxilla, ethmoid, and frontal bones. They are small at birth and enlarge as the animal grows. The frontal sinuses are the largest. Each frontal sinus is located between the lateral and medial tables of the frontal bone. The frontal sinus is in communication with the nasal chamber and is lined by mucous membranes. It is partially divided into rostral, lateral, medial, and caudal compartments. The maxillary sinus is a diverticulum of the nasal chamber, sometimes called the maxillary recess (antrum). The rostral roots of the fourth premolar (carnassial) tooth lie within it. The ethmoid sinus is small.

Radiography
The frontal sinuses are most clearly seen on lateral, rostrocaudal, and caudorostral (frontal) views of the skull. The rostrocaudal view is made with the animal in dorsal recumbency. The atlantooccipital articulation is flexed so that the hard palate is at an angle of 90 degrees to the film. The x-ray beam is directed parallel to the hard palate (RCd). Alternatively, with the animal in ventral recumbency, a caudorostral view with a horizontal beam may be used (see p. 450).

Normal Appearance
On the lateral view, the frontal sinuses are clearly seen, superimposed on one another above the orbit. They have an air opacity, and fine bony septa are visible within them. Both sinuses are seen individually on the rostrocaudal or caudorostral view. On ventrodorsal and dorsoventral views of the skull, a portion of each sinus is seen just rostral to the cranium. The maxillary and ethmoid sinuses are not usually identifiable on radiographs (Figure 5-13, A to C).

Abnormalities
Infection. With infection in a frontal sinus, the normal air opacity within it is replaced by a fluid or soft tissue opacity (Figure 5-13, D). Unless the condition is of long standing, there is usually no associated bone abnormality. Thickened mucous membranes may be visible within the sinus. Infection may reach the sinus from the nasal chambers. Fluid may
occasionally be seen on a horizontal beam caudorostral view. A horizontal line is evident at the air/fluid interface. Infection in a maxillary sinus, such as that associated with malar abscess, is not readily demonstrable radiographically unless there are associated bone changes. Expansion of the frontal sinus may be caused by a cyst in the sinus (Figure 5-13, E and F). Obstructive sinusitis is a common sequela to primary nasal neoplasia in dogs.

Neoplasia. Neoplasia affecting the frontal sinus causes loss of the normal air opacity within the sinus. The tumor mass replaces the air. Invasion of the surrounding bone, with destruction and periosteal reaction, becomes evident as the condition progresses. The frontal bone may be a site of osteosarcoma. Squamous cell carcinoma is the most common primary soft tissue tumor. Adenocarcinoma also occurs. These tumors are highly destructive, and considerable

Figure 5-10, cont’d F to I, Nasal aspergillosis in a dog. This patient had unilateral disease. This series of CT images are through the nasal cavities from rostral to caudal. F, There is complete destruction of the nasal turbinates within the left nasal chamber rostrally. There is thickening of the mucosa along the lateral border of the septum. The nasal turbinates in the right nasal chamber are intact. G, In the middle part of the nasal chambers, there is incomplete destruction of the nasal turbinates on the left side. The nasal mucosa is moderately and unevenly thickened (arrows), best seen in the middle part of the nose. H, At the caudal aspect of the nasal chambers, a granuloma (arrows) is present within the left nasal chamber, dorsal to the ethmoid turbinates. This contains multiple, small, irregularly shaped pockets of gas. There is mild thickening of the overlying maxillary bone. I, The left frontal sinus is filled with soft tissue, with multiple small interspersed gas pockets. There is moderate, nonuniform thickening of the frontal bone (arrows). The findings of extensive turbinate lysis, mucosal thickening, granuloma formation, and hyperplasia of the facial bones is characteristic of nasal aspergillosis.

Continued
erosion of bone may have occurred before they are detected. Invasion of the sinuses by tumors arising in the nasal cavity is more common than primary sinus tumors (Figure 5-14, A and B).

Ultrasonography. Ultrasonography of a soft tissue swelling caused by an eroding neoplasm can be used to locate a site for needle aspiration biopsy through a disrupted bone surface (Figure 5-14, C).

Hemorrhage. The frontal sinus may be the site of hemorrhage. Blood within the sinus causes loss of the normal air opacity. Hemorrhage may be the result of fracture of the frontal bone. The hemorrhage...
Figure 5-12 Neoplasia. A and B, Nasal adenocarcinoma in a dog. A, The rostrocaudal ventrodorsal open-mouth view of the maxilla shows increased soft tissue opacity within the left nasal chamber. The fine linear opacities of the nasal turbinates have been destroyed. The right nasal chamber is normal. B, The rostrocaudal view of the frontal sinuses shows uniform increased soft tissue opacity within the left frontal sinus. There is no evidence of bone destruction. The increased opacity in the frontal sinus may be the result of a tumor mass within the sinus or fluid accumulation caused by obstruction of the sinus drainage by a tumor within the nasal cavity. C and D, Chondrosarcoma. C, There is obliteration of the nasal turbinates within the right nasal chamber. The right first premolar tooth is absent. D, The caudorostral view shows an increased soft tissue opacity in the right frontal sinus.

Continued
may make identification of the fracture line more difficult.

THE AUDITORY SYSTEM

Anatomy
The anatomy of the temporal bone is complex. Its tympanic portion consists of a bulbous enlargement that is air filled and readily seen on radiographs. It is called the tympanic bulla. It lies ventral to the petrosal portion of the temporal bone. In the cat the bulla is large and divided in two, giving it a double-walled appearance. The middle ear also contains air. The external auditory canals are air-filled tubular structures readily visible on radiographs. The inner ear lies within the petrosal part of the temporal bone. Pathology is rarely demonstrable radiographically.

Radiography
Dorsoventral, oblique, open-mouth views and the caudorostral view in cats are used to study the auditory system. In cats a modification of the rostrocaudal view for profiling the tympanic bullae has been reported. The mouth is closed and the head tilted caudally 10...
degrees from the vertical; the x-ray beam is aligned perpendicular to the tabletop and centered just ventral to the nares (R10°V-Cd DO) (see Figure 5-1).

**Positive Contrast Ear Canalogy.** This technique may occasionally be useful when it is difficult or impossible to visualize the tympanic membrane directly. In many cases this procedure is unrewarding and of limited value. The dog is placed in lateral recumbency with the affected ear uppermost. The ear canal should be gently cleansed. Iopamidol or iohexol is diluted with an equal volume of normal saline. The ear canal is filled with the mixture. The contrast material is massaged along the length of the vertical and horizontal canals. The ear is plugged with cotton wool or a cotton ball, and radiographs of the area are made. If the tympanic membrane is ruptured, contrast material will leak into the tympanic bulla. If the horizontal canal is occluded with debris, the procedure may prove nondiagnostic. The ear should be flushed out after the procedure to remove the contrast agent. Ultrasonography of the tympanic bullae has been reported as useful in assessing the presence of fluid or air within the bullae.

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**Figure 5-12, cont’d** I to L, Nasal adenocarcinoma in a dog. I, A mass within the rostral part of the left nasal chamber has completely destroyed the nasal turbinates. The mass has also destroyed part of the septum and extended into the right nasal chamber (arrows). J, In the mid part of the nasal chamber, there is lysis of the hard palate and maxilla (arrows). Complete destruction of the nasal turbinates is again present at this level. K, In the caudal nasal chamber, there is partial destruction of the ethmoid turbinates. There is also moth-eaten lysis of the ventral aspect of the medial wall of the orbit on the left side (black arrow). The tumor extends into the internal choanae, occluding the left side (white arrow). The frontal sinus is filled with tissue or fluid. L, The image at the level of the frontal sinuses shows almost complete filling of the left frontal sinus. A small gas pocket is seen at the dorsal aspect of the sinus. This may represent accumulation of nasal secretions (obstructive sinusitis) or tumor extension into the frontal sinus.
Figure 5-13 Normal frontal sinuses (see Figure 5-1). A, Lateral view. B, Ventrodorsal view. Arrows mark the outline of the left frontal sinus. C, Rostrocaudal view. D, The normal air opacities of the frontal sinuses (arrows) of this cat have been lost because of infection. E and F, A 7-month-old Collie with a hard swelling over the midfrontal sinus area. Lateral (E) and rostrocaudal (F) views show an expansile soft tissue mass extending dorsally with a mineralized rim. This was a cyst in the frontal sinus. This is a benign condition.
Figure 5-14  A and B, An osteosarcoma affecting the right frontal sinus. There is destruction of bone and invasion of the overlying soft tissues. The ventrodorsal view shows invasion of the cranium on the right side. C, Longitudinal sonogram of a swelling on the dorsal aspect of the rostral cranium. Rostral (R) lies to the left; caudal (C) lies to the right. The bright hyperechoic line lying under the R is the frontal bone. The anechoic area (arrow) caudal to the rostral frontal bone represents disruption of the bone. This is the result of an expanding soft tissue tumor that has eroded the bone and is extending dorsally. The irregular hyperechoic area seen caudal to the defect is an irregular periosteal reaction. This was a fibrosarcoma. D, Otitis media and bulla osteitis in a dog. The right tympanic bulla is normal. There is increased soft tissue opacity within the left tympanic bulla. Moderate, uniform thickening of the bony wall of the left bulla is also present. No evidence of destruction/lysis of the bulla is present. The endotracheal tube is visible between the two bullae. 
R, Right. E, A 10-year-old cat with recurrent otitis externa. This rostrocaudal projection shows the tympanic bullae lying ventral to the mandibles. The right bulla has an increased opacity and a thickened irregular ventral wall. Diagnosis: otitis media. F, This young cat had a chronic stridor and nasal discharge. The lateral radiograph illustrates a large pharyngeal mass in the caudal pharynx, occluding the normal airway (arrow). Diagnosis: nasopharyngeal polyp. There is an endotracheal tube in place.

Continued
Figure 5-14, cont’d  G to K, Otitis media. Lateral (G), dorsoventral (H), and right lateral oblique (I) views of the tympanic bullae. This cat had a history of nasal discharge and dyspnea. The wall of the right tympanic bulla is thickened and expanded. The external ear canal on the right side is occluded by a nasopharyngeal polyp. J, An 11-year-old cat presented with a history of head tilt to the right and inability to swallow food. The open-mouth rostrocaudal view shows an increased opacity within the left tympanic bulla. Diagnosis: squamous cell carcinoma. K, A 10-month-old Cocker Spaniel. The left auditory canal is not visible. There is a soft tissue swelling extending caudally from the zygoma (curved arrow). The air outlining the pinna (straight arrow) is displaced caudally and laterally compared with the opposite ear. This was an avulsion of the left auditory canal with a subsequent paraaural abscess.
Abnormalities

Otitis Externa. Otitis externa is inflammation of the external ear canal. Clinically, there is scratching of the ear, head shaking, a bad smell, and pain. The ear is tender to the touch. Acute cases show no radiologic signs.

Radiologic Signs
1. Soft tissue swelling and exudate in the external ear canal will cause it to lose its air opacity.
2. In chronic cases there is calcification of the walls of the canal.
3. Occlusion or narrowing of the canal by a soft tissue opacity is seen in severe cases.

Hemorrhage into the external ear canals, such as may occur after a fracture at the base of the skull, will cause loss of normal air opacity (see Figure 5-3, C).

Otitis Media. Inflammation of the middle ear, otitis media, is frequently a sequel to inflammation of the external auditory canal. The inflammation is usually accompanied by exudate. It may be present in the absence of radiographic evidence. Clinically there is head tilt and possibly circling. There may be signs of otitis externa if the condition has arisen externally. Otitis media occurs in cats as a sequel to viral upper respiratory infections because the auditory tubes are lined with respiratory epithelium. Nasopharyngeal polyps should be ruled out. Otitis interna sometimes ensues. Radiographs are insensitive in the diagnosis of otitis media. CT is significantly more sensitive but does not detect all cases.

Radiologic Signs
1. A fluid opacity appears in the auditory bulla. Because the condition is often unilateral, comparison with the opposite side is useful.
2. The wall of the bulla is thickened, irregular, and sclerotic.
3. There may be increased opacity of the superimposed temporal bone.
4. Destruction of the wall of the bulla with or without periosteal reaction may be seen.
5. Rarely there is expansion of the bulla.
6. There may be obliteration of the air opacity in the external ear canal and calcification of its walls in longstanding cases resulting from otitis externa (Figure 5-14, D, E, G to I, L, M).

Avulsion of the Auditory Canal. This is an uncommon condition in which the horizontal ear canal has been avulsed from the skull. It follows trauma, often a road traffic accident. Clinically, there is swelling around the base of the pinna. Over time a paraaural abscess develops. This is not an acute condition.

Radiologic Signs
1. There is interruption and disruption of the normal aerated horizontal canal.
2. A soft tissue opacity occludes the canal.
3. The external soft tissue swelling, which may represent an abscess, disrupts adjacent fascial planes.

Ultrasonography can be useful in identification of the abscessation (Figure 5-14, K).

Nasopharyngeal Polyp. In cats a polyp sometimes extends on a stalk from the eustachian tube into the pharynx and nasal cavity, which it may obstruct. The presenting signs are nasal discharge, sneezing, and stridor.
Radiologic Signs
1. A soft tissue mass is seen in the pharynx lying dorso- 
tal to and touching the soft palate.
2. The mass is outlined by air in the nasopharynx.
3. Nasopharyngeal air is reduced or absent.
4. Signs of otitis media may be present.
5. Thickening of one or both tympanic bullae has 
been described (Figure 5-14, F and L).

Neoplasia. Neoplasia arising in the external ear 
canal, particularly squamous cell carcinoma or adeno-
carcinoma, may cause bone destruction in the area of 
the tympanic bulla and petrosal part of the temporal 
bone. There is usually an associated soft tissue swell-
ing. Neoplasia may also affect the middle ear and the 
tympanic bulla (Figure 5-14, J).
Craniomandibular osteopathy may cause prolif-
erative bony changes in this region that should not be 
missed for neoplasia (see Figure 5-8, A to E).

THE EYE
Radiography is of little value in evaluating the eye 
except for locating metallic foreign bodies or evaluat-
ing periorbital structures.
As an incidental finding, opacification of the lens (cat-
aract) can be seen lying rostromedial to the caudal root 
of the zygoma. Cataracts are often bilateral and should 
not be mistaken for foreign bodies (see Figure 5-6, G).

Ultrasonography
Ocular masses, retrolubar masses, corneal or lens 
opacification, and hyphema are clinical instances in 
which ultrasonography may be of diagnostic benefit.
Ocular ultrasonography requires at least a 10-MHz 
transducer with a small footprint. However, a 13- 
to 15-MHz transducer gives superior resolution of the 
surface structures. In larger dogs a 7.5-MHz transducer 
may be necessary to image the retrolubar structures.
With older machines, a standoff is usually required to 
examine the cornea. To obtain the best possible image, 
the highest possible transducer frequency should be 
used. If the eye is painful or the animal is uncooper-
ative, sedation and topical analgesia are required. Gen-
eral anesthesia is occasionally necessary, particularly 
if fine-needle aspiration will be attempted. The disad-
antage of general anesthesia is that the eyeball tends 
to rotate and may have to be held in position with 
small retractors. Most animals are cooperative when 
a topical anesthetic is used.

The animal should be restrained in a standing or 
sitting position with the head held still. The technique 
requires sterile coupling gel application to the cornea 
and then placing the transducer on the gel. Direct 
contact with the cornea is inadvisable because it may 
cause corneal damage and ulceration. This gel must 
be subsequently rinsed off with sterile saline. Alter-
atively, the orbit can be examined through the eye-
lids. The surface hair must be clipped and coupling 
gel applied in the usual manner. This technique is less 
informative than the direct corneal approach. Exam-
nation of the eye, particularly the retrolubar region, 
can also be carried out through the dorsolateral soft 
tissue aspect of the orbit just posterior to the eyelid 
and dorsal to the zygomatic arch.
Horizontal and sagittal (longitudinal) plane sections 
should be obtained and the transducer swept gently 
in dorsoventral and mediolateral directions. The small 
groove or mark on sector, convex, and microconvex 
transducers indicating the plane of section helps ori-
entation of the ultrasound beam. This groove should 
be kept at the lateral aspect of the eye when scanning 
in a transverse plane and at the dorsal aspect of the eye 
when scanning in a sagittal plane (Figure 5-15, A).

Anatomy
The eye is spherical, smooth, and well defined. The 
cornea is examined by using a standoff and is identi-
fied as a smooth, hypoechoic, well-marginated 
structure lying in the near field. With high-frequency 
transducers, three layers are usually visible within the 
cornea. The anechoic anterior chamber lies just behind 
it. The curved lens is usually anechoic but casts hyper-
echoic horizontal linear echoes at its anterior (rostral) 
and posterior surfaces. The ciliary body lies to either 
side of the lens and can be identified as hyperechoic 
streaks running laterally and medially. The anterior 
and posterior vitreous chambers are anechoic, and 
the curved hyperechoic posterior wall of the globe is 
seen caudally. The sclera, retina, and choroids cannot 
be individually recognized. The optic nerve is identi-
fied as a small hypoechoic depression in the posterior 
wall. Retrolubar tissues are poorly defined. They are 
identified as a cone-shaped structure running from 
the back of the globe caudally. They consist of the 
moderately echogenic fat tissues with the hypoechoic 
medial rectus muscle lying medially (Figure 5-15, A).

Abnormalities
Cataracts result in thickening of the lens capsule so that 
the entire circumference becomes visible. There is also 
increased echogenicity of the lens parenchyma. Intra-
ocular masses disrupt the normal architecture. They 
have a variable echotexture and displace the vitreous 
ciliary body and lens. Retrolubar masses may cause 
displacement of the posterior wall. They have mixed 
echogenicity. Differentiation between neoplasia and 
infection is not usually possible without ultrasonog-
guided fine-needle aspiration or biopsy. Variable 
amounts of anechoic or flocculated fluid may be pres-
ent with either neoplasia or infection (Figure 5-15, B 
to D). Intraocular hemorrhage causes increased echo-
genicity in the affected chamber. With time, echoes 
become organized and form hypoechoic masses.
Deformities or abnormal position of the lens are 
readily demonstrated (Figure 5-15, E to H). High-fre-
cquency transducers of 13 to 15 MHz permit the iden-
tification of subtle abnormalities such as persistent 
yaloid membrane. This membrane extends from the 
caudal aspect of the lens to the retina (Figure 5-15, H).
Retinal detachment is seen as a linear arc extend-
ing from the posterior wall of the eye rostrally into the 
vitreous humor. Anechoic fluid lies behind the reti-
nal membrane. If it is completely detached, it forms a 
curved V centered at the optic disk, where it remains
Figure 5-15 Ocular ultrasonography. A, Normal transverse scan through the orbit. The anechoic anterior chamber (Ac) and vitreous (P) are clearly seen. The contours of the lens (L, arrows) are also visible. The ciliary body (CB) lies lateral and medial. C, Cornea; I, iris; L, lateral. A shows the transducer in contact with the cornea. Direct contact with the cornea is inadvisable because it may cause corneal damage and ulceration. B to D, This 3-year-old Retriever presented with exophthalmos and marked pain when the affected area was manipulated. After topical analgesia, ultrasonography was performed. The transverse sonograms display the lateral aspect of the head to the left side of the image. An anechoic fluid-filled eye structure is seen (e). B, The hyperechoic linear structure (short arrow) is the posterior surface of the lens. The retina should be concave, but it is convex and displaced, forming two arcs. A large hypoechoic mass (m) is seen to the medial and caudal aspects of the eyeball. C, By changing the depth of field of examination, this mass (m) can be seen to extend caudally and to contain anechoic fluid-filled areas (f). The probable diagnosis was a retrobulbar abscess. A general anesthetic was given and a fine-needle aspirate obtained. Drainage of the fluid was performed under ultrasound guidance. D, The fluid-filled areas (f) have reduced considerably in size after aspiration of 4 mL of turbid fluid. Cytologic analysis showed neoplastic cells. Diagnosis: lymphosarcoma. E and F, A 5-year-old male Tibetan Terrier with diabetes had diabetic cataracts. E, In the right eye the lens (L, arrows) is irregularly hyperechoic. C, Cornea; AC, anterior chamber; V, vitreous; L, lateral. F, Congenital ocular deformities. The lens is compressed and severely deformed. The vitreous contains hyperechoic floccules (short arrow). I, Iris; L, lens; AC, anterior chamber; V, vitreous.

Continued
attached (Figure 5-15, I and J). Intraocular or retrobulbar foreign bodies are seen as echogenic structures with variable degrees of acoustic shadowing. Floating echogenic foci (floaters) are often seen in the vitreous humor. They are of no clinical significance. They should not be confused with resolving hemorrhage or inflammatory exudates (Figure 5-15, F).

THE TEETH
Radiography is of value in the assessment of periodontal and periapical disease and in the demonstration of fractures, neoplasms, foreign bodies, malocclusion, and other abnormalities (see Figure 5-18).

Anatomy
The dental formula for the dog is

Deciduous: $2 \times \frac{3}{3} C \frac{1}{1} P M = 28$

Permanent: $2 \times \frac{3}{3} C \frac{1}{1} P M = 42$

The dental formula for the cat is

Deciduous: $2 \times \frac{3}{3} C \frac{1}{1} P M = 26$
The permanent teeth develop beneath or to one side of the deciduous teeth that they eventually displace. The first premolar tooth in the dog has no deciduous counterpart. All the permanent teeth have erupted by the seventh or eighth month of age. In the young animal the pulp cavity occupies almost the whole of the tooth. It becomes narrower as the animal grows older.

The root of the tooth is embedded in the skull. The exposed part of the tooth is covered by enamel and is called the crown. The tooth itself is composed of dentin, a bonelike structure that surrounds the pulp cavity and underlies the enamel. The tooth roots are covered by a thin layer of bonelike tissue called the cementum, which cannot be distinguished, grossly or radiographically, from the underlying dentin. The pulp cavity, or hollow center of the tooth, contains nerves, arteries, veins, lymphatics, and connective tissue. At the apex of each root is the apical foramen, through which nerves and vessels enter the pulp cavity.

The mandible has three mental foramina: (1) the rostral foramen lies ventral to the alveolus of the central incisor tooth; (2) the middle foramen lies ventral to the septum between the first two cheek teeth; and (3) the caudal foramen lies about 1 cm caudal to the middle foramen.

**Radiography**

A ventrodorsal view, with an intraoral film pushed corner first back to the commissures of the lips, will show the mandibular teeth as far caudally as the first molar. The x-ray beam is centered between the mandibles at approximately the level of the third premolar tooth. The mandibular incisor teeth are best demonstrated on a ventrodorsal view, using intraoral film with the beam directed rostrocaudally at an angle of 20 degrees (V20°R-DCdO). A lateral view may also be useful. The standard focus film distance may be halved. A lateral view may be useful. The standard focus film distance may be halved. A lateral view of the mandibular premolar and molar teeth can be made by using a lateral oblique view with the arcade of interest nearest to the film. The mouth is opened, and the skull is rotated on its long axis through approximately 45 degrees away from the side under examination. The x-ray beam is directed perpendicular to the tabletop (Le45°D-RIVO or Rt45°D-LeVO).

