Multidetector CT of Midfacial Fractures: Classification Systems, Principles of Reduction, and Common Complications

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The advent of titanium hardware, which provides firm three-dimensional positional control, and the exquisite bone detail afforded by multidetector computed tomography (CT) have spurred the evolution of subunit-specific midfacial fracture management principles. The structural, diagnostic, and therapeutic complexity of the individual midfacial subunits, including the nose, the naso-orbito-ethmoidal region, the internal orbits, the zygomaticomaxillary complex, and the maxillary occlusion-bearing segment, are not adequately reflected in the Le Fort classification system, which provides only a general framework and has become less relevant in contemporary practice. The purpose of this article is to facilitate the involvement of radiologists in the delivery of individualized multidisciplinary care to adults who have sustained blunt trauma and have midfacial fractures by providing a clinically relevant review of the role of multidetector CT in the management of each midfacial subunit. Surgically relevant anatomic structures, search patterns, critical CT findings and their management implications, contemporary classification systems, and common posttraumatic and postoperative complications are emphasized.

Abbreviations: NOE = naso-orbito-ethmoidal, ORIF = open reduction and internal fixation, ZMC = zygomaticomaxillary complex

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Introduction

Midfacial fractures fall into predictable patterns, yielding a unique set of management principles for each subunit of the midface, including the nose, the naso-orbito-ethmoidal (NOE) region, the internal orbits, the zygomaticomaxillary complex (ZMC), and the maxillary occlusion-bearing fragment. Treatment is guided by a subunit-specific risk-benefit calculus aimed at restoring the preinjury facial symmetry, width, height, and anteroposterior

SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe the most common and surgically relevant systems of fracture classification for each midfacial subunit.
- Identify CT features that guide management, and recognize best practices in the utilization of axial, multiplanar reformatted, and three-dimensional volume-rendered images.
- Discuss the key limitations of multidetector CT in guiding management.

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TEACHING POINTS

■ Septal fractures and dislocations cause the upper lateral cartilages to exert deforming forces on fractured nasal bones during healing, and up to 50% of patients with initially successful closed reduction develop malunion requiring septorhinoplasty.

■ The five cardinal tracts of the NOE region follow multiple curving planes, hindering mental integration and resulting in frequent misdiagnoses if three-dimensional volume-rendered CT images are not used. However, the thin floor and the medial wall are volume averaged on volume-rendered CT images and are best depicted on coronal multiplanar reformat ted images and axial CT images, respectively.

■ CT features of defects at high risk for clinically important late enophthalmos include (a) a surface area greater than 2 cm², (b) more than 25%–50% orbital floor or medial wall involvement, (c) collapse of the junctional bulge and internal orbital buttress, and (d) soft-tissue herniation with volume displacement greater than 1.5 mL.

■ The zygomaticosphenoid suture, a component of the lateral wall of the internal orbit, is rarely used as a fixation point; but displacement, telescoping, or angulation at this site is the most sensitive CT indicator of overall ZMC malalignment and orbital volume changes.

■ The primary management goal for occlusion-bearing maxillary fractures is to prevent handicapping malocclusions by restoring the pretrauma alignment of the maxillary and mandibular dental arches (the occlusion) by using maxillomandibular fixation with arch bars and wires. Even 2–3-mm malocclusions result in impairment, whereas 2–3-mm bone gaps along the maxillary buttresses are of little clinical consequence.

Anatomy

The nose is the most frequently fractured facial subunit and is involved in more than half of facial fractures (1). The two nasal bones articulate with the frontal bone and the frontal process of the maxilla at the frontonasal and nasomaxillary sutures, respectively, forming the bony nasal pyramid (Fig 2a). The nasal septum acts as a keystone for the bone-cartilage framework of the nose, maintaining dorsal and tip projection, symmetry, and airway patency (1–4). The quadrangular septal cartilage, anchored by the bony septum and the anterior nasal spine (Fig 2b), articulates with and maintains the symmetric alignment of the upper lateral cartilages (4,5) (Fig 2c). Because septal cartilage fractures more readily than bone, minimally displaced fractures at CT belie the true injury severity (2). Septal fractures and dislocations cause the upper lateral cartilages to exert deforming forces on fractured nasal bones during healing, and up to 50% of patients with initially successful closed reduction develop malunion requiring septrhinoplasty (1–3,6). Direct trauma to the septal cartilage, extensive mucosal injury, and septal hematomas, which elevate the vascular mucoperichondrium, can all result in septal necrosis and collapse, with saddle nose deformity (6,7). Although nasal fractures are often discounted as minor, all nasal fractures should be considered nasoseptal injuries that put the patient at risk for permanent disfigurement.

CT Evaluation Pearls

Axial CT images miss 25% of nasal pyramid fractures, and minimally displaced or transversely oriented fractures are easily overlooked. Sagittal multiplanar reformatted images are 85%–99% sensitive for these injuries and should be routinely used (8). Three-dimensional volume-rendered CT images are of little added diagnostic utility in the absence of NOE region involvement (8–10). Septal hematomas, which are often obscured by blood in the nasal cavity, are rarely evident at CT. Pyramidal bone, anterior nasal spine, and bony septal fractures can all be subtle and easily missed (Fig 3). Identification of any of these injuries should trigger a speculum examination of the...
patterns, such as Rhee grade 2 or higher septal injuries or Stranc grade 3 injuries with fracture-dislocations of the bilateral frontal processes, closed reduction often requires a combination of digital manipulation, elevators for disimpaction, and forceps for septal straightening, followed by the use of temporary nasal splints. Open reduction is rarely performed, because this procedure risks disrupting the already compromised septal vascular supply (1,2).