The maxillary, premolar, and molar teeth are demonstrated in the ventrodorsal position with the film placed under the skull. The animal’s mouth is held fully opened with a bandage or tape, and the x-ray beam is angled rostrocaudally at 20 degrees (V20°R-DCdO). The teeth can also be demonstrated on a lateral oblique view, which is useful in evaluating the teeth roots. The arcade of interest is placed nearest to the film. The mouth is opened, and the skull is rotated on its long axis through approximately 45 degrees toward the side under examination. The x-ray beam is directed perpendicular to the tabletop (Le45°V-RtDO or Rt45°V-LeDO). The maxillary incisor teeth are demonstrated in the dorsoventral position, with the intraoral film placed behind the teeth and pushed dorsocaudally as far as the roof of the mouth. The x-ray beam is directed rostrocaudally at an angle of 20 degrees and is centered just behind the nares (D20°R-VcDO). The standard focus film distance is halved. A lateral view is also occasionally useful.

Standard lateral, ventrodorsal, and dorsoventral views result in superimposition of the dental arcades. High-definition single screen-film combinations or nonscreen dental film will give very good detail of the teeth.

**Normal Appearance**

The pulp cavity can be seen as a relatively radiolucent canal surrounded by the more radiopaque dentin. It is widest in young animals and almost completely fills the tooth in recently erupted permanent teeth. The pulp cavity gradually decreases in width with age and by middle age is a thin, linear, lucent structure in the center of the tooth. A thin radiolucent line surrounds the tooth root. This line represents the periodontal membrane. The bone lining the tooth socket (alveolus) is more opaque than the surrounding bone and appears as a discrete radiopaque line. This line represents the lamina dura. The ridge of bone between adjacent teeth is called the alveolar crest. It forms a right angle with the lamina dura at the amelocemental junction (the junction of enamel and cementum). The enamel is radiopaque.

The mandibular canal appears radiolucent and lies parallel to the ventral border of the mandible. Teeth roots occasionally project into the canal. In some animals a zone of radiolucency is seen just caudal and ventral to the roots of the mandibular canine teeth. This feature should not be mistaken for an abnormality (Figure 5-16).

**Abnormalities**

**Variation in Number.** Anodontia, complete absence of teeth, is rare. Oligodontia, partial absence of teeth, is not infrequently seen in the brachycephalic type of skull. The first premolar and lower third molar are most commonly absent. Polyodontia, supernumerary teeth, may be seen in the area of the first two premolars. Less frequently there may be extra maxillary incisors or molars. Polydontia affects the permanent dentition and may result in overcrowding of the teeth; in some cases a number of teeth must be removed. Deciduous teeth are occasionally retained, causing displacement of the permanent teeth. Congenital anomalies of individual teeth also occur (Figure 5-17).

**Periodontal Disease.** Periodontal disease is common in dogs and less common in cats. The periodontium includes the gingivae, the periodontal membrane or ligament, the cementum, the dentin, and the alveolar bone. Oral infections involving the gingivae may spread to the periodontal membrane, alveolar bone, cementum, and dentin. In untreated cases, there will be widespread infection, destruction of bone, and eventual loss of the affected tooth or teeth. Radiography helps evaluate the spread of the disease in the...
Figure 5-16 Normal teeth. A, Intraoral view of the upper incisors and canine teeth. There is a pellet in the lip. B, Intraoral view of the lower incisors, canines, and molars. A loose piece of tartar is seen. C, An oblique view shows the superior (upper) dental arcade. Superimposition of the dental arcades can be eliminated using oblique views. This is an old dog, as evidenced by the narrow pulp cavities and the lack of sharp definition of the laminae durae. D, Normal teeth in a 1-year-old Doberman Pinscher. The anatomic landmarks are as follows: enamel (1); dentin (2); pulp cavity (3); lamina dura (4); both edges of the superimposed rostral root (5); tubercle (6); amelocemental junction (7); cementum, periodontal membrane, and lamina dura (8) (inset E); and mandibular canal (9). (From Zontine WJ: Dental radiographic technique and interpretation, Vet Clin North Am 4(4):741–762, 1974.)
periodontal space around the tooth root and the surrounding bone.

Radiologic Signs
1. The first demonstrable sign of advancing infection is loss of the sharp angle at the junction of the alveolar crest and lamina dura as a result of resorption of the crest. The alveolar crest becomes less distinct, or less sharp, because it has become eroded. This erosion has been called apical migration, meaning that the alveolar crest appears nearer than usual to the apex of the tooth.

2. The periodontal space becomes wider.
3. The sharply defined radiopacity of the lamina dura is lost.
4. Rarefaction and, in more advanced cases, destruction of the surrounding alveolar bone occurs (Figure 5-18, A). Resorption of the alveolar crest may also be part of the normal aging process.

Periodontal (Periapical) Abscess. A periodontal abscess occurs in the periodontal tissues. Such abscesses are often deep seated, affecting the area surrounding the tooth root. When they occur around
Figure 5-18 Periodontal and periapical disease. A, The right canine tooth has not erupted. A zone of radiolucency surrounds the tooth, and the adjacent alveolar bone is being destroyed. The dog presented with a mandibular sinus tract. B, Malocclusion. The mandibles project rostrally well beyond the level of the maxillae. C, A 3-year-old Labrador Retriever had picked up a live firework, which exploded in its mouth. There was considerable soft tissue swelling and crepitation on the left side of the mouth. On the dorsoventral study of the maxilla, a transverse fracture through the left third maxillary premolar tooth is seen (arrow). The dog also has a comminuted mandibular fracture on the left side extending from the mesial aspect of the first molar tooth and running rostrally to end between the third and fourth premolar teeth. Diagnosis: fractured tooth; fractured mandible. D, This 7-month-old English Springer Spaniel had a history of a swelling on the left side of the mouth. An open-mouth, left lateral oblique view demonstrates an amorphous, mainly soft tissue mass with focal areas of mineralization. It is expansile and deforms the mandibular contour. The teeth are displaced rostrally. Diagnosis: ameloblastoma.
the apex of the tooth, they are referred to as periapical abscesses. An abscess may be the result of periodontal disease, trauma, cyst formation, neoplasia, fracture of a tooth, or a retained root after tooth extraction. A malar abscess presents clinically as a discharging sinus on the face, just below the medial canthus of the eye. It is seen in middle-aged and older dogs and cats. The cause is infection and destruction of the alveolar bone over a root of the upper fourth premolar. Radiographs may show an area of radiolucency around the affected root apex. Osteomyelitis of the maxilla or infection of the nasal chamber may ensue. Frequently no radiographic changes are observable.

Radiologic Signs
1. There is resorption of alveolar bone in the immediate neighborhood of the abscess.
2. The root may be partially resorbed.
3. If the abscess is at the apex of the tooth root, a zone of radiolucency surrounds the affected root apex. There is thinning of the adjacent medullary cortex. Superimposition of the mental foramen can simulate this appearance in the canine tooth.
4. A sclerotic margin often surrounds the radiolucent defect (Figure 5-18, A).
5. Tooth root remnants may be seen.

6. There may be signs of osteomyelitis extending from a fractured tooth.
7. The pulp cavity is often enlarged (Figure 5-18, E and F).
8. Fracture of a tooth is occasionally seen.
9. Rhinitis may occur (see Figure 5-10, E).

Caries. Caries is a bacterial destruction of the tooth enamel, dentin, or cementum. It is not common in dogs or cats. Visual inspection is superior to radiography in the diagnosis of the condition. Radiographically, radiolucent defects may be seen in the affected area of the crown.

Feline Odontoclastic Resorptive Lesions. Resorptive lesions at the gum line are the most common form of acquired dental disease in cats. The etiology is unclear. The lesions appear as lytic defects in the root just below the gum line and progress to become large cavities that involve both the crown and roots. Large lesions may cause fracture of the tooth and loss of the crown with the roots left in situ.

Fractures. Although dental fractures are usually obvious on clinical examination, radiography may be helpful in demonstrating the degree of involvement.
of the tooth root. Radiographs in two planes should be made because the fracture may not be evident on a single study. Animals that chew stones show undue wear of the teeth (Figure 5-18, C and F).

**Neoplasia.** Tumors of dental origin are uncommon and are seen in young animals. *Ameloblastoma* appears as a lacelike, expansive, multiloculated lesion with associated soft tissue masses. *Adamantinoma,* or *odontoma,* is similar to ameloblastoma but contains foci of radiopaque enamel. These form on or near the crown or root of a normal tooth. Adjacent teeth may be displaced. Another form of dental neoplasia is the *dentigerous cyst,* which has toothlike remnants within an expansive, well-defined radiolucent mass. Malignant neoplasms originating in adjacent tissues, such as fibrosarcoma, carcinoma, and melanoma, may destroy alveolar bone and cause the teeth to become loose. They metastasize to local lymph nodes and the lungs. *Epulides* are tumor or tumorlike masses of periodontal tissues occurring in the vicinity of the incisor teeth. They may be fibromatous, ossifying, or acanthomatous (squamous). The first two are noninvasive and benign, whereas the acanthomatous type is locally invasive, causing bone destruction. Benign cysts may occur. Biopsy is needed for a definitive diagnosis (Figure 5-18, D and G).

**THE SALIVARY GLANDS**

The salivary glands and their associated ducts are not visible on plain radiographs. **Sialography** (the use of contrast medium to outline the ducts and glands) is sometimes used. The principal indication for such studies is the presence of a salivary mucocele when it is necessary to establish which side of the skull is affected. Sialography may demonstrate rupture of a duct.

**Anatomy**

The **parotid gland** lies at the junction of the head and neck around the base of the auricular cartilage. Its duct opens in the mouth on a papilla on the mucosal ridge opposite the caudal margin of the fourth upper premolar (carnassial) tooth. The **zygomatic gland** lies ventral to the zygomatic arch. Its duct opens approximately 1 cm caudal to the parotid papilla. Smaller ducts discharge individually into the mouth caudal to the opening of the main duct.

The **mandibular gland** lies just caudal to the angle of the jaw, between the external and internal maxillary veins. It is in a common capsule with the caudal portion of the sublingual gland. The mandibular duct opens on the lateral surface of the lingual caruncle at the frenum linguae. The **sublingual gland** consists of several lobulated masses. The caudal portion is in a common capsule with the mandibular gland. The rostral portion of the gland lies along the line of the mandible. Its duct opens 1 to 2 mm caudal to the opening of the mandibular duct. In approximately one third of cases, the sublingual and mandibular ducts join and have a common opening.

**Sialography**

Plain radiographs in the lateral and ventrodorsal positions should be made before sialography is performed. Blunt cannulas made from fine-gauge needles (25 or 26 gauge) or lacrimal catheters or cannulas are necessary for cannulating the ducts. Iodine-based, water-soluble contrast agents are used. The dose depends on the size of the dog—up to 2 mL for each duct.

The mandibular duct opening appears as a small red spot on the lateral surface of the lingual caruncle. Gentle rubbing of the cannula tip in a rostrocaudal direction usually results in the cannula entering the duct. The sublingual duct, 1 to 2 mm caudally, is not as easy to find and enter. Patience is required. The caruncle can be steadied by grasping it with a fine, smooth forceps. However, it quickly becomes edematous if it is handled excessively and unless care is exercised. Entry to the parotid duct is facilitated by grasping the oral mucosa with a forceps caudal to the duct papilla and pulling it gently rostromedially. After injection of a duct, lateral and ventrodorsal radiographs of the skull are made. This is a difficult technique of limited value except in the demonstration of sialoliths.

**Normal Appearance**

After successful injection of a duct, the duct and associated gland are outlined. A normal gland shows an arboreal type of pattern because branching ductules are also outlined. The mandibular duct runs parallel to the horizontal ramus of the mandible and then dips ventrally into the gland. The sublingual duct parallels the mandibular duct, giving off branches to several lobules of the gland. The parotid duct runs to the angle of the jaw, where it divides into several smaller ductules before entering the gland. The zygomatic duct is short and runs in a dorsocaudal direction to enter the gland (Figure 5-19).

**Abnormalities**

**Sialocele.** Sialocele (salivary mucocele) is a collection of extravasated salivary gland secretion. It results from rupture of a salivary duct. The cause remains obscure. The duct of the rostral portion of the sublingual gland is most commonly affected. The usual presenting sign is a gradually enlarging, painless swelling in the caudal intermandibular region. A swelling may occasionally develop under the tongue (*ranula*) or in the pharynx.

If a duct is ruptured, sialography will show that the contrast medium leaks from the duct into the fluid collection and outlines the mucocele. If a duct is intact, its integrity will be demonstrated on the contrast study, and the corresponding gland will be outlined (Figure 5-20, A, B, F, and G).

A salivary fistula may develop after facial trauma. Clinically, there is a discharge at the site. Sialography will confirm the diagnosis.

**Ultrasoundography.** A fluid-filled anechoic area with no floccules differentiates a salivary mucocele from an abscess or hematoma (Figure 5-20, C).
**Sialoliths.** Sialoliths are rare in dogs and cats. They are seen as discrete radiopacities along the course of a salivary duct. Air introduced into the duct during injection of positive contrast medium may simulate sialoliths (Figure 5-20, D and E).

**Neoplasia.** Adenocarcinoma of the mandibular or parotid glands is occasionally encountered in older dogs and cats. The condition is rare. Metastases may occur to the regional lymph nodes or lungs. Diagnosis is usually made by methods other than radiography, but the use of sialography may enable a salivary gland to be identified and distinguished from an adjacent mass.

**Ultrasonography.** A mass can be identified, and ultrasound-guided fine-needle aspiration performed.

**THE NASOLACRIMAL DUCTS**
The nasolacrimal ducts can be studied by dacryocystorhinography (the introduction of water-soluble positive iodine-based contrast medium into the ducts). A cannula is inserted into the superior punctum. However, the information gained is limited (Figure 5-21).

**THE BRAIN**
The brain lies within the bony cranium and is not visible on plain radiographs. Abnormalities within the brain can be demonstrated on contrast studies. The radiographic methods of studying the brain are (1) cerebral angiography, (2) cranial sinus venography, and (3) ventriculography.

CT and MRI yield more information and have superseded these contrast techniques.

**Anatomy**
The surface of the brain is covered with the meninges. The outer meningeal layer, the dura mater, is composed of dense fibrous tissue and is closely opposed to the inner peristem of the calvarium. The arachnoid layer of the meninges is loosely attached to the surface of the brain. The pia mater is closely adhered to the cortex of the brain and extends into the sulci of the cerebrum. The brain is divided into anatomic regions: the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon. The telencephalon is the cerebrum, which is composed of two hemispheres covered with alternating ridges and grooves, the sulci and
gyri. The deep division between the two cerebral hemispheres is the falx cerebri. The two lateral ventricles are contained within the cerebrum. There is a choroid plexus within each of the lateral ventricles and the fourth ventricle. These structures are highly vascular and produce the CSF. The lateral ventricles communicate with the third ventricle, which lies on midline within the diencephalon, which also includes the thalamus and hypothalamus. The midbrain contains several nuclei and white matter tracts from the cerebrum, the crus cerebri. The cerebellum is composed of two hemispheres and the vermis, which is on the midline and lies dorsal to the fourth ventricle. Ventral to the fourth ventricle are the pons and medulla oblongata.

The left and right carotid arteries and the left and right vertebral arteries furnish the blood supply to the brain. These vessels are interconnected by several anastomotic branches. The internal carotid artery, within the cranium, runs rostromedially, traversing the cavernous venous sinus, which separates the dura mater into two layers. At the level of the optic chiasma, it perforates the dura mater and reaches the subarachnoid space. Here it divides into rostral, middle, and caudal cerebral branches.

Figure 5-19, cont’d C and D, Sublingual duct and chain of glands. E, Normal parotid sialogram.
Figure 5-20  A and B, Leakage of contrast medium into salivary mucoceles after injections into ruptured sublingual ducts. C, This cross-bred dog presented with a recurrent fluctuant submandibular swelling. Ultrasonography indicates that the mass consists of anechoic fluid lying between the hyperechoic V-shaped mandibular rami. Diagnosis: salivary mucocele. D and E, This dog had fluctuant swelling on the side of the face in the vicinity of the parotid gland. Plain radiographs were unremarkable. A sialogram was performed. The parotid duct is outlined. It is enlarged throughout its length and there is a distinct narrowing rostrally, just lateral to the oral papilla. At surgery a small sialolith was successfully removed. Diagnosis: sialolith. (D and E, Courtesy Dr. W. Hayden.)
The vertebral arteries (branches of the subclavian arteries) anastomose within the cranium to form the basilar artery. The vertebral artery, having given off the caudal cerebellar, acoustic, and pontine arteries, bifurcates and contributes to the arterial circle at the base of the brain caudally, in common with the internal carotid artery rostrally and the caudal communicating artery laterally.

Radiography
Contrast studies of the brain have been largely superseded by cross-sectional imaging techniques—CT and MRI.

Computed Tomography of the Brain. Transverse images of the skull are acquired at a slice thickness of 1 to 5 mm depending on the size of the patient and the type of CT scanner used. Thinner slices are acquired when imaging smaller patients. Thinner slices also reduce image artifacts, but their use in larger patients may be limited by the scan time and ability of the scanner to dissipate heat load. In large and medium-sized dogs, it is usually possible to resolve the gray and white matter of the brain and the lateral ventricles. In smaller patients, internal structures of the brain may not be visible. Dark streak artifacts (beam hardening) are common in the caudal fossa because of the density of the petrous temporal bone and temporomandibular joints. These artifacts limit evaluation of lesions in the caudal fossa but can be reduced by selecting the thinnest slice thickness possible and using advanced reconstruction algorithms. The iodinated water-soluble contrast agents used in diagnostic radiology are also used in CT. The blood-brain barrier is impermeable to these agents. Lesions that alter its permeability will result in contrast enhancement (see Figure 5-1, (O)).
Magnetic Resonance Imaging of the Brain. MRI is the preferred imaging technique to evaluate the brain. It offers superior soft tissue contrast resolution to CT, and images can be obtained in any plane. In a routine examination, T1- and T2-weighted images are obtained, with a slice thickness of 3 mm to 5 mm depending on the patient size and type of equipment used. These imaging protocols can depict normal anatomy and most pathology. T2-weighted images are quite sensitive to the presence of edema within the brain. Fluid attenuation inversion recovery (FLAIR) image sequences are also commonly used in brain imaging. FLAIR suppresses the normal CSF signal, but not that from parenchymal edema, and is most helpful in detecting subtle edematous lesions close to the ventricles. Contrast agents used in MRI are based on chelates of gadolinium, a rare earth element. As with the iodinated contrast agents, the normal blood-brain barrier is impermeable to these substances. Pathology that damages the blood-brain barrier allows ingress of gadolinium, which alters the local magnetic field and makes the lesion appear hyperintense (brighter) on T1-weighted images (Figure 5-22).

Cerebral Arteriography. Outlining the cerebral arteries by contrast medium allows identification of mass lesions within the brain. It requires general anesthesia. Atropine is recommended 15 to 30 minutes before the induction of anesthesia. A rapid film changer is necessary for serial studies, although much information can be gained from one or two studies made 3 and 6 seconds after completion of injection of the contrast medium. Later radiographs will show venous filling. Alternatively, fluoroscopy may be used. A pressure syringe injector ensures complete filling of the cerebral vessels. The internal carotid artery can be cannulated directly in the neck, and the vertebral artery can be cannulated via the femoral artery. The reader is referred to specialized works on the subject for technical details. Nonionic, iodine-based, water-soluble contrast medium is used. The normal appearance of cerebral arteriograms is shown in Figure 5-23, A and B.

Internal carotid injections are recommended for the demonstration of abnormalities in the rostral portion of the brain; vertebral artery injection is recommended for midbrain and brainstem lesions. Diagnosis is based on the displacement of normal vessels or on the appearance of abnormal vessels in the case of tumors or aneurysms (Figure 5-23, C).

Cranial Sinus Venography. This relatively simple technique for outlining veins and sinuses at the base of the skull may demonstrate lesions on or near the floor of the cranial fossa. Within the dura mater there are venous passages into which the veins of the brain and the surrounding bone drain. These are the dorsal and ventral sinuses, which communicate with one another. Dorsally, there are the dorsal sagittal sinus, the straight sinuses, and the transverse sinus. Ventrally, there are the intercavernous sinus and the paired cavernous, sigmoid, occipital, dorsal, and ventral petrosal sinuses. The cavernous sinuses lie on the floor of the middle cranial fossa.

General anesthesia is required. Positive contrast medium is injected into the vena angularis oculi (angular vein of the eye) to outline the intracranial and extracranial venous systems. The injection can be made percutaneously into the vein on the face, just rostral to the orbit. It is preferable to use a needle-catheter complex. Any nonionic, water-soluble, iodine-based contrast medium (370 mg iodine per milliliter) is recommended at a dosage range of 5 to 10 mL, depending on the size of the dog. The injection is made rapidly, and dorsoventral radiographs are made as the injection is completed. The jugular veins should be compressed as the injection is made. Pressure on the facial vein during injection may reduce unwanted visualization of extracranial vessels. In many cases, both right and left sides will be opacified after injection into either the right or the left vena angularis oculi. If only one side is opacified, the study may be repeated on the opposite side. Both veins can be catheterized and injected simultaneously through each catheter, using half the recommended dose on each side. Alternatively, a U-attachment may be used to deliver the contrast medium to both sides simultaneously. The normal appearance of the sinuses is illustrated in Figure 5-23, D and E.

Abnormalities are manifested as displacement or obstruction of the normal vessels. The cavernous sinus on the floor of the cranial fossa lies close to the pituitary gland and to the second, third, fourth, and sixth cranial nerves. Mass lesions involving any of these structures may cause displacement or obstruction of the sinuses (Figure 5-23, F).

Orbital venography has been described as a means of demonstrating the veins around the orbit and retrobulbar space. Contrast medium is injected into the facial vein, the dorsal vein, or the vena angularis oculi.

Ventriculography. This technique is now rarely used because CT and MRI are more readily available and are more informative. Ultrasonography is a less-invasive method of demonstrating hydrocephalus. Contrast medium, usually air, is injected into the ventricular system to outline the ventricles. Needles are passed through small drill holes in the skull, through the cerebral cortex, and into the lateral ventricles. The procedure is specialized and is used to demonstrate hydrocephalus, cerebral atrophy, or masses displacing the ventricles. In cases of hydrocephalus with open fontanelles, direct puncture of the ventricles is possible. Altering the position of the head, using a horizontal beam, will cause the bubble of introduced air to move and thus outline various parts of the ventricular system (Figure 5-24, A and B).

Abnormalities

Hydrocephalus. Dilatation of the ventricular system is referred to as hydrocephalus. The lateral ventricles are most commonly affected. The congenital form occurs
most commonly in dome-headed breeds such as the Yorkshire Terrier and Chihuahua. It is rare in cats. Radiographic signs include doming and thinning of the calvarium, which has a homogeneous appearance because of loss of normal skull markings.

The disease may be congenital, but there is considerable variation in normal ventricular size in dogs, and in many cases a diagnosis of congenital hydrocephalus is subjective. Acquired hydrocephalus occurs as a sequela to atrophy or necrosis of the brain. 

Figure 5-22 Normal brain in a dog. These are paired transverse images of the brain in T1-weighted and T2-weighted sequences. A and B, In the rostral brain, the lateral ventricles are seen as two small curvilinear structures just left and right of the midline. A, On the T1-weighted image, the lateral ventricles (arrow) appear darker (hypointense) compared with the cerebral parenchyma. B, On the T2-weighted image, the fluid within the lateral ventricles appears bright (arrow)—that is, hyperintense. The fluid within the subarachnoid space appears as a bright rim around the cerebrum on T2-weighted images. The fluid can be seen extending into the sulci of the cerebrum. C and D, T1- and T2-weighted images at the level of the midcerebrum. The lateral ventricles are roughly symmetric and appear rounded. On the T1-weighted image (C), the third ventricle is seen as a thin, slightly dark structure on the midline ventral to the lateral ventricles. The well-defined, dark, linear structure on the midline at the dorsal aspect of the brain is part of the falx cerebri, which is most likely mineralized. This mineralization is often seen as a normal appearance. It may appear dark even if composed of dense fibrous tissue.
or obstruction of CSF outflow from the skull. Hydrocephalus caused by generalized atrophy of the brain is roughly symmetric, and the sulci of the cerebrum appear wider and deeper than normal. Hydrocephalus as a result of necrosis of the brain may be a sequela to an infarct. These lesions are typically asymmetric. Obstructive hydrocephalus is most commonly caused by a mass lesion in the caudal fossa. The mass lesion results in compression of the fourth ventricle or central aqueduct and prevents outflow of cerebral spinal fluid from the fourth ventricle to the subarachnoid space of the spinal cord. There is symmetric dilation of the lateral and third ventricles. The surface of the cerebral cortex may appear flattened, and the sulci may be difficult to see. CT or MRI aids the diagnosis and may reveal the underlying cause.

**Radiologic Signs**
1. There is doming of the cranial vault.
2. The calvarium is thinned, and its internal convolutional marks are less prominent.
3. The fontanelles persist and are seen as radiolucent defects in the cranial vault.
4. The cranial vault has a homogeneous appearance (*Figure 5-24, A and B*).

**Ultrasonography.** Ultrasonography with high-frequency transducers can be used to evaluate the brain through an open fontanelle. Care should be taken to avoid exerting undue pressure through the fontanelle. Normally the lateral ventricles are small, linear, anechoic structures. With hydrocephalus, enlarged, anechoic, fluid-filled ventricles are seen within a rim of relatively hyperechoic brain tissue (*Figure 5-24, C and D*).

**Neoplasia.** Primary and metastatic neoplastic lesions occur in the brain. Primary neoplasia is a more common imaging diagnosis. Metastatic lesions are frequently recorded at postmortem examination but are uncommonly diagnosed by imaging. Brain tumors are best identified by CT or MRI. Standard radiographs are usually uninformative unless the neoplasm is markedly calcified or has caused changes in adjacent bones. Meningiomas are common in old dogs and in cats. In cats meningiomas may cause a thickened calvarium, calcification, and sclerosis of neighboring bones, which may be seen on survey radiographs. MRI and CT are more informative.

The most common types of primary brain neoplasm are meningiomas, astrocytomas, and other glial neoplasms. Most brain neoplasms appear isointense on T1-weighted images, that is, comparable in signal intensity to normal brain tissue. Edema within the tumor and the surrounding brain parenchyma appears hyperintense—brighter than normal on T2-weighted images. Peritumoral edema can be quite extensive, and T2-weighted images tend to overestimate the size of the primary lesion. Most brain tumors demonstrate moderate or intense contrast enhancement.

**Inflammatory Central Nervous System Disease.** Inflammatory disease of the central nervous system may be the result of bacterial, viral, rickettsial, or protozoal infection. However, many cases do not have an infectious cause. In some cases of inflammatory disease, no abnormalities are seen on any MRI sequence. Abnormalities within the
brain caused by inflammatory disease are usually multifocal or diffuse in nature. Lesions are usually isointense on T1-weighted imaging sequences. On T2-weighted images, lesions usually appear hyperintense because of edema. Contrast enhancement is variable. Some lesions demonstrate no significant uptake of contrast. Mild or moderate multifocal enhancement is a common pattern. There may also be focal, multifocal, or diffuse enhancement of the meninges.
Vascular Disease. Ischemic lesions of the brain are recognized with increasing frequency with the routine clinical use of MRI. Infarcts occur because of occlusion of a major arterial tributary, most commonly the middle cerebral artery or cerebellar arteries. Hemorrhagic infarcts are uncommon in dogs. On T1-weighted images, ischemic lesions are slightly hypointense or isointense to normal brain tissue. Edema within the lesion results in a hyperintense appearance on T2-weighted imaging. In acute lesions, there is usually no contrast enhancement. In subacute and chronic lesions, contrast enhancement is usually evident, with greatest intensity at the periphery of the lesion. Cerebellar infarcts are among the more common lesions identified. Infarction may affect the lateral part of the cerebellum, approximately two thirds of the
Cerebral infarcts are most commonly caused by occlusion of the middle cerebral artery. This results in a focal lesion within the rostral and middle thirds of the cerebrum. Occlusion of small arteries or arterioles produce lacunar infarcts. These are visible as small, hyperintense foci within the cerebrum on T2-weighted images. These are an occasional incidental finding.

THE VERTEBRAL COLUMN

The vertebral column consists of the vertebrae, intervertebral disks, meninges, and the spinal cord. It is frequently studied radiographically. Bone abnormalities are demonstrated on plain radiographs. Associated soft tissue abnormalities can be demonstrated by using contrast medium. Cross-sectional imaging in three planes is more informative and complements survey and contrast radiographs.

Anatomy

The Vertebrae. The vertebral column consists of approximately 50 vertebrae comprising cervical, thoracic, lumbar, sacral, and caudal (coccygeal) vertebrae. The dog and the cat have 7 cervical, 13 thoracic, 7 lumbar, 3 sacral, and a variable number of coccygeal vertebrae.

A typical vertebra consists of a body, an arch, and a variable number of processes. The arch consists of right and left pedicles and right and left laminae. The laminae form the roof of the vertebral canal and the pedicles its lateral walls. The vertebrae articulate with one another through the intervertebral articular facets. These facet joint articulations are diarthrodial joints. All vertebrae except C1 and C2 have intervertebral disks interposed between their bodies. These are syndesmotic joints with no joint fluid. Some vertebrae have modified shapes.
Cervical Vertebrae. There is a marked variation in the structure of the various cervical vertebrae. The first cervical vertebra, or atlas, consists of a central arch and two wide horizontal wings. Each wing is perforated by a foramen, the transverse foramen, which is visible radiographically. The second cervical vertebra, or axis, carries a long, thin, dorsal spine that overhangs the arch of the first cervical vertebra to a variable extent. The odontoid process, or dens, is a cranioventral eminence on the axis that is long and rounded and extends along the ventral floor of the atlas. The transverse processes are directed caudally, and each is perforated by the transverse foramen. From the third to the fifth cervical vertebrae, the transverse processes are bifid, and, in the case of the fourth and fifth, they take the form of a wide plate. The transverse processes of the sixth have small tubercles cranially and broad plates caudally that project ventrally and overlie the cervical soft tissues. The body of the seventh cervical vertebra is comparatively short. The spinous processes become more prominent on each succeeding vertebra from the fourth caudally (Figure 5-25, A to D).

Thoracic Vertebrae. The bodies of the thoracic vertebrae are shorter than those of the cervical. The spinous processes are directed caudally as far as the antical vertebra, which is usually the eleventh. This is where the dorsal spinous processes from T11 caudally change angulation from a caudal to a cranial direction. The disk space between T10 and T11 is slightly narrower than the other spaces, particularly in the cat. Demifacets are present for rib articulations. Accessory processes are present on the last four or five vertebrae (Figure 5-25, J).

Lumbar Vertebrae. The bodies of the lumbar vertebrae are longer than those of the thoracic. The spinous processes are directed cranially, and the transverse processes are directed cranially, laterally, and somewhat ventrally. Accessory processes are present on the first four vertebrae. They overlie the intervertebral foramina and are particularly prominent in cats. The spinous processes increase in height from the first to the sixth. The cranioventral aspect of the fourth lumbar vertebra projects more ventrally than do the other vertebrae. The ventral margins of the third and fourth lumbar vertebrae are often poorly defined on radiographs, particularly in larger dogs. This is because of a diaphragmatic attachment in that area (Figure 5-25, E to I).

Sacral Vertebrae. The sacrum is composed of three fused vertebrae, and the spinous processes form a notched crest. The angle between the seventh lumbar vertebra and the sacrum is variable, depending on the degree of flexion or extension of that joint.

Caudal (Coccygeal) Vertebrae. These vary in number from six to 23. Their shape is variable, being longer cranially and shorter caudally.

Intervertebral Foramina. The intervertebral foramina are formed from notches on the caudal aspects of the vertebrae that complement similar notches on the cranial aspects of succeeding vertebrae. They are present from the second cervical vertebra to the sacrum. Caudally projecting accessory processes overlie the intervertebral foramina in the caudal thoracic and cranial lumbar regions.

Intervertebral Disks. The intervertebral disks lie between the vertebral bodies from the junction of the second and third cervical vertebrae caudally as far as the lumbar-sacral junction. There is no disk between the first and second cervical vertebrae. Each disk has an outer, laminated, fibrous ring (annulus fibrosus), which is attached to the adjacent vertebrae. It also has a central pulpy nucleus (nucleus pulposus), which is composed of a homogeneous, gelatinous material. The ventral part of the annulus fibrosus is much thicker than the dorsal part. The dorsal longitudinal ligament overlies the disks on the floor of the spinal canal. From the first to the tenth thoracic disks, the dorsal longitudinal ligament is reinforced by ligaments (intercapital) that traverse the floor of the canal, running from each rib head to its fellow of the opposite side. Disk protrusions consequently are rare in this region.

The intervertebral disk spaces vary somewhat in width. The widest spaces are those between C4 and C5 and L2 and L3. The narrowest are those between C2 and C3, T10 and T11, L4 and L5, and L7 and S1.

Meninges. Meninges are membranes that cover the spinal cord and nerve roots. The outer membrane is a tough, thick, fibrous structure called the dura mater, to the outer side of which is the epidural space. The inner membranes are more delicate and are termed the leptomeninges. They are the arachnoid membrane, which is closely applied to the dura mater, and the pia mater, which is firmly attached to the spinal cord and has a rich blood supply. Between the arachnoid and the pia mater is the subarachnoid space, which contains the CSF.

Cerebrospinal Fluid. There are four ventricles, or cavities, in the brain filled with CSF. There is a lateral ventricle in each cerebral hemisphere, a third ventricle, and a fourth ventricle. The ventricles intercommunicate. The fourth ventricle lies in the hindbrain. CSF is elaborated by choroid plexuses within the ventricles. The lateral ventricles drain into the third ventricle, and the third drains into the fourth. From the fourth ventricle the CSF flows mainly into the subarachnoid space. A much smaller amount reaches the central canal. The fluid drains away through villi in the arachnoid and through lymph channels so that a circulation of fluid is maintained.

The Spinal Cord. The spinal cord consists of a core of gray matter and an outer layer of white matter. It is divided into symmetric halves by fissures. It stretches from the medulla oblongata of the brain to the conus medullaris, which lies at approximately the level of the intervertebral disk between the sixth and seventh
lumbar vertebrae. There are variations in different breeds of dogs. In large dogs the cord terminates at L4-L5 or L5-L6. The conus medullaris lies slightly more caudally in the cat. The cord has a central canal that contains CSF. Both the subarachnoid space and the central canal communicate with the fourth ventricle of the brain. The spinal nerve roots emerge from the cord dorsolaterally and ventrolaterally. In the cervical and lumbar regions where the nerves to the limbs originate, the diameter of the spinal cord is increased. These areas are called intumescences. They give rise to the brachial plexus nerves innervating the forelimbs.
Figure 5-25, cont'd Normal vertebrae. D, Cervical vertebrae. E, A lateral view of the spine from T1 to L7 shows pseudonarrowing of the intervertebral disk spaces cranial and caudal to the central beam. Only the disk spaces from T9 to L1 can be accurately evaluated. There is some axial rotation indicated by the ribs, which are not superimposed proximally. This is an example of an inappropriate study to evaluate intervertebral disk spaces. F and G, Lateral radiograph of the normal lumbar spine of a dog. G, Lateral view of normal lumbar vertebrae.

Continued
and the lumbosacral plexus nerves that innervate the pelvic cavity and hindlimbs.

**Epidural Space.** The epidural space is the space lining the spinal canal. It contains blood vessels and fat. There is no epidural space in the atlas.

**Radiography.** Individual vertebral sections should be examined with the centering point moved four or
five vertebrae each time. It is particularly important to follow this procedure when examining the intervertebral disk spaces on the lateral view because of the pseudonarrowing that occurs at the margins of the radiograph (Figure 5-25, E). The vertebrae in the cat are more slender than in the dog. They have a finer trabeculation and are longer than they are tall, particularly in the thoracic and lumbar regions.

*Cervical Vertebrae.* Adequate relaxation is necessary for satisfactory radiography of the cervical vertebrae. General anesthesia is recommended. Close collimation improves results.

For the lateral view, the patient is placed in either left or right lateral recumbency, ensuring that the long axis of the skull is parallel to the tabletop. A radiolucent foam cushion is placed under the midneck region to ensure that the cervical and thoracic vertebrae are in the same plane; that is, the midneck should not sag down toward the table. The forelimbs are drawn caudally to prevent superimposition of the scapula on the caudal cervical region. Gentle traction is exerted between the forelimbs and the skull. The neck should not be rotated on its long axis. On the finished radiograph, the transverse processes should be superimposed on one another. The x-ray beam is centered on the midcervical region and collimated to include the caudal skull and the first thoracic vertebra. In large dogs an adequate lateral study of the neck may require two radiographs, one centered between the second and third cervical vertebrae and one centered between the fifth and sixth. In puppies, the cranial aspect of the spine of the second cervical vertebra may not be visible because it is incompletely formed.

For the ventrodorsal view, the animal is placed in dorsal recumbency with the head extended and the forelimbs drawn caudally on either side of thorax. The x-ray beam is centered on the midcervical region. Care must be taken that the animal is not rotated to the left or right. The endotracheal tube should be withdrawn for this view.

*Thoracic Vertebrae.* For the lateral view, the animal is placed in lateral recumbency with the forelimbs drawn cranially. The sternum is supported by a radiolucent foam pad so that it is in the same plane as the thoracic vertebrae. For the ventrodorsal view, the animal is placed in dorsal recumbency with the

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**Figure 5-25, cont’d**

J, Normal thoracic vertebrae in a cat with a narrowed T10-T11 intervertebral disk space. This is of no clinical significance. K, A 30-degree axial rotation of the head displaces the wings of C1 and clearly profiles the dens.
forelimbs drawn cranially. The x-ray beam is centered over the area of interest. Sedation is required to ensure relaxation.

**Lumbar Vertebrae.** For the lateral view, the animal is placed in lateral recumbency with the midlumbar vertebrae supported on a radiolucent foam cushion to maintain them on the same plane as the thoracic vertebrae. The spine should not be rotated on its long axis, and the transverse processes on each side should overlie one another. To ensure that the hindlimbs are parallel to one another and that there is no rotation of the spine, a foam pad is placed between the femurs. The ventrodorsal view is made with the animal in dorsal recumbency, without rotation, and with the x-ray beam centered over the area of interest. If the animal is in pain, the limbs can be flexed in the “frog leg” position.

**Sacral and Caudal Vertebrae.** The sacrum is usually included on views of the lumbar region. The coccygeal vertebrae can be studied on conventional lateral and ventrodorsal views.

### Contrast Techniques

**Myelography.** Myelography is the introduction of positive contrast medium into the subarachnoid space. It is used to demonstrate (1) lesions within the spinal cord or (2) lesions extrinsic to the cord but causing pressure on it. Myelography is indicated when it is desirable to demonstrate cord compression before surgery and when other findings are inconclusive. Because of the associated hazards, it should be used only when necessary, usually because surgery is being contemplated or because the findings may influence treatment. Myelography is contraindicated if inflammatory disease is suspected and should not be performed if the CSF is cloudy instead of clear. General anesthesia is required. Phenothiazine premedications are contraindicated. The practice of demonstrating spinal abnormalities by using contrast medium in the epidural space or in the vertebral veins is not common. Plain radiographs should be made before the contrast medium is introduced. Intervertebral disk disease for which surgery is contemplated is the most common indication for myelography.

Iopamidol and iohexol are the agents of choice for myelography. These are water-soluble, iodine-based compounds that are nonionic and have a low osmolality. They have a lower neurotoxicity than other water-soluble agents and remain longer in diagnostic concentrations in the subarachnoid space. They are excreted through the kidneys, which are opacified.

Iopamidol and iohexol are supplied ready for use in sterile solutions in a variety of iodine concentrations. Concentrations of 200 to 370 mg of iodine per milliliter may be used, although 240 mg and 300 mg of iodine per milliliter are more commonly used. The higher iodine concentration gives better definition of contrast columns. For myelography the iodine content of the dose should be approximately 50 mg of iodine per kilogram of body weight. The volume administered is of the order of 0.3 mL/kg body weight. The contrast agent should be warmed to body temperature. A spinal needle is used. This has an outer sleeve, an inner stylet, and a short bevel. The short bevel reduces the risk of laceration of the cord and inappropriate deposition of the contrast medium. Long bevels may result in contrast medium being placed partially in the subarachnoid space and partially in the epidural space or in the spinal cord.

The volume of any concentration administered depends on the size of the animal and the area being examined. Large dogs are given smaller relative volumes. A practical guide is as follows:

- Small dogs and cats (1 to 5 kg) 0.5 to 2 mL
- Medium dogs (5 to 15 kg) 1.5 to 3 mL
- Large dogs (15 to 35 kg) 3 to 5 mL
- Giant breeds (>45 kg) 8 to 9 mL maximum

Poor column definition and nondiagnostic studies may result from insufficient volume or insufficient concentration.

Iopamidol or iohexol may be injected into the subarachnoid space, either at the cisterna magna between the occiput and C1 or in the lumbar region. An aseptic technique is required. A 1⅜ to 3-inch (38 to 76 mm), 20- to 22-gauge spinal needle is preferable for the cisterna magna. For the lumbar area, a spinal needle of up to 3½ inches (90 mm) may be required. Air bubbles can mimic space-occupying defects within the contrast column. Tilting the animal usually displaces an air bubble.

**Cisternal Myelography.** For cisterna magna injection, the dose used varies with the site of the suspected lesion. A cervical lesion requires a dose of 0.3 mL/kg, whereas a lumbar lesion may require up to 0.45 mL/kg of a contrast agent containing 300 mg iodine per milliliter. The anesthetized patient is placed in lateral or sternal recumbency. The cranial part of the animal or tabletop is elevated approximately 15 degrees. This elevated position aids caudal movement of the contrast medium. The head is flexed 90 degrees to the neck. Care should be taken not to occlude the endotracheal tube (see Figure 3-5, C). The depression between the external occipital protuberance and the dorsal lamina of the first cervical vertebra is palpated, and the needle is inserted on the midline, at the level of the cranial edges of the transverse processes of the atlas. The needle is directed slightly cranially, parallel to the hard palate, with the bevel directed caudally and advanced slowly. It can be felt to pass through the ligamentum nuchae, after which passage becomes freer. A slight popping sensation usually indicates proper positioning. The stylet should be withdrawn frequently until CSF flows from the needle.

When needle placement is correct, CSF will flow from the needle. It should not be aspirated but allowed to drip freely. A CSF sample is taken for laboratory examination. If blood flows but is seen to be mixed with CSF, injection may proceed. If only blood flows from the needle, the needle should be withdrawn and a second attempt made to reach the cisterna magna. If bone is encountered, the needle should be redirected...
on a line parallel with the hard palate. Care should be taken not to dislodge or move the needle when connecting it to the syringe. The contrast medium is injected slowly over a period of 2 to 3 minutes. The needle is then removed. If the head and neck have not already been tilted before the procedure, they are now elevated. This is to facilitate caudal flow of the contrast medium and to prevent it reaching the cerebral ventricles.

With cisternal puncture, the column may arrest cranial to a lesion, in which case the extent of the area of compression cannot be assessed. Evaluation of the lumbosacral region is best achieved by using a cisternal puncture with elevation of the head and neck. The cisternal site ensures against epidural spill, which can be a complication with a lumbar puncture site (Figure 5-26, A and B).

**Lumbar Myelography.** Contrast medium can also be injected into the subarachnoid space in the lumbar region, but the technique is appreciably more difficult. This technique is less desirable than cisterna magna injection because it involves transfixing the cord. However, a lumbar puncture consistently fills the lumbar and thoracic regions, and the contrast column often fills cranially beyond a site of compression. There is a reduced risk of seizures if only the thoracic and lumbar subarachnoid spaces are filled. The dose rate is 0.3 mL/kg of a solution with 300 mg iodine per milliliter. If a lumbosacral lesion is suspected, then cisternal myelography is advised. For lumbar myelography, the animal is placed in sternal or lateral recumbency with the back arched. Drawing the hindlimbs cranially on either side of the body facilitates arching of the back. A spinal needle with a short bevel is inserted between the neural arches and through the interarcuate space, preferably between the fifth and sixth lumbar vertebrae. Injection can also be made between the fourth and fifth vertebrae, but there is an added risk of complications. The needle is advanced through the cord to strike the floor of the spinal canal. The animal may flinch or jerk as the needle passes through the dura mater. The bevel of the needle is directed cranially. When the needle reaches the floor of the canal, it is withdrawn slightly and the stylet removed. Leakage of spinal fluid from the needle confirms that it has been correctly placed. If no fluid is obtained, the needle position is checked on a radiograph. If the location appears correct, a small test injection is made, and the position of the contrast medium is determined by making a further radiograph. If fluoroscopy is available, it can be used. Moving the animal with the needle in place is not recommended. An attempt may be made to enter the subarachnoid dorsally, without penetrating the cord. The attempt is monitored by frequent withdrawal of the stylet to allow CSF to escape when the needle is correctly positioned. This is not an easy technique. Injection of the contrast medium into the spinal cord is disastrous. Injection into the epidural space results in a very irregular outline of the column of contrast medium, and the spinal nerve roots may be outlined. Contrast may sometimes be seen in the central canal, particularly if the injection is made at the junction of the fourth and fifth lumbar vertebrae.

It has been recommended that injection of contrast medium should be made as near to the suspected site of interest as possible. However, most lesions can be outlined by a cisterna magna injection. If there is a suspicion of a cervical vertebral subluxation or fracture or cerebellar herniation, then the cisternal puncture should be avoided. Lumbar injection may be required when it is necessary to determine the caudal limit of a lesion, the cranial limit of which has been outlined by cisterna magna injection. Lumbar myelography, although technically more challenging, is safer and more useful in evaluating thoracolumbar lesions, especially where there is moderate or severe spinal cord compression (Figure 5-27).

**Complications.** It is possible to introduce the contrast material into the wrong place. If it is introduced into the epidural space, which can occur during lumbar puncture but not with cisternal puncture, the contrast column has a wavy appearance on its dorsal and ventral aspects (Figure 5-28). Contrast material tends to accumulate around nerve roots. If the contrast material is introduced into the subdural space, which may occur when either cisternal or lumbar puncture is performed, the contrast column tends to localize dorsal to the spinal cord. It has a smooth appearance dorsally and a wavy appearance ventrally, and appears more radiopaque than usual. The leading margin has a sharp, arrowhead-like appearance. If the contrast material enters the central canal, it is seen as a thin linear streak in the center of the cord. This is more likely to occur if the injection is made cranial to L5-L6. Depending on the volume of contrast material introduced into the canal, paresis may ensue. With incorrect locations, the subarachnoid space may be partially opacified. Air bubbles in the contrast material can result in filling defects in the contrast column and simulate pathology. They tend to change position as the animal is moved.

If convulsions or muscular spasms follow injection of contrast medium, they can be controlled by an injection of diazepam (Valium), which should be on hand before the procedure commences. If contrast material is injected into the spinal cord at the cisterna magna, death may result.

**The Normal Myelogram.** After a successful injection, on the lateral view the spinal cord will be outlined dorsally and ventrally by a line of contrast medium. The subarachnoid space is widest at the cisterna magna. The spinal cord is widest at the cervicothoracic and midlumbar regions. The caudal cervical region, on a ventrodorsal view, sometimes fails to fill fully. If so, a dorsoventral view should be made. This view allows the contrast material to pool in the dependent, caudal cervical region. The head should be higher than the thoracic inlet for this view. The cauda equina area often has a fishtail appearance as the spinal cord tapers. It is important that two orthogonal views be obtained because pathology may be
Figure 5-26  A and B, Normal cervical myelograms.  A, Cat.  There is some contrast material in the soft tissues at the site of injection.  B, Dog.  C, A lateral myelogram shows normal indentation of the ventral contrast column at C2-C3 and C3-C4.  There is a narrowed intervertebral disk space at C4-C5.  The ventral contrast column has a double outline, with one side elevated (arrows) and the other lying on the floor of the vertebral canal.  The dorsal column is thinned because of lateral displacement of the intervertebral disk, causing extradural compression.
visible in only one plane. Contrast may fail to pass a lesion, and a puncture at the alternate myelographic site should be performed subsequently to outline the limits of the lesion (see Figure 5-27, A).

**Abnormalities.** *Extradural lesions* will cause the contrast column to be indented at the site of the lesion, with a corresponding thinning of the column on the opposite side because of compression. A laterally located extradural lesion causes elevation of the contrast column on that side, resulting in a double line on the lateral view. On the ventrodorsal view, the column will be arrested or displaced at the site of the lesion. An *intramedullary lesion* will cause divergence of the dorsal and ventral contrast columns at the site of the lesion. Flow beyond the lesion may be inhibited. A ventrodorsal view will show lateral displacement and divergence of the contrast columns. Diffuse widening of the cord suggests hemorrhage or edema. An *extramedullary intradural lesion* causes displacement of the contrast column. If the lesion lies laterally, the cord appears expanded on the lateral view and
displaced on the ventrodorsal view. Focal widening of the subarachnoid space caused by a discrete mass in that region forms the “golf tee” sign (see Figures 5-26 and 5-27).

**Epidurography.** This is the injection of nonionic contrast medium into the epidural space. The concentration should be between 200 and 300 mg iodine per milliliter with a maximum volume administered of 5 mL in large dogs. Flexed, neutral, and extended studies are advised. Epidurography has been recommended for the demonstration of cauda equina lesions. The epidural space is relatively wide and often fills irregularly. Interpretation of such studies is difficult.

**Venography.** This has been described as a method of demonstrating cord compression. Depending on the size of the animal, 8 to 20 mL of a 60% water-soluble contrast medium is injected into the saphenous vein. The caudal vena cava is compressed by compression of the abdomen. Radiographs are made 15 to 20 seconds after completion of the injection. The vertebral veins are outlined. Compression is slowly released.

**Discography.** This is the injection of contrast medium into the substance of an intervertebral disk. Its use in the dog and cat is not common. It is usually performed before epidurography. The normal disk will accommodate approximately 0.2 mL, whereas an abnormal disk will take up to 3 mL.

**Normal Appearance of Vertebrae**

The normal appearance of the vertebral column is illustrated in Figure 5-25. The opaque lines on the dorsal aspect of each vertebral body and the ventral aspect of each dorsal arch identify the dorsoventral diameter of the spinal canal. On myelography the ventral subarachnoid space is often indented at the disk space between the second and third cervical vertebrae (see Figure 5-26, C). In the larger breeds of dogs, because of conformation and gravity, poor definition of the contrast column between C5 and T1 is occasionally seen on the ventrodorsal view. Dorsoventral views give good definition in such instances. The subarachnoid space is normally narrow ventrally in the caudal thoracic region. Small indentations are often seen on the ventrodorsal view. Another form of hemivertebra appears wedge shaped on the lateral view, the apex of the wedge being ventrally located. Still another form appears wedge shaped on the ventrodorsal view.

Hemivertebrae are usually accompanied by compensatory changes in the shapes of adjacent vertebrae. However, no inflammatory changes are present, and the disk spaces are preserved, although they may be misshapen. This feature helps distinguish the condition from compression fractures. With fracture, there is disruption of the cortex. Hemivertebrae are most commonly seen in the thoracic vertebrae and are frequently associated with kyphosis in that area. Alignment of vertebrae may vary. The ribs often appear crowded dorsally. Cord compression is demonstrated by myelography. Many cases are asymptomatic. Spondylitis may be a feature in older dogs. It is only occasionally of clinical significance. In severe cases in young animals, it may cause neurologic deficits. The disorder is most common in the Bulldog, Boston Terrier, Pug, and Manx cat (Figure 5-29, C and D).

**Block Vertebrae.** On occasion, two or more adjacent vertebral bodies are fused. These block vertebrae result from failure of the various segments to separate during development. The condition must be distinguished from inflammatory or degenerative conditions. Usually there is neither evidence of inflammatory reaction at the site nor an associated neurologic deficit. There may be abnormal angulation of the spine. Another developmental anomaly may be fusion of the spinal processes (Figure 5-30).
Transitional Vertebrae. Sometimes vertebrae at the atlantooccipital, cervicothoracic, thoracolumbar, or lumbosacral junctions have some features common to both types of vertebrae. A transverse process may have the appearance of a rib, or vice versa. Clinically, these anomalies are usually of no significance. They may be important from the point of view of accurately locating a surgical site, particularly in the thoracolumbar region. The terms lumbarization and sacralization have been used to describe these congenital anomalies in the thoracolumbar and lumbosacral areas. Foreshortening of the last lumbar vertebra is sometimes seen.

A lumbosacral transitional vertebra may cause positioning difficulties for the ventrodorsal view of the pelvis as a result of asymmetry. It has been suggested that changes in this region may be associated with cauda equina syndrome. Radiologically, on the lateral view there is often an apparent disk space between the first and second sacral segments, which are normally fused. On the ventrodorsal view the spinous processes of the second and third sacral segments appear to be displaced caudally in relation to the spinous process of the first sacral segment. The transverse process or processes of the last lumbar segment may be mildly or grossly elongated. The processes or lumbar vertebrae may also be foreshortened and broad and may be incorporated to a variable degree in one or both sacroiliac joints. The changes

Figure 5-29 A and B, Atlantoaxial subluxation. A, The extended lateral radiograph shows that C2 is located slightly more cranial than usual. The dens has a rounded appearance and is foreshortened. B, With slight flexion of the head, the axis has displaced dorsally in relation to the atlas. The dens is clearly rounded and malformed. C and D, Hemivertebrae. The eighth and ninth thoracic vertebrae of this English Bulldog are wedge shaped, resulting in deformity of the spine with kyphosis. The ventrodorsal view shows crowding of the ribs in the area of the deformity.
may be symmetric or asymmetric. There is often new bone formation around the sacroiliac joint. The pelvis may be asymmetric despite the spine being straight (Figure 5-31, A to H).

**Spina Bifida.** Spina bifida is a rare condition that results from failure of the neural arch to close properly. It may involve one or a number of vertebrae. An affected vertebra is best seen on the ventrodorsal view by comparison with normal vertebrae cranial and caudal to the abnormality. Failure of fusion of the spinous processes can be seen because the vertebra appears to have two spinous processes side by side anatomically. There may be an associated protrusion of the meninges (meningocele), spinal cord (myelocoele), and nerve roots (meningo(myelo)cele) through the defect. Although not seen on plain radiographs, these meningeal abnormalities can be demonstrated by myelography, CT or MRI. In mild cases no clinical signs are evident. More severe cases show ataxia and paresis (Figure 5-31, I).

**Sacroccygeal Dysgenesis.** This is a developmental defect in which there is absence of one or more vertebral bodies. There may be associated meningeal abnormalities, a short spinal cord, and cauda equina defects. Vertebral abnormalities such as hemivertebrae or transitional vertebrae may also be present. It is seen in Manx cats because of a genetic defect and commonly affects the sacral and coccygeal vertebrae. Agenesis of the sacrum also occurs in this cat breed.

**Other Anomalies.** Because of the complex nature of spinal development mechanisms, other anomalies occur, such as altered location of the anticlinal vertebra and variation in the number of vertebrae.
Figure 5-31 A to D, Abnormal vertebrae. A, The thirteenth thoracic vertebra has only one rib. The rib that is present has some of the features of a lumbar transverse process. B, There are apparently only six lumbar vertebrae. The first lumbar vertebra has attached ribs. C, The last lumbar vertebra has a malformed process (arrows) on the left side and is partly articulating with the sacrum on that side. This congenital anomaly makes symmetric positioning of the pelvis difficult. D, The last lumbar vertebra is a transitional vertebra showing abnormalities on both sides. The caudal aspects of the sacroiliac joints are at two different levels (arrows) because of anatomic malformation. The last three lumbar vertebrae and the pelvis are all tilted because of the anomaly.

Continued
Scoliosis is an abnormal curvature of the vertebral column in the lateral plane as seen on the ventrodorsal view. It may be congenital, or it may be the result of an injury (Figure 5-31, J). Kyphosis is an abnormal dorsal curvature of the vertebral column in the dorsoventral plane as seen on the lateral view (see Figure 5-36, H). Lordosis is an abnormal ventral curvature of the spine in the dorsoventral plane as seen on the lateral view.

Hypoplasia, aplasia, or nonunion of the dens may result in luxation or subluxation of the atlantoaxial joint. Deformity of the third cervical vertebral body has been reported as a cause of paralysis in young male Bassett Hounds.

Syringomyelia and Hydromyelia. Syringomyelia is cavitation of the spinal cord, and hydromyelia is dilation of its central canal. Syringomyelia is associated
with damage to the spinal cord from inflammation, neoplasia, or trauma. The exact mechanism of its formation is obscure. Hydromyelia is often associated with congenital anomalies, with obstruction to CSF flow at the foramen magnum, or it may be idiopathic. The two conditions may coexist with or without communication between them. Clinical signs depend on the location of the lesion and possible associated changes such as scoliosis. They may be acute or chronic. Cavalier King Charles Spaniels are reported to be particularly prone to this condition.

Myelography may be normal or show dilation of the central canal. Dilation may be seen in one or more segments of the spinal cord. It may show obstruction to CSF flow at the foramen magnum. MRI or CT scanning is invaluable as a diagnostic aid. Cisternal puncture is contraindicated if either condition is suspected (Figure 5-32).

Other Conditions
Lumbosacral Syndrome (Lumbosacral Stenosis; Cauda Equina Syndrome; Lumbosacral Instability; Lumbosacral Spondylolisthesis)
Anatomy. The spinal cord ends in a cone called the conus medullaris at approximately the level of the intervertebral disk between the sixth and the seventh lumbar vertebrae. The subarachnoid space extends caudally beyond the end of the cord, and its extension is called the lumbar cistern. Within the vertebral canal, sacral and caudal spinal roots course caudally beyond the conus medullaris to exit the canal through intervertebral foramina. These roots are collectively called the cauda equina. In the dog the cauda equina is caudal to the lumbar cistern.

Lumbosacral syndrome encompasses a number of abnormalities in this region—lumbosacral stenosis, in which the vertebral canal is narrowed; lumbosacral instability; spondylolisthesis affecting the lumbosacral junction; disk degeneration, usually of a type 2 herniation between the seventh lumbar vertebra and the sacrum; discospondylitis; and congenital deformities of the last lumbar vertebra, lumbosacral junction, or sacroiliac joint. Hypertrophy of the interarcuate ligament may cause compression dorsally. The sacrum is frequently displaced ventrally relative to the seventh lumbar vertebra. This syndrome may be congenital or acquired and is seen in the larger dog breeds, particularly the German Shepherd. It is rarely seen in the cat. Osteochondrosis of the craniodorsal aspect of the sacrum has been described (see p. 521 and Chapter 4, p. 387).
Figure 5-32 A to C, A 9-year-old Cavalier King Charles Spaniel with cervical pain. Survey radiographs were uninformative. A myelogram was performed. Lateral (A) and ventrodorsal (B) radiographs of the cervical and thoracic regions. C, Lateral view of the thoracolumbar region. On the cisternal myelogram, contrast material outlines a distended central spinal canal throughout the length of the spinal cord. The contrast is visible in the lateral ventricles. This is syringohydromyelia. D and E, Caudal occipital malformation syndrome/syringohydromyelia. This Cavalier King Charles Spaniel had a persistent scratching of its neck. These T1 sagittal (D) and T2 transverse (E) MRI images show dilation of the central canal (CC) within the spinal cord (SC). LV, Lateral ventricle; CE, cerebellum; B, brainstem; Rt, right; R, rostral.
Radiography. Survey radiographs cannot be used to diagnose compression of the cauda equina caused by degenerative processes. Instability may be suspected from radiographs, but confirmation of compression requires contrast studies or cross-sectional imaging. To demonstrate abnormality in this region, hyperflexed, hyperextended, and accurately centered, closely collimated lateral views are occasionally useful. However, such manipulations may exacerbate clinical signs. Cross-sectional imaging may give more information. A ventrodorsal view centered on the sacroiliac joint is also required. Myelography is often useful, but the contrast column sometimes fails to opacify this region. Cisternal puncture is the method of choice. Epidurography may also be used, but the images are difficult to interpret. Discography has been suggested. If available, CT and MRI are superior techniques and preferred to myelography, epidurography, and discography.

Clinically affected animals show pain on movement or palpation of the lumbosacral articulation or manipulation of the tail. There may be lameness, which is often unilateral, dragging of the toes, and difficulty in rising and jumping. There is often urinary and fecal incontinence and, in severe cases, paresis.

Radiologic Signs. There may be no associated radiologic signs on survey radiographs; conversely, radiographic changes of malalignment or spondylosis are not always accompanied by clinical signs.

1. Spondylosis at the lumbosacral junction.
2. A narrowed intervertebral disk space, which becomes wedge shaped between L7 and the sacrum.
3. Sclerosis of the end plates of the vertebrae at the lumbosacral junction. This should be confirmed on both lateral and ventrodorsal views. Superimposition of the iliac and sacral wings makes the lumbosacral end plates appear more opaque than others in the lumbar spine on a lateral view.
4. Ventral displacement of the sacrum relative to the seventh lumbar vertebra.
5. An obviously narrowed vertebral canal in the lumbosacral area. The normal ventral depressions on the lateral aspects of the sacrum may simulate narrowing of the canal in this region.
6. Osteophyte formation on the caudal aspect of the seventh lumbar vertebral body and on the cranial aspect of the sacrum.
7. Changes of degenerative joint disease are seen on the articular facets.
8. Flexed and extended views may reveal sacral subluxation.
9. Myelography may demonstrate dorsal or lateral displacement of the cauda equina. However, the contrast column may fail to pass beyond L7.
10. Epidurography may demonstrate displacement of the cauda equina and protrusion of the L7-S1 disk.
11. Discography of the disk between L7 and S1 may show disk protrusion (Figure 5-31, E to H).

THE INTERVERTEBRAL DISKS

Radiography

The intervertebral disk spaces are best evaluated on lateral radiographs of the spine. Short segments of the spine should be radiographed separately. There can be considerable distortion of the appearance of the intervertebral disk spaces cranial and caudal to the point of incidence of the central x-ray beam, and the distortions are exaggerated the farther one moves cranially or caudally. For this reason, the use of a large film to give a survey view of a large segment of the vertebral column is not recommended. Close collimation is helpful (see Figure 5-25, E).

Normal Appearance

On plain radiographs the intervertebral disk spaces are readily identified as radiolucent gaps between the vertebral bodies. Normally the disk spaces at the cervicothoracic junction and the lumbosacral junction are somewhat narrower than neighboring spaces. The space between the tenth and eleventh thoracic vertebrae may also appear narrowed normally. The width of the spaces is approximately equal in any region of the vertebral column, although there are slight variations. The widest spaces are at C4-C5, C5-C6, and L2-L3. The narrowest are at C2-C3 and L4-L5. Disk spaces appear to narrow gradually cranial and caudal to the point of incidence of the central x-ray beam. If the spine is not supported by radiolucent foam cushions to keep it parallel to the film, pseudonarrowing of the disk spaces may be observed. The vertebral end plates are parallel to one another if the spine is properly positioned, that is, neither flexed nor extended. Hyperextension causes the disk space to appear narrow dorsally, whereas flexion causes it to appear narrow ventrally. Excessive stretching of the spine during radiography may mask small degrees of narrowing of the intervertebral disk spaces. The accessory processes on the caudal thoracic and cranial lumbar vertebrae may be mistaken for abnormal opacities overlying the intervertebral foramina (see Figure 5-25).

Degeneration

Degeneration of the intervertebral disks is a common condition in dogs but less common in cats, in whom clinical signs are rare. Degeneration of the disks is part of the normal aging process. Problems arise, however, when the degenerative process proceeds more rapidly than usual.

Two kinds of degeneration are recognized:

1. In chondrodystrophic breeds such as the Dachshund, chondroid changes in the nucleus pulposus begin at an early age. Many of these disks show calcifications radiographically that are not necessarily of clinical significance. After degeneration of the nucleus pulposus, the annulus fibrosus also degenerates. If the annulus ruptures, nuclear material escapes into the spinal canal, causing spinal cord compression and possibly meningitis. This series of events is known as a Hansen type I protrusion and is the more common type in chondrodystrophoid breeds.
2. In other breeds, as the animal grows older, fibroid changes occur that are slower to progress and rarely show calcification. The annulus fibrosus may bulge (herniate) rather than rupture, with the bulge causing spinal cord compression. This is known as a Hansen type II protrusion. Because the annulus fibrosus is thicker ventrally, ventral protrusions are not common and do not cause spinal cord compression.

The clinical signs of disk disease depend on the severity and nature of the disk protrusion. With type I protrusions, clinical signs tend to be sudden in onset and severe, with pain, neurologic deficits, and paralysis. Pain rather than paralysis is a feature of cervical protrusions. Type II protrusions are usually less dramatic, with progressive ataxia and neurologic deficits as the main presenting signs.

It is not unusual to detect degenerative changes radiographically in the intervertebral disks of animals showing no clinical signs of the disease. Calcification of disks and narrowed intervertebral disk spaces therefore are not themselves indicative of cord compression. For this reason, correlation of radiologic and neurologic findings is essential in arriving at a diagnosis (Figure 5-33).

Radiologic Signs
1. Calcification of a disk or disks. Without displacement, this finding may or may not be clinically significant.
2. Narrowing of an intervertebral disk space or a wedge-shaped appearance of the disk space.
3. Demonstration of mineralized material in the area of the intervertebral foramen. The calcified disk material can sometimes be seen superimposed on the radiolucent shadow of the foramen. The foramen provides a background contrast different from the bone opacity of the vertebrae. Hence, small amounts of nuclear material sometimes seen in that area would not be seen if they were overlying the vertebrae.
4. Normally an intervertebral foramen in the lumbar area has a shape not unlike that of a horse’s head. If a disk space is narrowed, that shape is lost (Figure 5-33).
5. With severe narrowing of the intervertebral disk space, the intervertebral foramen is also narrowed.
6. There is sclerosis of the end plates of the vertebrae in chronic disease.
7. Myelographic demonstration of extradural cord compression. There will be narrowing and dorsal displacement of the ventral contrast column by an extradural lesion. The dorsal column may be compressed or absent. The lateral columns may also be displaced or absent.

Myelomalacia should be suspected if, during myelography, there is diffuse or segmental opacification of the spinal cord by contrast material.

The fact that changes are seen radiographically does not necessarily imply that the changes seen are associated with the clinical signs because many patients have multiple degenerating disks of varying chronicity. Radiologic signs must be correlated with neurologic findings. An acute disk displacement may not be detected radiographically on plain films. Ventrodorsal oblique studies are useful to determine the site or side of a lesion. Old lesions may be of no significance. MRI or CT is often more informative (see Figure 5-33, E). The demonstration of cord compression on myelography is always significant (Figure 5-34, A to F).

Osteopenia
This is a generalized reduction in the opacity of the vertebrae. In dogs and cats this is often caused by calcium/phosphorus metabolic disorders such as primary or secondary hyperparathyroidism. In young animals, it is usually associated with nutritional secondary hyperparathyroidism. In older animals, common causes are renal secondary hyperparathyroidism, hyperadrenocorticism, and neoplasia.

Radiologic Signs
1. There is a generalized decrease in radiopacity of the vertebral bodies.
2. The vertebral end plates seem sclerotic in relation to the vertebral bodies.
3. The trabecular pattern is prominent.
4. In cats, vertebral deformities occur with secondary hyperparathyroidism.
5. There is lack of contrast between the vertebral bodies and the soft tissues.
6. The radiograph appears to be overexposed (see Chapter 4, p. 355) (Figure 5-34, G to I).

Spondylosis (Spondylosis Deformans)
Spondylosis is a degenerative condition of the vertebrae that is seen in dogs and cats. It is characterized by new bone formation on the cranioventral and caudoventral aspects of the vertebral bodies at the margins of the intervertebral disk spaces. Bone spurs or bone bridges may form. The cause is unknown. The thoracic and lumbar vertebrae are the most commonly affected, particularly at the antecinal vertebra and at the lumbosacral junction. Spondylosis rarely produces clinical signs. Its incidence increases with age. It is relatively rare in the chondrodystrophoid breeds.

Radiologic Signs. The lesions of spondylosis are best demonstrated on a lateral view.
1. In the early stages, small, hooklike projections develop on the cranioventral and caudoventral aspects of one or more vertebrae adjacent to the intervertebral disk spaces.
2. In more severely affected animals, the new bone formation becomes more pronounced, and larger projections form on affected vertebrae. The projections on the caudal aspects of affected vertebrae appear to grow ventrocaudally toward the body of the succeeding vertebra; those on the cranial aspects grow ventrocranially toward the body of the preceding vertebra.
3. Complete bony bridges may develop, joining two or more of the vertebrae together. Care must be taken not to mistake two overlapping projections seen on the lateral view for union of the projections. In such cases a ventrodorsal view may be helpful.
Figure 5-33  A, A calcified disk (arrow) is seen between the tenth and eleventh thoracic vertebrae. It is of no clinical significance and is a common ageing change. B, C2-C3 disk prolapse in a dog. There is slight narrowing of the C2-C3 intervertebral disk space. A large volume of herniated disk material (arrows), which is homogeneously mineralized, is seen within the vertebral canal, dorsal to the intervertebral disk space. There is a calcified disk between C3 and C4. C, This case shows a prolapsed calcified disk between C4 and C5. There is pseudonarrowing of the C2-C3 and C3-C4 spaces caused by insufficient support to the midneck region.

Continued
The bone growths of spondylosis do not usually affect the spinal nerves or the spinal canal (Figure 5-35).

Ossification of the ventral longitudinal ligament is sometimes seen in Boxers. It is termed syndesmitis ossificans.

Disseminated Idiopathic Skeletal Hyperostosis
Disseminated idiopathic skeletal hyperostosis (DISH) is a term given to bony proliferation at tendon and ligamentous insertions on the vertebrae. It is seen in young dogs of the larger breeds, particularly the Boxer and Great Dane. The etiology is unknown and the disease is of questionable clinical significance. It may be seen in association with disorders of the thyroid or parathyroids. Radiologically, there is mineralization on the ventral and lateral aspects of three or more adjacent vertebral bodies. New bone formation is seen around the intervertebral articulations, and there is mineralization of soft tissues around joints (Figure 5-35, D to F).

New bone formation between the spinous processes is occasionally seen in large breeds and in particular the Boxer; it is termed Baastrup’s disease.


Spondylopathy is commonly seen in adult Doberman Pinschers. Other breeds and ages may be affected, and cases have been reported in the Bassett Hound and the Rhodesian Ridgeback. Clinically, there is progressive incoordination of the hindlimbs. Incoordination of the

Figure 5-33, cont’d D, A narrowed intervertebral disk space is present between L3 and L4. The intervertebral foramen is different in shape from the foramina on either side. E, A sagittal T1-weighted MRI shows the intervertebral disks (IVD) between L3 and L7. The disk between L7 and S1 is prolapsed dorsally (PD).
Figure 5-34 A, L1-L2 disk prolapse in a dog. A myelogram was performed in this patient via lumbar puncture. There is extensive mineralization of the nucleus of the T13-L1 disk. There is partial mineralization of the L1-L2 disk and moderate narrowing of the disk space. There is good filling of the subarachnoid space. The ventral subarachnoid space is displaced dorsally and severely thinned at the L1-L2 disk space. There is near-complete loss of the dorsal subarachnoid space at this site. These findings indicate a ventral compressive lesion of the spinal cord. B and C, The survey radiograph (B) shows narrowing of the intervertebral disk space between the sixth and seventh cervical vertebrae. Both vertebrae show inflammatory changes. This finding does not necessarily indicate that signs of cervical pain are referable to this area. The contrast study, however, shows pressure on the spinal cord at this point. The contrast medium was given via the cisterna magna. C, The contrast study, however, shows cystlike lesions originating from the synovial facet joints in the caudal cervical spine. These occur in some dogs with cervical spondylomyelopathy. The lesions contribute to spinal cord compression. On myelography, dorsolateral extradural spinal cord compression is seen centered at the facet joints. On MRI, the cystlike lesions are best demonstrated by transverse T2-weighted images, where they appear as roughly round, hyperintense structures located dorsolateral to the spinal cord.

Continued
Figure 5-34, cont'd  D to F, A 3-year-old Cavalier King Charles Spaniel showed signs of neck pain and tetraparesis. D, A lateral myelo- graphic study, which is slightly rotated, shows calcification of the disks between C3-C4, C4-C5, and C5-C6. The C3-C4 disk space is narrowed. A myelogram on the lateral view shows an hourglass compression of the spinal cord at C3-C4. The ventral contrast column is displaced dorsally, and the dorsal column is narrowed. E, On the ventrodorsal view the contrast columns are displaced to the left (arrow) by an extradural mass, which was herniated disk material. F, A close-up study shows the cord displacement more clearly. At least two views should always be taken to help define spinal lesions.
forelimbs may also occur. There is pain on manipulation of the neck. Affected animals are usually between 3 and 10 months of age. Cervical spondylopathy may also be seen as a clinical entity in mature adults.

A number of vertebral abnormalities have been described associated with the syndrome. Deformity and malarticulation, subluxation, osteochondrosis, cartilage defects, narrowing and triangulation of the cranial aspects of affected vertebrae, synovial cysts of the intervertebral facet joints, hyperplasia of the ligamentum flavum, and hyperostosis of the vertebral laminae have all been encountered. The area of the fifth, sixth, and seventh cervical vertebrae is the usual site for these changes, particularly in Doberman Pinschers. Less commonly, the second, third, and fourth vertebrae may be involved. There may be a concomitant disk protrusion.

Cystlike lesions originating from the synovial facet joints in the caudal cervical spine occur in some dogs with cervical spondylomyelopathy. The lesions contribute to spinal cord compression. On myelography, dorsolateral extradural spinal cord compression is seen centered at the facet joints. On MRI, the cystlike lesions are best demonstrated by transverse T2-weighted images, where they appear as roughly round, hyperintense structures located dorsolateral to the spinal cord.

Flexed and hyperextended lateral radiographs are useful in demonstrating vertebral malalignment. Some dorsal movement is normally present at the cranial end of a vertebra in relation to the caudal end plate of the preceding vertebra when the neck is flexed. Care should therefore be exercised in evaluating this sign. The procedure should be carried out gently to avoid inflicting pressure damage on the cord.
Radiographic distraction techniques (e.g., stretching the neck) in combination with myelography are useful in assessing if the lesion is dynamic or adynamic (permanent or static malalignment). This differentiation is important when surgical intervention is being considered. Care must be taken with flexion, extension, and distraction techniques because clinical signs may be exacerbated. A vacuum phenomenon in the intervertebral disk space may be induced by this procedure.

Radiologic Signs
1. A change in the shape of an affected vertebra or vertebrae may be seen.
2. Narrowing of the cranial aspect of a vertebra gives that part of the vertebral canal a funnel-shaped or triangular appearance.
3. The cranial articular processes may be deformed or malpositioned.
4. If there is subluxation, flexed lateral views of the neck show the cranial end of affected vertebrae protruding dorsally into the spinal canal.
5. A hyperextended view of the neck may show displacement of a vertebra.
6. The disk space cranial to an affected vertebra may be widened and affected disks calcified.
7. There may be inflammatory osteophyte formation and sclerosis of the vertebral end plates.
8. Cord compression may be demonstrated by myelography. Care is required in assessing flexed views because some ventral indentation of the contrast column is evident in normal dogs at the intervertebral disk spaces when the neck is flexed.
9. Ventral compression with narrowing of the cord and thinning of the dorsal column indicates disk prolapse or hypertrophy of the dorsal longitudinal ligament, whereas dorsal compression indicates hypertrophy of the ligamentum flavum (Figure 5-36).

Vacuum Phenomenon
Gas accumulations, known as the vacuum phenomenon, have been described within intervertebral disks in the cervical, thoracic, and lumbar areas of the spine. The sternum and shoulder joint may also be affected. Associated degenerative changes are present in adjacent bones. The cause has not been determined, but it has been suggested that the phenomenon is associated with degenerative joint disease and joint instability (Figure 5-36, B).

Figure 5-35  A and B, An advanced case of spondylosis. The new bone formation on the vertebrae is also evident on the ventrodorsal view. C, The lumbosacral junction is a common site of spondylosis. It may occur as a result of lumbosacral instability.
Osteochondrosis of the Sacrum
Osteochondrosis of the sacrum is seen in large dog breeds such as the German Shepherd. The craniodorsal aspect of S1 is rounded or triangular in shape. There is sclerosis of the end plate, and a separated mineralized fragment may be seen at the craniodorsal aspect of S1. Occasionally it is displaced dorsally. The clinical signs are compatible with the cauda equina syndrome (Figure 5-37, A and B).

Dural Ossification (Ossifying Pachymeningitis, Osseous Metaplasia)
Dural ossification is characterized by the formation of bony plaques in the dura mater. Radiographically, a fine linear mineralized opacity is seen running just above and parallel to the floor of the vertebral canal. This line is best seen at the intervertebral foramina. Extensive plaque formation may be present in the absence of other demonstrable radiographic changes or clinical signs. It is seen predominantly in large dog breeds and occasionally in small breeds. The condition appears to have little clinical significance (Figure 5-37, C).

Degenerative Joint Disease
Degenerative joint disease affects the intervertebral joints but is frequently not demonstrable radiographically. New bone formation around intervertebral joints, particularly in the thoracolumbar region, may be seen. It is also seen in cervical vertebral malformation in the large and giant breeds (Figure 5-38).

Infection
Infection involving the vertebral column is not very common. It may be a hematogenous infection or arise from a wound. It may be an extension from a nearby lesion.

Spondylitis (Osteomyelitis). Osteomyelitis may affect the vertebrae just as it may affect other bones. The radiologic signs resemble those seen elsewhere with the condition. Bone destruction, periosteal reaction, and new bone formation with sclerosis of the surrounding bone are typical features (Figure 5-39). The cranial lumbar vertebrae are most commonly affected. Infection may arise from bacterial, fungal, or protozoal disease in adjacent tissues or from systemic disease. Grass seed foreign bodies that are inhaled and migrate through the lung and diaphragm into the sublumbar muscles have been implicated in some cases. Infection may spread to the spinal canal, causing meningitis and myelitis. The term spondylitis should be reserved to describe infection in a vertebra and spondylosis used to describe degenerative processes.

Discospondylitis. Discospondylitis is a term applied to a condition in which the intervertebral disk and the vertebral end plates are involved in an infectious process. Brucella canis, Staphylococcus aureus, Aspergillus spp., mycoses, and mycobacteria organisms have been reported in association with discospondylitis. The infection may spread to
Figure 5-36 Cervical spondylopathy. A to C, A 7-year-old male Doberman Pinscher with a chronic history of hindlimb ataxia. The intervertebral disk space between the sixth and seventh cervical vertebrae is grossly narrowed, with remodeling evident on the adjacent vertebral end plates. A cervical myelogram was performed. A, The contrast column failed to pass beyond the cranial margin of the seventh cervical vertebra. B, After traction, the intervertebral disk space is widened, and the contrast passes caudally. The intervertebral disk space between the sixth and seventh lumbar vertebrae is more radiolucent than adjacent disk spaces. This is known as the vacuum phenomenon. C, The release of traction restores the vertebrae to their original alignment.
D. The flexed view of the neck shows dorsal displacement of the cranial aspect of the fifth cervical vertebra and, to a lesser extent, the cranial aspect of the sixth. E. The myelogram shows marked pressure on the cord at the cranial aspect of the fifth cervical vertebra. F. Malformation of the sixth and seventh cervical vertebrae in an adult Doberman Pinscher.

Continued
Figure 5-36, cont’d  

G, In this dog, myelography shows compression of the spinal cord associated with the malformation in F. 

H, Malformation of the cervical vertebrae may be accompanied by kyphosis of the thoracic vertebrae. 

I, There is dorsal displacement of the cranial aspects of the fifth, sixth, and seventh cervical vertebral bodies. On this lateral view of the neck, subluxations of several cervical vertebrae are evident.
Figure 5-37  A and B. Osteochondrosis of the sacrum. This was a 2-year-old Mastiff with hindlimb stiffness and lumbosacral discomfort. A, A lateral view of the lumbosacral junction shows a triangular mineralized opacity lying at the craniodorsal aspect of the sacrum and superimposed on the spinal canal. The sacral margin is sclerotic and has an associated subchondral defect at its craniodorsal margin. B, On the ventrodorsal view, the separated opacity is located in the middle third of the cranial sacral margin. There is marked sclerosis on the cranial aspect of the sacrum at the site of the lesion. C, Dural ossification (ossifying pachymeningitis). A thin radiopaque line (arrow) is seen within the spinal canal above the intervertebral disk space between the third and fourth lumbar vertebrae. This represents ossification of the dura mater. A less evident line is seen between the first and second lumbar vertebrae. Ossification or calcification of the dorsal longitudinal ligament would show a line that is similar but more closely related to the floor of the canal.
involve the meninges. Immunosuppression in some breeds may predispose to the condition. It has also been reported as a complication of systemic infection, as a sequela to a migrating foreign body, or as a complication of spinal surgery. Healing often takes place after the end plates have been destroyed, with fusion of the shortened, remodeled vertebrae. Myelography is useful to establish whether there is cord compression.

The clinical signs may be obscure. They include pyrexia; pain, which can be severe; stiffness; and general depression. Manipulation of the spine is resented. The severity of the signs depend on the location of the lesion, being most severe in the cervical and lumbosacral regions. If the lesion is chronic, differentiation from neoplastic disease can be difficult. Fine-needle aspiration under fluoroscopic or ultrasonographic guidance is a useful diagnostic procedure.
Radiologic Signs
1. Collapse of the disk space is the earliest sign of discospondylitis.
2. The intervertebral disk space becomes widened initially and then gradually becomes narrow.
3. Changes in opacity with lysis and sclerosis are noted in the adjacent end plates and vertebral bodies.
4. The bodies become shorter as their end plates undergo destruction.
5. Collapse of the intervertebral disk space with subsequent fusion of the vertebral bodies occurs in longstanding cases.
7. The new reactive bone formation may simulate spondylosis but is usually more extensive and more aggressive in appearance.
8. New bone formation may encroach on the spinal canal.
9. Several adjacent intervertebral disks may be affected, or several discrete sites along the vertebral column may be seen.
10. Myelography will demonstrate the degree of cord compression (Figure 5-40, A to C).

Schmorl’s Nodes
Schmorl’s nodes are an unusual observation of unknown clinical significance. The term is applied to radiolucent, semicircular, sharply defined indentations in the middle of adjacent vertebral end plates. These are reported to be the result of herniation of the intervertebral disk through the end plate. They are seen in medium to large dog breeds such as the German Shepherd. If seen, they may be indicative of osteopenia (Figure 5-40, D to F).

Fractures
Fractures are a common result of road traffic accidents. Pathologic fractures may affect the vertebrae.

A compression fracture causes the vertebral body to appear shorter than normal. Frequently the affected vertebra assumes a wedge shape. Normal bones subject to traumatic compression fractures have an increased opacity compared with unaffected vertebrae of similar type. Compression fractures that occur because of a pathologic process usually result in reduced opacity of the affected vertebra. Studies in both planes are necessary to evaluate the extent of the abnormality; however, the ventrodorsal view requires considerable care to avoid further spinal cord damage. A ventrodorsal view with a horizontal beam and the animal lying on its side may be considered. Compression fractures may be associated with neoplasia, osteomyelitis, and secondary hyperparathyroidism.

Oblique fractures are often associated with considerable displacement of the fracture fragments. Separation of the vertebral end plates is occasionally seen in young animals. Fractures of the articular facets can be difficult to identify.

Fractures in the cranial cervical region are sometimes difficult to demonstrate. Fracture of the odontoid process (dens) is occasionally seen. Fractures with displacement cause a disruption of the normal line of the vertebra—a “step” effect (defect) is commonly seen along the ventral border of the vertebra on the lateral view. A similar sign may be seen with dislocation, with a step defect evident between adjacent vertebral bodies. The separate center of ossification of the dens of the axis fuses by 6 months of age. It should not be mistaken for a fracture line. The
Figure 5-40 A to C, Discospondylitis. A, This is a 5-year-old Great Pyrenees (Pyrenean Mountain Dog). There is destruction of the vertebral end plates, which are irregular in outline. There is sclerosis in the adjacent vertebral bodies. The intervertebral disk space is narrowed dorsally and widened ventrally. There is slight remodeling on the ventral margins of L7-S1. B, This is a 4-year-old Bernese Mountain Dog. There is erosion of the vertebral end plates of T3 and T4. The vertebral end plates are irregular, and the intervertebral disk space is narrowed. C, This 3-year-old Boxer has chronic discospondylitis. The dorsal half of the cranial end plate of the sacrum is irregular with a focal osteolytic zone. New bone extends proximally, overlying the vertebral canal, and distally, forming spondylosis. The caudal aspect of L7 is rounded, sclerotic, and smooth.
Figure 5-40, cont’d  

D to F, Schmorl’s nodes in the dog. This defect is associated with herniation of the disk into the end plates and is termed a Schmorl’s node. D, Concentric semicircular deficits (arrow) are seen in the vertebral end plates of the second and third lumbar vertebrae. E, There are well-defined concave central defects of the end plates at T4-T5 and T5-T6 (arrow). A similar abnormality is seen at the T9-T10 (arrow) disk space. F, There is a well-defined central, concave defect in the cranial end plate of T5. This has a sclerotic margin. There are similar but slightly smaller defects in the caudal end plate of T5 and the cranial end plate of T6. These abnormalities are consistent with herniation of the disk nucleus into the end plate. The presence of a Schmorl’s node may indicate loss of bone mineral content, resulting in weakening of the end plates.
spinous processes and transverse processes may be fractured, but clinical signs are not always present. Particular care is necessary in handling animals suspected of having a serious spinal injury so that further damage is not inflicted, particularly to the spinal cord, during the radiographic study (Figure 5-41, A to D; also see Figure 5-27, B). The clinical signs vary depending on the site of the lesion and the duration of the injury.

**Luxations and Subluxations.** Complete dislocation of a vertebra is usually obvious radiographically. Subluxations are more difficult to evaluate. The intervertebral disk space may be narrowed, and there will frequently be a slight disruption of the line of the vertebra relative to the preceding or succeeding vertebrae. Myelography will show cord compression at the site. The body of the fourth lumbar vertebra is often a little more ventral than that of the third lumbar vertebra. This feature should not be misinterpreted as a dislocation. In subluxation or instability of the atlantoaxial articulation, the body of the axis and the dens are displaced dorsally and cranially, and the distance between the arch of the atlas and the dorsal spine of the axis is greater than normal (Figure 5-41, E to I).

Some subluxations involve rotational disruption of an intervertebral junction in the cervical spine. This results in luxation and possibly fracture of the facet joints with minimal disruption of the disk and with no obvious step defect. Such subluxations may be easily overlooked.

**Neoplasia.** Neoplasia of the vertebrae is relatively rare. Osteosarcoma and osteochondroma have been described, as have metastatic lesions (Figure 5-42). The vertebral column is a site that has a predilection for multiple myeloma, when circular osteolytic defects are seen (Figure 5-42, G). In most cases, malignancies associated with the vertebrae are destructive rather than proliferative in nature. The vertebral end plates and disk spaces are usually not involved in the destructive process. Compression (pathologic) fractures may occur (see Figure 5-41, D).

Neoplasms of the spinal cord may cause changes in the subarachnoid space that are demonstrable by myelography. The changes may be intramedullary, as in astrocytoma, or extramedullary/intradural, as in meningioma. Differentiation between neoplasms and other space-occupying masses may not be possible (Figure 5-43). Soft tissue tumors adjacent to vertebrae may invade them. CT and MRI are useful in assessing the extent of a neoplasm and associated soft tissue and bony changes.

**Hypervitaminosis A.** Cats fed excessive amounts of liver may have hypervitaminosis A. Vitamin A is essential for endochondral bone growth. It acts as a stimulus to osteoblasts. Excess of vitamin A provokes the formation of subperiosteal new bone. In young animals, the longitudinal growth of long bones is impaired. In older animals, bony exostoses develop on the cervical and thoracic vertebrae, on the ribs, and around the limb joints. Ankylosis of vertebral and limb joints may occur. There may be an associated secondary hyperparathyroidism. Cats between 2 and 4 years of age are most commonly affected (see Figure 4-45, A to C).

Clinically, affected animals show cervical pain and restricted neck movements. As the condition progresses, the spine becomes rigid, and limb joint movements become restricted or impossible. Anorexia, abnormal abdominal distention, and a disinclination to move have also been reported. Restoration of a normal diet results in some improvement. In young animals, growth may be permanently retarded. In mature animals, exostoses and joint fusions remain. Mucopolysaccharidosis may cause similar changes on the vertebrae.

**Radiologic Signs**

1. New bone formation is seen on the vertebrae, especially in the cervical region. The thoracic and lumbar vertebrae may also be involved. The new bone may be seen on the dorsal, lateral, and ventral aspects of the vertebrae.
2. Exostoses form bridges between adjacent vertebrae, inhibiting normal movement. These changes are often most clearly seen on the ventral aspects of the vertebral bodies. They should not be confused with the spondylosis sometimes seen in older cats. Generally lesions associated with hypervitaminosis A are larger and more extensive than they are in spondylosis associated with age.
3. Deformities of the spine may occur. Scoliosis and kyphosis may be seen.
4. The new bone formation may cause fusion of the spinous processes.
5. New bone formation may be seen at other sites, for example, on the ribs, on the metaphyses of long bones, and around joints. Fusion of joints may occur.
6. Long bones often show a laminar periosteal reaction.
7. Osteopenia may be evident, particularly in the bones of the forelimbs.
8. Isolated skeletal lesions may be confused with neoplasms (Figure 5-44, A).

Although uncommon in dogs, growth retardation as a result of hypervitaminosis A has been reported in young animals.

**Mucopolysaccharidosis.** The mucopolysaccharidoses are a series of hereditary conditions associated with disorders of lysosomal storage. One type affects the Siamese cat, whereas another affects domestic short-haired breeds. Other types have been reported to affect mongrel dogs. Resulting abnormalities affect the skull, the vertebrae, and the appendicular skeleton. Clinically affected animals are lame, and manipulation of the vertebrae or limb joints elicits pain. There may be paresis or paralysis resulting from compression of the spinal cord or nerve roots by bony masses. There may be clouding of the cornea. The condition may become evident as early as 8 weeks of age.
Figure 5-41 A to D, Vertebral fractures. 

A, The odontoid process of the axis is fractured. This is best seen on the ventrodorsal view (arrow). 

B, The lateral view shows that the normal space between the spinous process of the axis and the atlas has been narrowed. 

C, Fracture of the seventh lumbar vertebra. 

D, Collapse of the first lumbar vertebra caused by an osteosarcoma. The vertebral body shows a decreased opacity in its caudal half, leaving a fine opaque rim. The body is foreshortened and wedge shaped. New bone formation is present ventrally.

Continued
Radiologic Signs
1. The rostral bones of the skull are smaller than usual, giving the face a short, wide appearance (facial dysmorphism). These changes are not so well marked in the form of the condition affecting the domestic short-haired cat.
2. The vertebrae are short and thick, and the end plates are distorted (epiphyseal dysplasia). There may be abnormalities of the dens.
3. Changes of spondylosis deformans are common.
4. There is widespread degenerative joint disease.
5. Coxofemoral luxation is common.
6. There is generalized osteopenia.
7. Joints may ankylose.
8. Pectus excavatum may be a feature.
9. There may be dwarfism.

The changes seen with mucopolysaccharidosis (Figure 5-44, B) often resemble those seen with hypervitaminosis A (Figure 5-44, A).

Multiple Cartilaginous Exostoses. The condition of multiple cartilaginous exostoses affects young dogs and mature cats. Cartilage-capped exostoses arise from the vertebrae. The condition is usually of no clinical significance unless it impinges on the spinal canal, causing spinal cord compression. Lesions are more commonly seen in the thoracic and lumbar areas. They may be expansile and cystic or proliferative. Myelography is necessary to demonstrate the degree of extradural cord compression.

Osteochondrodysplasia. Osteochondrodysplasia is the term used to describe a number of developmental abnormalities of the skeleton (Figure 5-44, C) (see Chapter 4, p. 395).

Ischemic Spinal Cord Disease: Fibrocartilaginous Embolism. Ischemic lesions of the spinal cord are most commonly attributed to fibrocartilaginous emboli. These are thought to originate within the disk nucleus and occlude small arteries within the spinal cord. However, some patients have no evidence of degenerative disk disease and the origin of the thrombi is unclear. Affected patients have a rapid onset of signs with limited or no progression.
Large breeds of dogs are more commonly affected, but it is also seen in smaller dogs and in cats. Clinical signs depend on the location of the emboli. The panniculus reflex is lost. Affected muscles are spastic. If the lesion is in the cervical region, Horner's syndrome may result. Lesions in the lumbar area affect the anal and urinary sphincters and the tail. Affected animals show inability to use one or both hindlimbs (hemiparesis or paresis). There is usually no associated spinal pain, and the neurologic deficits are markedly localized and often unilateral.

Myelography may reveal mild or moderate segmental spinal cord swelling but is usually unremarkable and serves to exclude the possibility of spinal cord compression. MRI may reveal no abnormalities. T2-weighted images are the most sensitive imaging sequence and may show a focal hyperintense lesion. This may be segmental, affecting the entire width of the cord, or unilateral, affecting only the right or left side of the cord. Acute lesions usually demonstrate no contrast enhancement. Subacute or chronic lesions may demonstrate mild or moderate contrast enhancement.

**Spinal Arachnoid (Subarachnoid) Cyst.** This is a cystic-like structure, sometimes called pseudocyst, occurring usually in the dorsal subarachnoid space. In young dogs of the larger breeds, it occurs in the cranial cervical region, whereas in older animals in the smaller breeds, it is seen in the caudal thoracic region. Clinically, there is a progressive nonpainful ataxia with hypermetria and incontinence. Myelography is necessary to demonstrate the lesion. A localized, teardrop-shaped enlargement, usually of the dorsal contrast column, may be seen. Occasionally it is seen as a radiolucent filling defect outlined by the contrast column. MRI is often necessary to diagnose this condition (Figure 5-45).
Figure 5-42 A to C, Metastases. A, This Doberman Pinscher had severe neck pain for 3 days. The ventrodorsal radiograph shows a radiolucent defect in the right half of the third cervical vertebra. The right transverse process is eroded at its junction with the vertebral body. Diagnosis: metastatic bone lesion. B, This was a 12-year-old Terrier with hindlimb paraparesis. This lateral view of the lumbar vertebrae shows bone destruction in the body, pedicles, and spinous process of L5. Pinpoint lucencies are seen throughout the vertebra. The ventral canal margin is absent. Similar though less marked changes are seen in L3. These are metastases. C, On this lateral view of the thoracic vertebrae, the body of the fourth thoracic vertebra is foreshortened and lytic. The animal had a mammary tumor. D to F, A 6-year-old Cocker Spaniel with cervical pain of 4 weeks' duration. D, On the plain radiograph there is a mineralized opacity overlying the bases of the spinous processes and intervertebral articulation of T3-T4. The costal vertebral articulations are indistinct on T4, and new bone formation is seen around the left rib head.
Figure 5-42, cont’d E, A myelogram shows complete arrest of the contrast columns at T3-T4. F, The ventrodorsal view shows the columns are arrested at T3-T4, and the left column is displaced to the right because of extension of a neoplasm into the spinal canal. G, This was a 10-year-old Labrador Retriever with weight loss, hindlimb ataxia, depression, and hypercalcemia. An expansile, soap bubble–type lesion is seen in the proximal third of the right femoral diaphysis. The spinous process and pedicles of the third lumbar vertebra show circular, sharply defined radiolucencies. This was a multiple myeloma.
Figure 5-43  A, An 8-year-old Cocker Spaniel presented with a history of a progressive onset of tetraparesis over 5 months. Plain studies were unremarkable. A cervical myelogram was performed. A large, lobulated, radiolucent filling defect is outlined in the vertebral canal. It lies at the level of the junction of the first and second cervical vertebrae (arrows). A large inoperable fibrous mass was located at surgery. Diagnosis: histopathology showed that the mass was mature fibrous tissue. B and C, This 11-year-old male cross-bred Terrier had insidious foreleg lameness present for several weeks. Plain studies were unremarkable. On cervical myelography, the contrast column failed to pass the sixth cervical vertebra. A lumbar puncture was then performed and contrast medium introduced. The lateral (B) and ventrodorsal (C) views show that the resulting contrast column passed cranially and defined an expansile lesion at the level of the sixth and seventh cervical vertebrae (arrows). The contrast columns are thinned in this area as a result of expansion of the spinal cord. Diagnosis: intramedullary lesion—an angioblastic meningioma. D, An expansile lesion has caused divergence of the dorsal and ventral columns of contrast medium. This was a meningioma.
Figure 5-44  A, Hypervitaminosis A. New bone formation on the cervical and thoracic vertebrae of a cat being fed exclusively on liver. B, Mucopolysaccharidosis. The lateral radiograph of this Siamese cat shows abnormally shaped vertebral bodies. They are foreshortened in a craniocaudal direction, and new bone formation is evident along the ventral aspects of the vertebral bodies. The shoulders are also abnormal. This is an inherited condition. C, Osteochondrodysplasia. A 12-week-old Hovawart puppy presented because the owner noticed that it was smaller and had shorter limbs than its littermates. It had an unusual stance. The cranial and caudal epiphyses of all the vertebrae are irregular, have a patchy opacity, and are poorly defined. The ventral margins of the bodies are indistinct, and the vertebrae are vaguely cuboidal in shape and foreshortened in a craniocaudal direction. Similar changes were seen affecting the epiphyses of the pelvis and femorotibial joints (B, Courtesy of Dr. D. Biery, University of Pennsylvania.)
Figure 5-45  A and B, A 6-month-old Rottweiler with a history of ataxia over the previous 2 months. Plain radiographs were uninformative. A, A cisternal myelogram shows a discrete widening of the dorsal subarachnoid space at the level of C2-C3. B, A T2-weighted sagittal MRI study confirms the lesion site. There is widening of the subarachnoid space at the level of the intervertebral disk space between C2 and C3 (large white arrow). The cord is slightly narrowed at this level. This was a subarachnoid cyst. CSF, Cerebrospinal fluid; CE, cerebrum; CB, cerebellum; SC, spinal cord; C2, second cervical vertebra; CD, caudal. There is a separate center of ossification on the caudodorsal aspect of C2 in A. It is an incidental finding.
REFERENCES

Radiology


Ultrasonography


CALCIFICATION (MINERALIZATION)
Calcification is a process by which calcium salts are deposited in tissue. Dystrophic calcification is the deposition of calcium salts in abnormal tissue or tissue that is dead, degenerating, or damaged. Metastatic calcification is the deposition of calcium salts in tissue that is not the site of a disease process. It results from abnormalities in blood and tissue calcium and phosphate levels. It is associated with such metabolic disturbances as hyperparathyroidism (hypercalcemia) or hypervitaminosis D.

Calcific deposits may be found in such soft tissues as the lungs, gastric mucosa, and kidneys (see Chapter 2, pp. 46, 58, and 136), as well as those around joints (see Chapter 4, pp. 420-422, 428, and Figure 4-45, A to C) and in the walls of blood vessels (Figure 6-1).

Calcification of the external ear canals may occur in old dogs (Figure 6-1, A). Hematomas or bursae may calcify, as may tumor tissue (Figure 6-1, B). Calcification of the medial meniscus of the stifle has been reported in dogs and cats (see Figure 4-5, B and C).

Calcium may be laid down in the skin and subcutis in Cushing’s syndrome (see Chapter 2, p. 123) and secondary to hyperparathyroidism (calcinosi cutis). The tracheal rings and bronchial walls may be affected and there may be diffuse pulmonary parenchymal mineralization (see Figures 3-12, E, and 6-1, F and G).

Mineralization of the coronary arteries may be seen as faintly radiopaque lines extending caudoventrally from the aortic root. Mineralization of the aortic bulb is occasionally seen at the level of the fourth intercostal space in the craniodorsal region of the cardiac silhouette (Figure 6-1, O).

Ultrasonography of calcified tissue can be unrewarding if a structure is only partially calcified. Deposits will be seen as hyperechoic foci scattered in the tissues (Figure 6-1, M). In myositis ossificans, bony plaques are deposited in muscle, or the muscle itself may become ossified. Trabeculated bone opacities may be seen. It may occur as a result of chronic trauma. Calcification cannot be distinguished from ossification unless a trabecular pattern can be identified (Figure 6-1, Q).

In calcinosi circumscripta (calcium gout, kalk gicht [chalk gout], tumoral calcinosi), deposits of amorphous calcified material are laid down in the subcutaneous tissue and skin. Lesions are usually found on the limbs, under the pads, or over bony prominences. Similar lesions have been described in the mouth.

The etiology remains obscure. Chronic renal disease, hyperparathyroidism, and hypovitaminosis D have been suggested as possible causes. Approximately half the cases seen occur in young German Shepherds that are otherwise apparently normal (Figure 6-2).

ARTERIOVENOUS FISTULA
An arteriovenous fistula is a direct communication between an artery and a vein without an interposed capillary bed. Numerous small vessels develop in the affected area. Such fistulas may be found centrally, as in patent ductus arteriosus or ventricular septal defect, or they may be peripheral.

Peripheral fistulas may be congenital or acquired as a result of injury. Peripheral arteriovenous fistulas have been reported in dogs and cats, but they are uncommon. The clinical signs are variable. They may appear as small, painless, warm swellings with a faintly palpable pulse, or they may be large and painful. Ulceration may occur. If pressure is exerted proximal to an arteriovenous fistula, the venous return to the heart is diminished and the heart rate falls. This is known as Branham’s bradycardia sign. Large fistulas, in time, produce compensatory cardiac changes.

Radiologically, arteriovenous fistulas on the limbs may cause alterations in the trabecular pattern of bones in the neighborhood. The trabecular pattern becomes coarse. The vascular bed can be demonstrated by arteriography (Figure 6-3; also see Figure 4-25 and Chapter 4, p. 398).

FASCIAL PLANES
The fascial planes between muscles are frequently visible on radiographs because of the fat that is present in the connective tissue between the muscles. The use of a bright light assists in seeing them (see Chapter 4, p. 361, Figure 4-11, A). If fascial planes are of particular interest, a soft tissue technique is used to demonstrate them. Air may be injected into the subcutaneous fascia, where it will spread to the intermuscular fascial planes and be visible radiographically.

Displacement of fascial planes is of diagnostic significance. For example, displacement of the fascial plane usually visible caudal to the stifle joint indicates intraarticular swelling of the stifle joint. The infrapatellar fat pad may lose its radiolucency if intracapsular hemorrhage or edema is present (Figure 6-4).
SOFT TISSUE PATHOLOGY

Swelling of soft tissue or soft tissue masses are frequently seen on radiographs. More detailed information is usually obtained by clinical examination. Emphysema is seen as gas shadows within the soft tissues or under the skin. Gas opacities are seen within the soft tissues after puncture of the skin, such as with a compound (open) fracture. Air shadows are seen within the soft tissues after surgery. Radiopaque foreign bodies in soft tissues are visible radiographically (Figure 6-5, A to E).

Soft tissue masses may be recognized because they displace adjacent structures. For example, a retropharyngeal mass will displace the larynx ventrally; a thyroid mass will displace the cervical trachea ventrally or laterally (see Figure 3-3, E). More specific details concerning soft tissue shadows are given in earlier chapters of this text.

Ultrasonography

A soft tissue mass in the subcutaneous tissues is easy to examine ultrasonographically with a high-frequency transducer. An assessment can be made regarding its echotexture and whether it contains fluid. The degree of infiltration or margination helps differentiate neoplastic disease, cyst, abscessation, or hemorrhage.

Hematomas have a variable echogenic pattern, depending on the age of the lesion and the degree of clot retraction. Abscesses are predominantly anechoic,
with floccules representing cellular debris. Focal hyperechoic areas may indicate the presence of free gas or mineralization.

Foreign bodies may be located in the soft tissues. Nonmetallic foreign bodies cause variable degrees of acoustic shadowing, whereas metallic foreign bodies are highly echogenic, causing large acoustic shadows and multiple reverberation artifacts. Failure to demonstrate a foreign body does not preclude its presence (see Figure 6-5, G).

**CERVICAL SOFT TISSUES**

**Ultrasonography**

Soft tissue structures in the neck or limbs lend themselves to ultrasonographic examination, provided air-filled or bony structures are avoided. The tissue depths to be penetrated range from 1 to 10 cm. Depending on the tissue depth, a 10- to 15-MHz high-resolution transducer will be necessary. For structures lying close to the surface, a standoff is required if a lower resolution transducer is used.

**THYROID GLAND**

The thyroid gland lies caudal to the larynx and adjacent to the trachea. It is a paired structure that lies on either side of the trachea, and each part lies medial to the carotid artery. The two halves may be connected ventral to the trachea. It is not seen on plain radiographs until it becomes enlarged. An enlarged thyroid displaces the trachea in a variety of ways, depending on the location of the enlargement.

**Figure 6-1, cont’d** Calcification. E, Calcification of the biliary tract, an incidental finding. F, This dog had a pendulous abdomen, polydipsia, and polyuria. The lateral radiograph shows a generalized mineralization of the soft tissues, particularly well seen in the soft tissues of the inguinal area. Diagnosis: Cushing’s syndrome—hyperadrenocorticism. G, A female 3-year-old cat with severe dyspnea, polydipsia, and harsh respiratory sounds on auscultation. Extensive mineralization of the soft tissues is seen. Note the prominent aorta, which is mineralized throughout its length. Diagnosis: dystrophic calcification caused by renal disease. Continued
Ultrasonography
Examination of the thyroid gland provides anatomic but not functional information. As with other tissues, it is not possible to assess whether lesions are benign or malignant.

The thyroid gland is found by locating a carotid artery as a linear anechoic, pulsing structure deep to the jugular furrow. The transducer angle is approximately 45 degrees between the lateral and ventral aspects of the neck. The lobes lie medial to the carotid arteries and are fusiform, well-defined, homogeneous structures that are contained within the carotid sheath. They are isoechoic or hypoechoic with a granular echotexture. Each lobe is 2.5 to 3.0 cm long and 0.4 to 0.6 cm wide in dogs. In cats the length is about 2 cm, and the width is approximately 0.2 cm (Figure 6-6, A).

Thyroid adenomas or carcinomas are often seen. Ectopic thyroid tissue is difficult to differentiate from lymph nodes. Functional thyroid adenomas occasionally involve both glands and are the most common cause of hyperthyroidism in cats. The glands are enlarged and hypoechoic, with either a homogeneous

Figure 6-1, cont’d Calcification. H, This 1-year-old Labrador Retriever presented with a left foreleg lameness of 2 months’ duration. The carpus was hyperextended, and tendon injury was suspected. Radiographs at the time of the injury were unremarkable. This subsequent study illustrates extensive mineralization of the soft tissues just proximal to the accessory carpal bone. This mineralized tissue extends distally to involve the body of the accessory carpal bone. Diagnosis: posttraumatic calcification. I and J, A 5-month-old kitten with a history of dyspnea. Lateral (I) and dorsoventral (J) views show widespread, symmetrical, pinpoint infiltrations throughout the lungs obscuring the normal thoracic structures. The diaphragm is flattened, and the gastric wall is mineralized. Rugal folds are visible as parallel radiopaque stripes. This was metastatic calcification caused by renal failure.
Figure 6-1, cont’d Calcification. K to M. A 12-year-old Yorkshire Terrier had polydipsia, polyuria, and an enlarged abdomen. Lateral (K) and ventrodorsal (L) radiographs show hepatomegaly, a pendulous abdomen, and poor serosal detail. There is a vaguely circular soft tissue opacity in the left dorsal abdomen. It has a mineralized rim. It lies cranio-medial to the kidney, with which it shows border effacement. M, An ultrasound shows a 5-cm-wide heterogeneous mass (M) invading the cranial pole of the left kidney. It has anechoic areas and hyperechoic foci (arrowhead) caused by calcification within the mass. This neoplastic mass could have arisen either from the adrenal gland or from the kidney.

or mixed echotexture. Discrete nodular infiltrates or generalized enlargement of a lobe is seen (Figure 6-6, B).

Thyroid carcinomas are seen in dogs but rarely in cats. They are usually unilateral and hypoechoic. They tend to have poorly defined margins and mixed echotexture. Local tissue invasion often means that vital structures such as the jugular vein or carotid artery are closely associated with or directly involved in the mass. Local lymph nodes should also be examined. Ultrasound-guided fine-needle aspiration is particularly useful in making a definitive diagnosis of benign or malignant thyroid disease. Less common causes of thyroid masses include cysts, hemorrhage, and inflammatory disease. Thyroid cysts are sometimes seen in hyperthyroid cats. They appear as anechoic structures within the gland with hyperechoic septa (Figure 6-6).

Scintigraphy using radioactive markers (iodine or technetium) can be used to localize ectopic thyroid tissue. An increased uptake of the radioactive pharmaceutical can be observed in abnormal thyroid tissue (Figure 6-6, C to E).

THE PARATHYROID GLANDS
The parathyroid glands are intimately associated with the thyroid. Each half of the thyroid gland is associated with two parathyroid glands. They may be embedded within the thyroid. One often lies immediately adjacent to the cranial pole of each thyroid segment. The other is usually located in the caudal portion of the gland. They are usually anechoic or hypoechoic well-margined structures less than 2 mm in size. Ultrasonography with high-frequency transducers...
may identify enlarged parathyroid glands as discrete hypoechoic structures. Abnormalities include neoplasia and hyperplasia. Parathyroid adenomas are a cause of hypercalcemia. These lesions are usually single and appear as well-defined, spheroid nodules 5 mm or greater in size. They are closely associated with the ipsilateral thyroid gland (Figure 6-6, F and G).

**MUSCLES**

Muscle injuries seldom result in radiographic change other than soft tissue swelling. However, injury to the origin or insertion of a muscle may cause change in the underlying bone. Small, well-defined lucent defects may be seen in the greater tubercle of the humerus as a result of injury of the insertion of the infraspinatus muscle. Avulsion of the insertion of the cleidobracialis muscle results in an exuberant, ill-defined periosteal new bone reaction on the cranial cortex of the mid-diaphysis of the humerus (Figure 6-7, A and B). New bone on the craniodistal, lateral aspect of the humerus occurs with avulsion of the origin of the extensor carpi radialis. New bone may be present at the origin of the gastrocnemius on the caudodistal femur.
Ultrasonography

Muscle bellies are amenable to ultrasonographic examination. A transducer with a frequency of at least 8 MHz is used for most muscle examinations. In general, they have a mixed hypoechoic texture with linear striations running along the long axis of the muscle. Because muscles overlie and are superimposed on each other, different fiber directions of various muscles can be assessed. Any muscle fiber disruption can be readily appreciated as an interruption in the fiber alignment.

Disruption of the muscle striations or pattern may be seen with neoplasia. Focal hyperechoic areas indicating mineralization or necrosis may also be present. Vascular tumors are difficult to differentiate from hematomas. A fine-needle aspirate or biopsy is needed for a definitive diagnosis.

Where muscle changes into a tendinous or fibrous component, the fiber striations become less well marked. Tendons such as the Achilles and the biceps may be examined for injury, inflammation, or mineralization. Mineralization in a muscle is seen as bands of acoustic shadowing interposed between muscle planes (see Figure 6-1, Q). Ultrasonography is an invaluable aid to the surgeon who wishes to assess the integrity of an area before surgical repair. Hemorrhagic or serous fluid is sometimes identified between muscles or in tendon sheaths. Smaller tendons in the distal limbs require 10-MHz transducers for examination (Figure 6-7, C to K, and Figure 6-8).

Avulsion fracture fragments within a tendon may be identified as small hyperechoic areas with associated acoustic shadowing. Normally the bone margin at the site of a tendon or ligamentous insertion is smooth and hyperechoic. Avulsion fractures result in the bone margin becoming irregular in outline, indicating the site of the avulsion (see Figure 4-30, W).

Sinus and Fistulous Tracts. A sinus tract is a blind, purulent tract that shows no tendency to heal. The cause is often a foreign body. A sinus may also result when there is infection in tissue that is unable to mount an efficient inflammatory response. A fistulous tract is a communication between two body cavities or between a body cavity and the exterior. A fistulous tract is lined by epithelium. The terms sinus and fistula are often incorrectly used interchangeably.

Survey radiographs should be made before contrast studies are used because radiopaque objects are visible on such studies. A tract may be visible on a radiograph because of gas (air) within it.

A sinus tract can be outlined by injecting iodine-based aqueous contrast medium into it (sinography). The procedure is often unsatisfactory in demonstrating the full extent of the tract. Such tracts regularly have many ramifications, not all of which are patent at any one time. Furthermore, it is difficult to inject the contrast medium under sufficient pressure to ensure that the entire tract is outlined. Using a cuffed catheter or
a purse-string suture around the skin opening enables pressure to be increased within the tract and improves filling. Iodine contrast medium may outline a foreign body as a filling defect (Figure 6-9). False-positive and false-negative results are common because of artifacts or incomplete filling.

A fistulous tract can be outlined by introducing iodine-based aqueous contrast medium (fistulography) into an affected body cavity. For example, in the esophagus it will demonstrate an esophageal fistula. In the use of contrast agents to outline tracts, spillage of the medium onto the skin makes interpretation very difficult.

Ultrasonography. Ultrasonography can be performed to identify foreign bodies within such tracts and in general is more useful than sinography or fistulography. It should be performed before contrast studies to prevent artifacts induced by the introduction of air. Soft tissue changes surrounding a tract range from hypoechoic to hyperechoic. Foreign bodies such as grass awns, thorns, or wood splinters within a tract are usually hyperechoic with acoustic shadowing. Air within a tract may simulate a foreign body. Because a foreign body may be at some distance from the point of a discharge, the entire region should be examined.

LYMPH NODES

Lymphography (Lymphangiography)

Lymph nodes and ducts can be demonstrated radiographically after injection of contrast medium into the lymphatic system. Identification of the lymph vessels is achieved by the injection of methylene blue into the subcutaneous tissues distal to the site of interest. Injection may then be made either into a lymph vessel outlined by the methylene blue or directly into a lymph node. Water-soluble agents are used and are absorbed within a few hours. Lymphography may be used to demonstrate chyloperitonum, chylothorax, and lymph node enlargement in lymphadenopathy or neoplasia. Its use is contraindicated if there is local infection near the site of injection or in inflammatory pulmonary disease because of the danger of embolization. The use of lymphography in veterinary practice is limited (Figure 6-10, A).

Ultrasonography

Most lymph nodes are seen to be hypoechoic, well defined, and of variable contour. Diffuse infiltrates are difficult to appreciate. Localized masses may be seen and sampled by ultrasound-guided fine-needle aspiration or biopsy (Figure 6-10, B and C).
Computed tomographic (CT) lymphangiography may be used in the investigation of lymphedema of the hindlimbs. With ultrasound guidance a peripheral lymph node, usually the popliteal, is located and a small volume (1 to 3 mL) of iodinated water-soluble contrast is injected into the lymph node. The contrast is transported through the lymphatic vessels toward the abdomen. CT imaging of the hindlimbs, pelvis, and caudal abdomen can then be used to evaluate the lymphatic vessels and lymph nodes. This technique may also be used to evaluate lymphatic drainage from the gastrointestinal tract. With ultrasound guidance, a mesenteric lymph node is isolated and injected with a small volume of iodinated contrast (1 to 3 mL). CT images of the abdomen and thorax will then identify the cisterna chyli and thoracic duct. This can be used to identify a lesion in the case of suspected chylothorax.

**ULTRASOUND-GUIDED ASPIRATION AND BIOPSY**

Ultrasonographic examination of tissue structures is a useful aid to the diagnosis of disease. However, the echogenic and echotexture changes seen do not necessarily indicate the presence of pathology. Similarly, a normal ultrasonogram does not preclude the presence of significant tissue pathology. Percutaneous fine-needle aspiration or tissue core biopsy is often required for a definitive diagnosis. The accuracy of sampling is greatly enhanced when ultrasound guidance is used. Sampling a specific area of either tissue or fluid while imaging the needle track permits the avoidance of vital structures and minimizes the risk of hemorrhage or erroneous sampling, both of which might occur with a blind aspirate.

There are two main methods of tissue biopsy. One uses a clip-on or dedicated biopsy guide attached to
the side of the transducer. The guide ensures that the needle, which travels alongside and at a slight angle to the transducer, remains within the ultrasound beam and therefore is continuously visible. The machine has a biopsy guide selector that, when engaged, shows the projected track of the needle between a pair of dotted lines. The needle is passed through the guide and is perceived as a hyperechoic linear echo between the dotted lines on the monitor. This method is useful but slightly restrictive because manipulation of the transducer is reduced. This drawback is particularly evident with animals of small body size. It is also a problem when an intercostal approach is required because the skin contact area required for examination is considerably greater. The needle is introduced at a slight angle and somewhat removed from the transducer; therefore its passage may be obstructed by the ribs. Such positioning often results in the biopsy needle lying at an awkward angle for the operator. Special transducers are available with a dedicated biopsy channel incorporated in the transducer to avoid this problem.

An alternative method is the so-called freehand method, in which the needle is introduced without the use of a guide. The needle is often best seen when it is introduced at an angle of 90 degrees to the path of the ultrasound beam. It is important to ensure that the needle track remains within the width of the beam so that its path can be continuously visualized. This technique is much more flexible but does require expertise and dexterity to keep the needle tip in view.

Before the procedure is performed, the animal should be examined and an evaluation of its hematocrit status performed. Assessment should include prothrombin time, platelet count, partial thromboplastin time, and whole blood clotting time. Any hematocrit disorder should be treated before the procedure because there is a risk of hemorrhage after sampling, particularly with tissue core biopsy. Fine-needle aspiration has a minimal risk of complications.

Sedation combined with an analgesic is usually necessary to ensure that the animal does not move during the procedure. Sometimes local anesthesia may be required, depending on the structure being sampled.

The skin should be prepared with an aseptic technique, and the transducer should be covered with a sterile sleeve or glove. Gel is essential between the transducer surface and the glove to displace any air that may be present. The skin should be cleaned with
spirit. Sterile gel may be applied to the skin to improve image quality. If a biopsy guide is being used, it should also be sterile. The area of interest should be located within the optimal focal zone of the transducer.

Fluid aspiration or fine-needle aspirates for cyto-logic examination, analysis, and culture may be taken with a syringe and a 1.5-inch (4 cm) 22-gauge hypodermic needle. For deeper structures, a fine 22- or 23-gauge spinal needle of appropriate length may be used. Needles with etched surfaces, which render them more easily seen, are specially designed for ultrasound-guided fine-needle aspiration but are costly. The needle should be introduced with the syringe attached and the syringe vacuum broken before its introduction into the tissue. When in the selected location, the plunger is slightly withdrawn and the needle moved in and out of the tissue over several millimeters. The plunger is then allowed to rest in a neutral position, and the needle and syringe are removed together. Alternatively, in vascular structures such as the spleen and kidney, the needle is moved to and fro without withdrawing the syringe plunger. The site should be monitored after sampling to check for hemorrhage. The needle track is often visible as a result of some minor hemorrhage in the area. The aspirate or tissue should be immediately removed for processing. If a biopsy guide is being used or if the area of interest is situated deep in the animal, spinal needles must be used. The stylet can be removed before introduction if the procedure is being carried out without any operator assistance. Otherwise, the stylet would have to be removed by the operator, and the transducer would have to be released midway during the procedure.

When aspirating a fluid-filled area, there is no need to maneuver the needle to and fro. Some fluids may require a 20- or 21-gauge needle or larger, depending on their viscosity. Tissue core biopsies are necessary if a sample of tissue is required for histopathologic examination. General anesthesia is often required for biopsies. Usually 14- to 18-gauge biopsy needles are used. Many needle types are available. Different biopsy needles have a variety of cutting motions, so before the procedure is begun the operator should be completely familiar with the device. Some needles, when engaged, extend farther into the tissue than

Figure 6-5 A and B, A large soft tissue mass is visible on both the dorsopalmar and lateral views. The lesion was caused by a bite wound. Continued
Figure 6-5, cont'd  C, Numerous shot grains are present in the shoulder region. Air has entered the soft tissues and is visible as radiolucent shadows in the ventral neck and cranial to the shoulder. There is a comminuted fracture of the humerus. D, This 6-year-old Jack Russell Terrier had a 3-week history of lameness. The lateral radiograph of the stifle shows a radiopaque structure overlying the cranial joint space. This proved to be a small stone lodged in the subcutaneous tissues. Diagnosis: foreign body. E, This dog had a swelling in the area of the thigh. A lateral radiograph shows a fat mass within the soft tissues caudal to the femur. Diagnosis: lipoma. F, This 4-year-old Yorkshire Terrier presented with a swelling on the dorsal aspect of the neck that had been present for 3 weeks. A mixed echogenic soft tissue mass (arrows) with hypoechoic foci is seen. The hyperechoic undulating line is the dorsal aspect of the cervical vertebrae. The histopathologic diagnosis was hemangiosarcoma. G, This 2-year-old German Shepherd presented with a firm, painful swelling over the proximal aspect of the twelfth rib. Tangential radiographic studies of the area were uninformative. A transverse sonogram shows a large hypoechoic mass (a) overlying the last three ribs (r), which cast acoustic shadows. The mass is closely adherent to the ribs, and its medial margin undulates between them. Some echogenic foci were evident within the mass. Gentle compression of the mass while performing the examination indicated that the contents were fluid and compressible. Diagnosis: abscess.
Figure 6-6 A1 and A2, This is a transverse sonogram of the right (A1) and left (A2) lobes of the canine thyroid gland. The gland tissue (short arrows) is relatively hyperechoic, and each lobe is triangular in shape. The carotid (C) and trachea (T) are seen in cross-section. The esophagus is outlined by long arrows. B1, This dog had a firm swelling in the midcervical region. A mixed echogenic mass (arrows) with some hyperechoic foci is evident. Fine-needle aspirate confirmed a diagnosis of thyroid carcinoma. B2, In this case of thyroid carcinoma, the neoplastic tissue (star) is more uniform and has a slightly loose echotexture. Fine-needle aspiration or biopsy is required to make a definitive diagnosis. B3, Lateral thoracic radiograph showing widespread metastases from a thyroid carcinoma.

Continued
Figure 6-6, cont’d C, Normal thyroid scintigraphy in a cat. There is uniform, symmetric uptake of the radiotracer in the thyroid glands. The uptake in the thyroid glands seen in the mid-neck is comparable to the zygomatic salivary glands seen in the skull area. D, Unilateral feline hyperthyroidism. A nuclear medicine thyroid scan in a cat. This ventral view of the head and neck shows a single, well-defined focus of intense increased radiotracer accumulation in the mid-neck, in the area of the thyroid gland. The uptake within the abnormal thyroid gland is much greater than in the zygomatic salivary glands. E, A nuclear medicine thyroid scan in a cat. This is a ventral view of the neck showing multiple well-defined foci of increased radiopharmaceutical (radiotracer) uptake in the mid-neck. The uptake in the thyroid glands is greater than in the zygomatic salivary glands. These findings are consistent with hyperthyroidism. F and G, Parathyroid glands. F, This is a longitudinal scan of part of the left thyroid lobe (short arrows). The lobe length extends beyond the width of the transducer. The small echolucent oval structure (long arrows) seen at the cranial extremity of the lobe is one of the parathyroid glands. G, On this transverse sonogram a parathyroid gland (long arrow) is seen within the substance of thyroid gland (arrowheads).
Figure 6-7 A and B, Trauma to the insertion of the cleidobrachialis muscle results in an exuberant, ill-defined periosteal new bone formation on the cranial, medial, and lateral cortices of the mid-diaphysis of the humerus. C to E, This 2-year-old-German Shepherd had a recurrent swelling of the soft tissues just proximal to the calcaneus. Transverse (C and D) and longitudinal (E) sonograms were made with a 7.5-MHz transducer with a fluid offset or standoff. C, An anechoic elliptical defect (arrows) is seen within the substance of the Achilles tendon close to the calcaneus. D, Six centimeters proximally, the defect has a hypoechoic texture and occupies approximately two thirds of the cross-sectional area of the tendon (arrow, ACT). E, Longitudinal scan of the tendon illustrating the variable echogenicity of the tendon in the distal 6 cm. The open arrow indicates the hypoechoic and thickened tendon. The closed arrow indicates the markedly anechoic area seen in A. Diagnosis: Achilles tendon rupture. P, Proximal; D, distal; ACT, Achilles tendon.

Continued
others; this fact should be kept in mind when placing the needle tip. Automated biopsy devices are preferred because the procedure can be performed quickly, with limited assistance and reduced risk of complications. The quality of samples obtained from automated devices is generally better than those obtained from manual biopsy needles. As long as the animal does not have a bleeding disorder, hemorrhage should be minimal. Biopsy of infected tissue may cause local leakage and infection. Seeding of the needle track with neoplastic cells may occur, but its practical significance is debatable.
Figure 6-8 A to C, This dog had been in a road traffic accident and had a fracture of the humerus. There was marked swelling of the upper limb. Ultrasonography of the region was performed. A, This sonogram indicates that the swelling was caused by a large hematoma (h) that was forming between the bone and the muscles. B, Transverse sonogram of the muscles (m) surrounded by hemorrhage (h). b, Bone. C, Longitudinal sonogram of the triceps region illustrates disruption of the triceps muscle (t). The rough edge is seen floating free (arrows) in swirling echogenic fluid. This fluid was blood (h). m, Muscle. Diagnosis: rupture of the triceps muscle.

Figure 6-9 A to C, Sinus tract. A 6-year-old Tibetan Terrier had a soft tissue swelling and a discharge at the level of the eleventh rib. A, A dorsoventral view shows an old fracture at the mid-portion of the left twelfth rib (arrow) with periosteal reaction on the eleventh rib. B, A 22-gauge catheter was introduced at the point of discharge, and 2 mL of iohexol 240 was introduced. Some contrast is seen on the skin. A small quantity forms a linear pattern superimposed on the lateral aspects of the eleventh and twelfth ribs. C, The catheter has been removed, and this close-up study shows a linear radiolucency outlined by two positive contrast linear shadows. The radiolucency was caused by a lollipop stick (arrow, twelfth rib).
Figure 6-10 A, A 7-year-old German Shepherd presented with a pitting edema of the right hindlimb. Ten milliliters of a positive, nonionic contrast medium was slowly introduced through the medial metatarsal lymph vessel with a 25-gauge catheter. A collar of abnormal lymph vessels forms an interlocking network pattern. Bulbous distentions of the lymph vessels are seen (straight arrow). Proximally, the popliteal lymph node (curved arrow) and normal lymph vessels are seen. This is a lymphangiectasia. B, This 7-year-old Labrador Retriever presented as being off form for a few days. The dog had a retained abdominal testicle removed 2 years earlier. It had a Sertoli cell tumor. A mass was palpable in the caudal midabdominal region. The midline abdominal longitudinal sonogram shows a hypoechoic, roughly circular structure (arrows) lying dorsal to the bladder. Diagnosis: medial iliac lymph node enlargement—possible metastases. L node, Lymph node. C, This dog had peripheral lymphadenopathy. The medial iliac lymph node is enlarged, rounded, and hypoechoic (short arrows). A fine-needle aspirate was obtained under ultrasound guidance. A hyperechoic needle (long arrows) is seen within the substance of the gland. Diagnosis: lymphoma.

Thorax

Lung. Pulmonary masses may be sampled through an intercostal approach. The needle should remain within the mass and should not be allowed to slide into adjacent normal lung tissue. Blood vessels and vascular areas should be avoided. Pneumothorax, although a potential complication, is rarely of clinical significance (Figure 6-11, A).

Mediastinum. Mediastinal masses are often located adjacent to the heart and great vessels and can be particularly hazardous to sample. General anesthesia is usually a prerequisite.

Pleural Cavity. Pleural fluid can be aspirated without ultrasound guidance, but it is desirable to determine the best location by ultrasonography. Ultrasound-guided therapeutic drainage is useful in cases of fibrin deposition or adhesions. Biopsy of pleural masses or specific areas of loculated fluid requires ultrasound guidance.

Pericardium. Pericardial fluid can be more safely removed with ultrasound guidance. Pericardial masses attached to the heart may not be amenable to fine-needle aspiration because access may be hazardous unless the mass is large.

Abdomen

Clotting disorders are a contraindication for biopsy. The presence of intraabdominal fluid makes organ aspiration a more difficult technique. Tissue tends to float in the fluid and move away from the needle tip.

Liver. Dorsal recumbency is usually preferred, and the liver is imaged from the cranioventral abdomen. If diffuse liver disease is suspected, biopsy of the left lateral or medial liver lobes should be performed because this avoids the gallbladder, portal vein, and caudal vena cava. Depending on the location of the lesion, or if the liver is small, an intercostal approach may be necessary. The gallbladder should be avoided. It may be advisable to feed some fatty food to the
animal about an hour before sampling. The needle tip should not penetrate beyond the liver tissue, and vascular and biliary structures should be avoided. Cavitary lesions may be aspirated or drained. If there is hepatic congestion or obstructive biliary disease, sampling is contraindicated. Cats with hepatic lipodosis appear to be at increased risk of hemorrhage, and the number of samples should be limited. The pleural cavity should not be entered (see Figure 6-11, B).

**Kidney.** The kidney is a highly vascular structure. To avoid movement by the animal and therefore the risk of renal hemorrhage, short-acting general anesthesia is usually a prerequisite. The paralumbar approach is adequate if the tissue lies within the focal zone of the transducer. If diffuse renal disease is suspected, biopsy of the renal cortex is preferably performed at the caudal pole. Biopsy of the cranial poles can be performed through a ventral abdominal approach if the other abdominal organs can be displaced and avoided. Only the cortex is sampled, and the corticomedullary junction should not be traversed by the needle tip because this is the site of the arcuate vessels, and there is risk of serious hemorrhage. The needle should be introduced at an angle to the kidney surface. After the procedure, the kidney should be carefully examined for any signs of hemorrhage. Biopsy of focal lesions can be performed if they lie in the cortex. If such lesions are situated elsewhere, the risk of serious hemorrhage after biopsy is greater. Hematuria is a common complication but is usually short lived and rarely of clinical significance. Intravenous fluids may help reduce the formation of clots within the kidney.

**Bladder.** Intraluminal or mural masses are amenable to biopsy or aspiration. Ultrasound can be used to guide a traumatic catheter biopsy. Cystocentesis in animals with small amounts of urine in the bladder is greatly facilitated by ultrasound guidance.

**Spleen.** Fine-needle aspiration is possible, but aspirates are often contaminated with blood; therefore the cellular content is diluted, and analysis can be unrewarding. Biopsies are inadvisable because of the vascularity of the organ.

**Gastrointestinal Tract.** Gastric and small intestinal masses can be sampled by fine-needle aspiration. Biopsy of larger masses can be performed. The lumen should be avoided because perforation and subsequent leakage along a needle track may cause peritonitis. If the operator is inexperienced in percutaneous biopsy techniques, endoscopy or surgical intervention is preferable and probably more rewarding in obtaining a definitive diagnosis.

**Lymph Nodes.** Aspiration or biopsy of enlarged intraabdominal or sublumbar lymph nodes can be performed. Normal-sized lymph nodes are often not seen. The colon and vascular structures should be avoided (Figure 6-10, B and C).

**Prostate.** Fine-needle aspiration and biopsy of prostatic tissue are useful diagnostic techniques. Sampling of focal areas such as cysts or abscesses, as well as drainage, is also possible. The urethra should be avoided. Prior placement of a fluid-filled urinary catheter in the prostatic urethra is useful to ensure that the urethra is visible and not damaged. Aspiration of a cavitated abscess may cause local peritonitis with adhesions if leakage occurs. This potential complication is reduced if a 22-gauge needle is used.

**Testes.** Testicular masses are amenable to fine-needle aspiration and biopsy.

**Female Genital Tract.** Ovarian and uterine masses can be sampled successfully, but large, thin-walled
cystic cavities should be avoided because they may rupture when perforated. Aspiration or biopsy of a fluid-filled uterus should not be performed because of the risk of uterine rupture.

Skull and Skeleton

Orbital and Retrobulbar Masses. If the mass can be located, fine-needle aspiration or biopsy is very useful, and drainage of cavitary lesions such as abscesses is possible (see Figure 5-15, B to D).

Musculoskeletal System. Subcutaneous masses or masses involving the musculoskeletal system are easily aspirated, and ultrasound guidance is usually unnecessary. However, more accurate sampling of abnormal tissue is facilitated by using the technique. Aspiration of bone lesions may also be more accurate if the site of interruption of the cortical bone and the source of the lesion can be precisely located (see Figure 4-41, K).

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Ultrasonography


Ultrason-guided biopsy


Figure 2-7 H, Color flow Doppler sonogram showing the caudal vena cava (long arrow, coded blue) traveling toward the diaphragm. The aorta is seen in the far field (short arrow, coded red).

Figure 2-10 B2, Extrahepatic portocaval portosystemic shunt in a dog. This is a sagittal plane ultrasound color flow Doppler image. The portal vein (PV, arrowheads) runs from right to left across the image. An aberrant vessel originates from the dorsal aspect of the portal vein and courses cranially and dorsally (arrows). With color Doppler examination flow within this vessel is coded blue, which indicates flow away from the portal vein and liver. PSS, Portosystemic shunt; CA, celiac artery; CMA, cranial mesenteric artery.

Figure 2-10 C3, Color flow Doppler shows turbulent flow, evidenced by a mosaic pattern, within the shunt vessel (arrow). PV, Portal vein; CVC, caudal vena cava.
Figure 2-11 L, Splenic torsion in a dog. This is a sagittal plane ultrasound image obtained in the left cranial abdominal quadrant. The spleen is enlarged. It appears diffusely hypoechoic, with small linear or lacelike hyperechoic foci scattered throughout the organ. The splenic vein in the center of the image is moderately distended. A color Doppler sample volume has been placed over the splenic vein and hilus. No evidence of arterial or venous flow is seen. The fat adjacent to the splenic hilus and surrounding the splenic vein is hyperechoic because it is inflamed and reactive.

Figure 2-36 R, A color flow Doppler image along the length of the caudal vena cava, which is running horizontally in the near field. The blood flow on the right of the image is obstructed by the mass in the center. Cr, Cranial.

Figure 2-36 S, Adrenomegaly. This color flow Doppler image along the length of the caudal vena cava in the cranial abdomen shows an enlarged right adrenal gland (arrows) compressing but apparently not invading the lumen.

Figure 2-42 F, This is a transverse abdominal scan of a bladder from the ventral abdomen. Using color flow Doppler, the right ureteral jet can be seen discharging urine from the ureteral papilla into the bladder and creating a Doppler signal (red jet). This technique can be useful to identify the ureteral entrances into the bladder.
Figure 2-48 S, A color Doppler sample volume placed over the lesion shows flow within vessels originating from the bladder wall and coursing into the mass lesion. This technique is useful in distinguishing a luminal blood clot from a tumor mass; clots show no evidence of blood supply. This was a transitional cell carcinoma.

Figure 2-58 H, This color flow Doppler scan of a 30-day pregnancy shows the fetal heart with the left ventricle in the center and aorta extending to the right. The ribs are seen along the thoracic wall in the near field.

Figure 3-35 F, Patent ductus arteriosus in a dog. Right-sided, parasternal short-axis view of the main pulmonary artery. A color-flow Doppler sample volume has been placed over the pulmonary artery. Flow within the pulmonary artery is away from the transducer and is coded blue. There is a mosaic pattern of flow within the ductus arteriosus that runs parallel to the pulmonary artery. The mosaic pattern, a random mixture of all colors from the color map, indicates turbulent flow. RPA, Right pulmonary artery; PDA, patent ductus arteriosus.

Figure 3-35 F, Patent ductus arteriosus in a dog. This is a right-sided, parasternal short-axis view of the main pulmonary artery. A continuous-wave Doppler cursor has been placed in the pulmonary artery, distal to the pulmonic valve. The Doppler trace shows continuous flow within the pulmonary artery, which is an abnormal finding.
**Figure 3-37** F. This is a right-sided, parasternal long-axis view with a color-flow Doppler sample volume placed over the interatrial septum. A defect is seen in the interatrial septum (arrows). A large jet (coded red) is seen passing from the left atrium (LA) to the right atrium (RA). LV, Left ventricle; RV, right ventricle.

**Figure 3-40** F and G, Color-flow Doppler sonograms from the right parasternal (F) and left parasternal (G) apical four-chamber locations. These two cases show mitral valve regurgitation, which is seen as a green jet extending into the left atrium during systole. Diagnosis: Mitral valve insufficiency.

**Figure 3-40** P, This is an apical parasternal color-flow Doppler sonogram from the left parasternal location. The Doppler gate has been placed over the tricuspid valve. Mild regurgitation is seen as a green jet extending into the right atrium during systole. Diagnosis: Tricuspid regurgitation.

**Figure 3-42** I, Right-sided, parasternal, long-axis, four-chamber view; moderate to severe hypertrophy of the interventricular septum is present. There is also moderate hypertrophy of the left ventricular free wall. A color Doppler sample volume is in place over the mitral valve. A small regurgitant jet lesion is noted. There is moderate enlargement of the left atrium in this view. LA, Left atrium; LV, left ventricular; RA, right atrium; MI, mitral insufficiency.
Figure 3-42 J2, Aortic embolus in a cat. This cat had hypertrophic cardiomyopathy and presented with acute-onset pelvic limb paresis. A slightly oblique sagittal ultrasound image of the caudal abdominal aorta shows an echogenic thrombus, indicated by the cursors, within the lumen of the aorta. Color-flow Doppler evaluation shows only limited flow around the periphery of the thrombus and flow within one of the lumbar arterial branches.

Figure 3-42 K and L, Hypertrophic obstructive cardiomyopathy. There is focal hypertrophy of the proximal aspect of the intraventricular septum of the left ventricular outflow tract. This causes turbulence in the left ventricular outflow tract, which pulls the septal leaflet of the mitral valve toward the septum in systole. K, In this right-sided, parasternal long-axis view, there is moderate to severe hypertrophy of both the intraventricular septum and left ventricular free wall. The interventricular septum bulges (arrow) into the left ventricular outflow tract. A color Doppler sample volume was placed at the ventricular outflow tract and mitral valve. A large regurgitant jet is seen within the left atrium (LA) because anterior displacement of the septal leaflet toward the septum during systole results in mitral incomelence (MI). AO, Aorta. L, This image was obtained at a slightly more cranial location and is a view of the left ventricular outflow tract (LVOT). Color Doppler interrogation shows a mosaic pattern of flow within the left ventricular outflow tract indicative of turbulence; anterior septal motion of the mitral valve leaflet causes a dynamic obstruction of the left ventricular outflow tract. LA, Left atrium; LV, left ventricle.
**Figure 3-42 Q.** On the left-sided, parasternal, long-axis, four-chamber view, the left ventricle is dilated. The apex of the ventricle is rounded. The full extent of the left atrial enlargement is not evident on this view. A color Doppler sample volume placed over the mitral valve shows the presence of a small regurgitant or incompetent jet.

**Figure 4-30 Z1.** This Greyhound had right hindlimb lameness with no clinical indication regarding the site of pain. The scintigraphic examination (bone phase) shows an increased uptake in the distal third of the tibial diaphysis (arrow).
Index

A
Abdomen, 23, 560–562
abnormalities, 27–33
distention, 30f
emptiness, appearance, 36f–39f
free air, post-laparotomy, 34f–35f
lateral views, 24f–27f
plain lateral radiograph, 95
plain radiograph, 100f–107f, 113f
radiologic signs, 29, 32–33
right cranial quadrant, oblique transverse
plane image, 93f–94f
right lateral view, 100f–107f
transverse CT image, 24f–27f
ultrasonography, 25–27, 29, 31
ventrodorsal radiograph, 95
ventrodorsal views, 24f–27f, 100f–107f
spleen head outline, 40f–41f
Abdominal arteriovenous fistulas, 46
Abdominal blood vessels, ultrasonography, 37–38
Abdominal cavity, 23–33
radiography, 23
Abdominal distention, 124
Abdominal masses, 28f–29f
abnormalities, 27–29
appearance, 143f–146f
Abdominal radiography
abnormalities, 27–33
evaluation, 24
normal appearance, 24–25
radiologic signs, 29, 32–33
ultrasonography, 29, 31
Abdominal swelling, radiograph, 3f–4f
Abdominal wall, 33–36
abnormalities, 33–36
hernias, 34–36
lateral abdominal radiograph, 34f–35f
ultrasonography, 36
Abortion, first signs, 190
Abscesses, presence, 36
Acetabula, remodeling changes, 40f–42f
Achondrodysplasia, 395–398
Acinar nodules, 225
Acoustic enhancement, 17
illustration, 13f
Acoustic impedance, equation, 12
Acoustic shadowing, 12, 17
artifact, 17
Acoustic window, 16
Acquired cardiac disease, 318–320
radiologic signs, 318–319
ultrasonography, 319–320
Acquired luxation, 361–365
Acquired pectus excavatum, 279–280
Acquired portal vascular anomalies, 47
Acute nephritis, impact, 143
Acute pyelonephritis, 135
Acute renal failure, 135
Acute renal infarcts, appearance, 144
Acute respiratory distress syndrome (ARDS), 225, 237
Acute splenic infarcts, 55
Adamantinoma, 486
Addison’s disease, 125–126, 306–307, 310
hypoadrenocorticism, impact, 125–126
Adenocarcinoma, impact, 116f–117f
Adrenal cortical insufficiency, 306–307
Adrenal glands, 123–126
anatomy, 123
bilateral enlargement, 124–125
close-up sagittal plane, 125f–131f
location, 125f–131f
mineralization, 124
neoplasia, 126
radiologic signs, 126
ultrasonography, 126
position, 123
ultrasonography, 123–126
usound examination, transducers
(requirement), 123
Adrenal mass
appearance, 126
diagnosis, 125f–131f
Adrenal neoplasia, 125f–131f
Adrenal tumor hyperadrenocorticism, 124–125
Adrenocorticotrophic hormone (ACTH),
secretion (excess), 123–124
Adrenomegaly, 123
appearance, 125f–131f
Adult cats, radiographs, 441f
Adynamic ileus, impact, 97
Aelurostrongylosis, 235–236
Adult heart disease, 310
Arrhythmogenic right ventricular
cardiomyopathy, 329, 330f–336f, 336
result, 329
Arteriovenous fistula, 398, 405f, 543, 550f
communication, 398
ultrasonography, 550
Arthritis, 381
types, 382–384
Arthography, 360–361
Articular cartilages
fissure formation/fragmentation, degenerative
joint disease (impact), 375–381
radiographic visibility, absence, 361

Page numbers followed by f, t, or b indicate figures, tables, or boxes, respectively.
Cranial sinuses: venography, contrast medium injection, 254–255, 491
Venography, 491
Cranial structures: abdominal radiography, 24
Cranial thoracic esophagus, dilation, 68f–72f
Cranial thoracic transverse CT image, 210f–216f
Craniomandibular osteoarthropathy, 461–463
Craniomandibular osteotropathy, 461–463
Diaphragmatic hernia (Continued)
primary signs, 494f–495f
radiologic signs, 254–257
rare signs, 257
secondary signs, 256–257
Diaphragmatic lobe, 221
Diaphragmaticum, transverse CT image, 210f–216f
Diaphragmaticsectorial ligament, 221–223
Diaphragmatic ruptura (hernia), 36f–39f, 254–257
Ultrasoundography, 257
Diaphragmatic shadow, 261
Distended proximal ureter, identification, 148
Dista small intestinal obstruction, 100f–107f
Distended small intestinal obstruction, 100f–107f
Distal ulnar metaphysis, radiolucent cartilage, 135
Distal radial epiphysis, distortion, 393
Distal jejunum, intussusception, 108f–112f
Distal femur, medial condyle (articular fracture), 410f–417f
Distal femoral trochlea, flexed skyline/tangential view, 125
Distal ulnar metaphysis, radiolucent cartilage (presence), 393
Distal ulnar physis, premature closure, 408f
Distal small intestinal obstruction, 100f–107f
Distended proximal ureter, identification, 148
Distension, image quality factor, 5
Diverticulum (diverticula), 74, 166
Bladder mucosa protrusion, 166
Diabetes insipidus, 221
Dogs (Continued)
midline sagittal ultrasonogram, 586–58f
Plain radiograph, 100f–107f
Abdominal arteriovenous fistulas, 46
Abdominal CT, dorsal plane reconstruction, 125f–131f
Adrenal glands, 125f–131f
Appearance, 125f–131f
Bladder calculi, 160f–161f
Sagittal plane ultrasound image, 21f
Bone tumor, 424
Brain, appearance, 492f–493f
Bronchi, mineralization, 219f–220f
Cardiomyopathy, 327f–328f
Carpus, mediolateral view, 370f–371f
Caudal abdomen
Mass, presence, 180f–184f
Caudal abdomen, sagittal sonogram, 180f–184f
Caudal vena cava, left-sided paralumbar transverse plane sonogram, 125f–131f
Cervical vertebral column
Appearance, 125f–131f
Congenital portal vein anomalies, types, 49f–57f
Coronary artery mineralization, 544f–548f
Cranial abdomen, examination, 11f–13f
Cranial mediastinal mass, 275f–278f
Cystic calculi, 171f–172f
Dental formula, 480
Dentigerous cyst, 486
Dental radiography, 8
Digital Imaging and Communication in Medicine (DICOM) files, saving, 8
Digital radiography (DR), 8
Digital radiography, 8
Digital Imaging and Communication in Medicine (DICOM) files, saving, 8
Digital radiography (DR), 8
Digital radiography, 8
Diaphragmatic hernia, 35–36, 254–257
Outline, loss, 258f–259f
Presence, 87–88
Liver (Continued)
gas, appearance, 87
hypoechogenic metastatic masses, 43f–46f
lobe, intrabdominal fluid, 43f–46f
localized masses, 42
margin, 43f–46f
metastatic lesions, 43f–46f
midline cranioventral sagittal sonogram, 49f–51f
midline sagittal sonogram, 40f–41f
midline sonogram, portal vessel appearance, 40f–41f
normal appearance, 39–42
parenchymal changes, 43f–46f
portal vein anomalies, 47
s integrative, 47
ultrasonography, 47
portal vessels, 40f–41f
position, 40f–41f
radiography, 39
shadow, enlargement, 83f–85f
size, reduction, 47
ultrasonography, 47
sonograms, 11f–13f
ultrasonography, 42
Living bone, remodeling, 352–353
L1-L2 disk prolapse, 517f–519f
Localized gastric wall thickening, 88
Locomotor impairment, 420
Long bones
blood vessel entry, 353
inflammation (panostitis), 442
laminar periosteal reaction, 350
ossification centers, 351
Long digital extensor tendon, 369
Lorodosis, 51f
Lower incisors, intraoral view, 48f
Lower-volume rapid infusion, 132
Lumbar cistern, 51f
Lumbarrassion, 507
Lumbar myelogram, 50f
Lumbar myelography, 503
compl ications, 503
Lumbar vertebrae, 497, 502
bodies, length, 497
osteomyelitis, 527f
ventrodorsal view, 49f–50f
Lumbosacral instability, 511
Lumbosacral junction, spondylosis, 513
Lumbosacral spondylosis, 511
Lumbosacral stenosis, 511
Lumbosacral syndrome, 511
anatomy, 511
radiography, 513
radiologic signs, 513
Lumen
calculi, grouping, 21f
distention, 119f–120f
ehogenic material, 36f–39f
Lungs (Continued)
appearance, 209
radiograph, 221
hyperlucent lungs, 231–233
hypervascular pattern, 230–231
hypovascular pattern, 228–230
interstitial disease, 229f
interstitial pattern, 225–227
radiologic signs, 225–227
lobar distribution, 225
lobe, torsion, 247
ultrasonography, 247
mixed pattern, 231
ultrasonography, 231
nonspecific changes, 233
obesity, impact, 233
paraskeletal sonogram, 250f–255f
pathology, suspicion, 210–212
patterns, abnormalities, 224–248
pneumonia, 233–245
pulmonary edema, 245
pulmonary hemorrhage, 247
pulmonary infiltrates, 245
pulmonary infiltrates with eosinphils (PIE)
ultrasonography, 245
pulmonary neoplasia, 247–248
radiologic signs, 247–248
ultrasonography, 248
vascular pattern, 228, 231f–232f
Lymphadenopathy, presence, 107
Lymphangitis, 107
Lymph (chyllothorax), 259
Lymph nodes, 550–551
enlargement, 281–282
hypoechogenic characteristic, 550–551
Lymphangiectasia, 107
Lymph nodes, 107
Malignant histiocytic sarcoma, 280f–286f
Mammary gland, 192–195
Malignant histiocytic sarcoma, 280f–286f
Mammary gland, 192–195
dystocia, 187f
radiographic recognition, 192
size, increase, 192–195
ultrasonography, 195
Mammary tissue, echogenic/homogenous characteristic, 195
Mandibular canal, radiolucency, 481
Mandibular duct
opening, appearance, 486
outline, 487f–488f
Mandibular gland
adenocarcinoma, 487
location, 486
opening, 487f–488f
Mandibular periositis, 461–463
Mandibular synovitis, ventrodorsal intraoral view, 453f–455f
Marie’s disease, 438
Magnetic resonance imaging (MRI), 9
contrast agents, usage, 9
contrast resolution, 9
ionizing radiation, absence, 9
Malar abscess, 485
Male cat, pleural fluid (thoracic radiographs), 330f–336f
Male dog
caudal abdomen, sagittal sonogram, 1808–184f
re tained testicle, 176f–179f
Male genital tract, 172
Male urinary catheter, placement, 108f–112f
Malignant bone tumor, 425f
Malignant histiocytic sarcoma, 280f–286f
Mammary gland, 192–195
dystocia, 187f
radiographic recognition, 192
size, increase, 192–195
ultrasonography, 195
Mammary tissue, echogenic/homogenous characteristic, 195
Mandibular canal, radiolucency, 481
Mandibular duct
opening, appearance, 486
outline, 487f–488f
Mandibular gland
adenocarcinoma, 487
location, 486
opening, 487f–488f
Mandibular periositis, 461–463
Mandibular synovitis, ventrodorsal intraoral view, 453f–455f
Marie’s disease, 438
57 8

Index

Stifle joint, 369
craniocaudal view, 376f–378f
medial aspect, patella (displacement),
376f–378f
mediolateral projection, 428f–432f
mediolateral view, 376f–378f, 381f–385f
osteochondrosis, 393
radiologic signs, 393
radiologic signs, 369
subluxation, 376f–378f
Stomach, 75–94
abnormalities, 83–94
air distention, 74f–77f
alpha agonists, avoidance, 77
anatomy, 75–76
anticholinergic drugs, avoidance, 77
appearance, 79–80, 80f–82f
body air, soft tissue circular opacity, 83f–85f
bubble, 79
compartmentalization, 86
complete torsion, 86
contrast study, 79
visualization, 79
CT gastrography, 79
dilation, 84–85
torsion, inclusion, 85
displacement, 43f–46f, 87–88
methods, 87–88
distensibility, loss, 88
dorsal displacement, 58f–61f
dorsoventral views, 80f–82f
requirement, 77–78
double contrast studies, left lateral recumbent/
ventrodorsal views, 80f–82f
dynamic function (evaluation), fluoroscopy
(requirement), 79–80
edema, radiolucent halo, 88
emptying time, 79
enlargement, 91
fasting, 81–82
fluoroscopy, requirement, 79–80
foreign bodies, 83–84
movement, 83
ultrasonography, 83–84
gross distention, 93f–94f
high-resolution 7.5-MHz transducer, requirement, 82
linear plastic foreign body, 83f–85f
lower frequency transducer, usage, 82–83
negative contrast, 79
negative radiographic examination, 88
neoplasia, 88
radiologic signs, 88
nonionic agents, preference, 78–79
oblique views, requirement, 77–78
opioids, avoidance, 77
outline, failure, 88
perforation, suspicion, 78–79
radiography, 77–79
double contrast, 79
negative contrast, 79
positive contrast, 77–79
radiologic signs, 86–87
radiopaque plastic foreign body, appearance,
83f–85f
right lateral recumbency, 79
usefulness, 81–82
shape, 75–76
sonograms, 11f–13f
transverse colon, relationship, 110
ultrasonography, 80–83
ventrodorsal view, 80f–82f
wall
localized rigidity, 88
ventral abdomen, gas bubbles (presence),
86f–87f
Stress
fracture, 401
indication, 400f
Stressed studies, 353

String foreign bodies, 97
String sign, 92
Strong echo returns, 14
Structured interstitial pattern, 225
Subaortic stenosis, 307, 309f–310f
Subarachnoid cyst, 533
Subarachnoid space
contrast medium, injection, 503
spinal cord neoplasm, impact, 530
Subchondral bone cyst, location, 437
Subcostal approach, 216–217
Subcutis, calcium deposit, 543
Subject density, 1
Sublingual duct, 487f–488f
rupture, contrast medium (leakage), 489f–490f
Sublingual gland, components, 486
Subluxations (partial dislocations), 361
Superior, definition, 6
Superior caval syndrome, 342
Supinator sesamoid, 352f–353f
Suture lines
fractures, differentiation, 452
presence, 461f
Swallowed air, presence, 97
Syndesmitis ossificans, 516
Synovial facet joints, cystlike lesions, 516–519
Synovial fluid, radiographic visibility (absence),
361
Synovial joint (diarthrodial joint), 360
Synovial neoplasia-joint tumors, 432
Synovial osteochondromatosis, 384–385
Syringomyelia, 510–511
Systemic aspergilliosis, 287f–289f
Systemic Aspergillus infection, rarity, 437
Systemic hypotension, 129–131
Systemic lupus erythematosus (SLE), 384

T

Talus, 379f–380f
Tarsus, congenital anomalies, 406f
Teat sign, 92
Technetium-99m pertechnetate, usage, 47
Teeth, 482f
abnormalities, 481–486
alveolar bone, rarefaction, 483
appearance, 481
fracture, 485–486
malocclusion, 484f–485f
neoplasia, 486
number, variation, 481
radiography, 481
root remnants, presence, 485
socket (alveolus), 481
ventrodorsal position, 481
ventrodorsal view, 481
Telencephalon, 487–488
Temporal bones, new bone formation, 462f–463f
Temporomandibular arthrosis, 453
Temporomandibular dislocation, 452–453
lateral oblique views, 452
open-mouth rostrocaudal view, 452
Temporomandibular dysplasia, 453
Temporomandibular joint, 456f–457f
dislocation, diagnosis, 452
osteoarthrosis, 453
Tension pneumothorax, 266f–268f
Terminal trachea, elevation, 304
Terrier
bone removal, 74f–77f
lameness, 36f–39f
lethargy/depression, 28f–29f
ribs, subcutaneous swelling, 36f–39f
right nasal cavity, dorsal/transverse/MRI
studies, 471f–473f
Testes, 172–175, 561
abnormalities, 173–175
anatomy, 172
appearance, 176f–179f
atrophy, 174

Testes (Continued)
enlargement, 173
neoplasia, 173
ultrasonography, 173
orchitis, 175
radiography, 172
retention, 174
ultrasonography, 174
sagittal/transverse sonograms, 176f–179f
scrotal hernia, 175
torsion, 174–175
ultrasonography, 172–173
Testicle
caudal displacement, sonogram, 176f–179f
retention, 176f–179f
Tetralogy of Fallot, 317–318, 319f
radiologic signs, 318
ultrasonography, 318
TGC sliders, example, 11f–13f
Third metacarpal bone, coccidioidomycosis,
428f–432f
Thoracic aorta, 286, 290f–297f
visualization, 224
Thoracic cavity, 208
ultrasonographic examination, 216
Thoracic vertebrae, 497, 501–502
calcified disk, 515f–516f
narrowing, 498f–501f
new bone formation, 537f
ventral aspects, 74
Thoracic wall, 278
Thorax, 199, 560
appearance, 68f–72f, 210f–216f, 214–216
dorsoventral view, 250f–255f
features, 221
lateral aspect, fascial planes (displacement),
551f–552f
lateral radiograph, 210f–216f
lateral views, 202, 222f–223f, 344f–346f
mass lesion, diagnosis, 275f–278f
radiographs (background opacity), skin
(impact), 208
radiolucency, increase, 266f–268f
ultrasonography, 216–217
ventrodorsal views, 202
Thrombus, presence, 126
Thymic lymphosarcoma, 278
ultrasonography, 278
Thyroid adenomas, presence, 546–547
Thyroid carcinomas, presence, 546–547
Thyroid glands, 545–547
location, 546
ultrasonography, 546–547
Thyroid scintigraphy, 555f–556f
Tibetan terrier, soft tissue swelling, 559f
Tibial tarsal bone, 379f–380f
Tibiotarsal joint, luxation, 379f–380f
Time gain compensation (TGC), 11–12
Tissue
biopsy, methods, 551–552
fine-needle aspiration, 16
sound transmission, characteristic, 12
sound velocity, 10
structures, ultrasonographic examination, 551
ultrasound beam, interaction, 17
ultrasound interaction, 10–12
Tomography, usage, 131
Torsion, 55, 84–87
splenic vein thrombosis, 55
ultrasonography, 55
Torus fracture, 400
Toxoplasmosis, 235
Trabecular pattern
change, 360
loss, 442
Trabeculations, presence, 354f–355f
Trachea, 202–208
abnormalities, 202–208
anatomy, 202
appearance, 202, 203f


Ultrasound (Continued)
Doppler ultrasonography, 14–16
high-frequency sound waves, 10
machine, operation, 20
performing, avoidance, 16
production, 10
technique, 16
tissue interaction, 10–12
transmission, body tissue density (impact), 10
waves, generation, 10
Ultrasound beam
attenuation, 11
generation, 206
interface, 19f
production, 10
strength, decrease, 11–12
Ultrasound-guided aspiration, 551–562
Ultrasound-guided biopsy, usage, 163–164
Ultrasound-guided needle biopsy, usage, 163–164
Ultrasound-guided portal scintigraphy, 49–57f
Ultrasound-guided pyelography, 147–148
Umbilical hernias, 36
Unilateral pneumothorax, 265
Unstructured interstitial pattern, 225
Untreated fracture, repair (stages), 418f
Ununited anconeal process, 389
radiologic signs, 389
Ununited medial humeral epicondyly, 393
Updating, increase, 14
Upper incisive, intraoral view, 482f
Upper jaw, right fourth premolar/fifth molar (displacement), 458f–460f
Upper limb, swelling, 559f
Urachal remnant, 169
Urinary bladder
appearance, 170
anatomy, 169–170
opacification, 173f–174f
Postpartum uterus, enlargement, 185
pregnancy, 181–184
pyometra (pyometritis), 185–188
transducer usage, 184
ultrasonography, 189–190
Urethra, 169–172
neoplasia, 171–172
ultrasonography, 172
polyps, 168f–169f
radiography, 170
rupture, 170
urologic catheter passage, impact, 173f–174f
stenosis, 170–171
appearance, 173f–174f
ultrasonography, 170
ureterography, 170
urine/seminal secrections, transportation, 169–170
Urothelial calculi, 170
identification, 161
Urethrogram, 170
Urinary bladder calculi, 170
midline/ventral abdominal ultrasound images, 162f–166f
mineral opacities, 171f–172f
sagittal plane, 162f–166f
sagittal/transverse ultrasound images, 160–161f
Urinary catheter, usage, 152
Urinary system, 126
Urine, expulsion, 144
Uterine horn, sonogram, 181–184
Uterine neoplasms, identification, 190
Uterus, 181–190
abnormalities, 185–190
anatomy, 181
appearance, 181–184
dystocia, 185
ectic pregnancy, 190
fetal death, 189–190
appearance, 190f–191f
ultrasonography, 189–190
genital tract, nonvisualization, 181
granuloma, 188–189
ultrasonography, 189
mummification, 189–190
ultrasonography, 189–190
neoplasia, 190
ultrasonography, 190
postpartum uterus, enlargement, 185
pregnancy, 181–184
pyometra (pyometritis), 185–188
ultrasonography, 187–188
transducer, usage, 184
ultrasonography, 184–185
Uterus, fluid (presence), 168
V
Vaginal masses, 192
rectal displacement, 194f
Valentine heart, 329
Valgus deformity, 393, 395–398
Vascular calcification, 124
Vascular system, congenital anomalies, 72–73f
Vascular rings, 70–71
anomalies, 70–72, 73f
Vascular system, congenital anomalies, 70–71
Vena angularis oculi, 491
Vena cava
appearance, 87
diameter, reduction, 310
Venography, 506
Ventral, definition, 5
Ventral abdomen, sagittal sonogram, 176f–177f
Ventral hernia, 34
Venital, neck, air (visibility), 553f–554f
Venricular septal defect, 314–315, 315f–316f
radiologic signs, 314–315
ultrasonography, 315
Ventricular system, dilatation, 491–492
Index

Ventriculography, 491
- contrast medium, injection, 491

Ventrodorsal (VD) radiograph, placement, 7

Ventrodorsal (VD) view, 6

Vertebrae, 496–497, 498f–501f
- abnormalities, 509f–511f
- anomalies, 508–510
- appearance, 506
- butterfly appearance, 506
- conditions, 511–513
- dislocations, 531f–533f
- end plates, sclerosis, 514
- fractures, 531f–533f
- hemivertebrae, 506
- hypervitaminosis, 530
- luxations, 530
- mucopolysaccharidosis, impact, 530
- neoplasia, 530
- new bone formation, 520f–521f, 530
- osteomyelitis, impact, 521
- radiologic signs, 530
- sclerosis, 513
- spinal development mechanisms, 508
- subluxations, 530

Vertebral abnormalities, 519

Vertebral arteries anastomose, 490

Vertebral body, compression fracture (impact), 527

Vertebral column, 447, 496–513
- abnormalities, 505–513
- anatomy, 496–503

Vertebral column (Continued)
- appearance, 506
- arrest, 534f–535f
- atlantoaxial subluxation, 506
- contrast techniques, 502–503
- developmental anomalies, 506
- discography, 506
- epidurography, 506
- fractures, 527–530
- infection, 521
- venography, 506
- Vertebral fractures, 531f–533f
- Vertebral heart scale, 298
- Vertebral malalignment, flexed/hyperextended lateral radiographs, 519

Vertebral malalignment, flexed/hyperextended lateral radiographs, 519

Vesicoureteral reflux, 155

Viable fractures, 408–409

Views, variety (necessity), 2f

Villonodular synovitis, 384

rarity, 384

Viral enteritis, 107

Viral pneumonia, 235

Volvulus (torsion), 84–87

radiologic signs, 86–87

right lateral recumbent view, 85–86

W

Water-soluble positive contrast agents, classes, 7

Weimaraner
- cataracts, 479f–480f
- dirofilariasis, 338f–341f

Weimaraner (Continued)
- eyes, transverse sonographic examination, 479f–480f
- West Highland White Terrier, new bone formation, 462f–463f
- Whippet, pulmonary infiltrates with eosinophils, 236f–244f
- Windowing, 8–9
- Wire Fox Terrier, tuberculosis, 236f–244f
- Wobbler syndrome, 516–520
- Wolfhound puppy, hiatal hernia, 36f–39f
- Woven bone (immature bone), 352

X

X-ray beam, direction, 6

X-ray pattern, 8

Y

Yorkshire Terrier
- kidneys, appearance, 125f–131f
- polydipsia/polyuria/calcification, 544f–548f

Z

Zollinger-Ellison syndrome, 65

Zygomatic gland, location, 486