Grading and Management
In 1979, Stranc and Robertson (11) introduced a mechanism-based classification system in which fractures involve either lateral-oblique or frontal force vectors. Lateral-oblique fractures can entail unilateral nasal pyramid depression (grade 1); lateral displacement of the contralateral nasal bones (grade 2); or displacement of both frontal maxillary processes (grade 3) (Fig 4). Frontal fractures are less common and are graded on the basis of the depth of injury in the coronal plane. Cartilaginous septal fractures anterior to the nasal bones and maxillary spines (grade 1) are not apparent at CT, but those with some flattening of the bony pyramid (grade 2) or with severe pyramid collapse with septal shortening (grade 3) can be characterized (Fig 5).

Rhee et al (2) introduced a CT grading system that was based on the degree of septal deviation. The septum can be classified as grade 0, straight; grade 1, deviated less than half the distance to the turbinates; grade 2, deviated more than half of this distance; or grade 3, touching or almost touching the turbinates. In grade 2 and 3 injuries, the septum assumes a bowed C-shape. The grade is commonly increased on the basis of the intraoperative findings (2). Additional patterns of increasing severity described by Rhee et al (2) include displaced linear (L-shaped) fractures (Fig 5), a segmented stepladder configuration, and severe comminution (2). Severe bony septal injury commonly occurs with NOE fractures (1,6).

Practitioners generally favor closed reduction for most injuries. For more severe fracture patterns, such as Rhee grade 2 or higher septal injuries or Stranc grade 3 injuries with fracture-dislocations of the bilateral frontal processes, closed reduction often requires a combination of digital manipulation, elevators for disimpaction, and forceps for septal straightening, followed by the use of temporary nasal splints. Open reduction is rarely performed, because this procedure risks disrupting the already compromised septal vascular supply (1,2,6,12).

NOE Fractures
NOE fractures result from high-energy blunt trauma and are the most difficult midfacial injuries to diagnose and manage (13–16). Isolated NOE fractures are uncommon; up to 60% of NOE fractures are associated with ZMC fractures, and 20% are associated with panfacial fractures (13).

Anatomy
All NOE fractures are made up of a single or comminuted central fragment liberated along five key fracture lines, or “cardinal tracts” (17–20). The five fracture lines involve (a) the lateral nose and piriform aperture, (b) the nasomaxillary buttress, (c) the inferior orbital rim and floor, (d) the medial orbital wall, and (e) the frontomaxillary suture (Fig 6). Diagnosis of an NOE fracture requires identification of at least four of the five cardinal tracts to distinguish NOE fractures from other fracture patterns involving the maxilla and orbits. The anterior and posterior limbs of the medial canthal tendon form as a result of fusion of the eyelid tarsal plates and orbicularis oculi muscles and insert on the lacrimal crests bordering the lacrimal fossa (14,15,21) (Fig 7). Lateral displacement of the central fragment or medial canthal tendon disruption causes telecanthus, or blunting and shortening of the medial palpebral fissure.
Laterally displaced NOE fragments displace the globes, causing hypertelorism. Associated dorsal nasal collapse is common (14,22).

NOE fractures frequently involve the nasolacrimal duct, the frononasal duct, and the frontal sinuses, with impairments in tear and mucociliary drainage. The nasolacrimal duct is encased by the frontal process of the maxilla, emptying into the nasal cavity through the inferior meatus (23,24) (Fig 8a). The frononasal duct is variable in length, extending from the frontal sinus floor through the anterior ethmoid labyrinth, to the ostiomeatal complex and the hiatus semilunaris (25–27) (Fig 8b, 8c).

CT Evaluation Pearls
Facial swelling camouflages deformities at physical examination (13,22), and diagnosis and grading are heavily dependent on CT findings. Because CT does not directly depict the medial canthal tendon, imaging is complemented by direct interrogation for mobility,
wherein the surgeon applies tension on the lower lid (13,14,28). The five cardinal tracts of the NOE region follow multiple curving planes, hindering mental integration and resulting in frequent misdiagnoses if three-dimensional volume-rendered CT images are not used. However, the thin floor and the medial wall are volume averaged on volume-rendered CT images and are best depicted on coronal multiplanar reformatted images and axial CT images, respectively (17).

The frontal sinuses are best assessed on axial CT images (14). Intrusion of the nasal dorsum into the anterior ethmoid complex on axial CT images is highly suspicious for frontonasal duct occlusion (22,26,27). Sagittal CT images depict the frontonasal duct in profile and correlate particularly well with intraoperative findings of obstruction, occlusion, or patency of this structure (27) (Fig 9). On the whole, CT has facilitated a more-conservative selective management-based approach to these injuries (26,29,30).
Figure 7. Anatomy of the NOE region. (a) Three-dimensional volume-rendered CT image shows the relationship of the soft tissues forming the suspensory sling of the globe to the lacrimal crests (thick open arrow), on which the medial canthal tendon inserts. The suspensory sling is comprised of the orbicularis oculi muscles and the eyelid tarsal plates, which are sheets of dense connective tissue within the eyelids (*). These structures condense medially to form the medial canthal tendon (thin solid arrows demarcate the approximate location). Disruption of the medial canthal tendon results in shortening and blunting of the palpebral fissure (the space between the upper and lower lids). (b) Photograph of a cadaveric dissection shows the anterior and posterior limbs of the medial canthal tendon inserting on their respective lacrimal crests (arrows). The anterior crest arises from the posterolateral aspect of the frontal maxillary process, and the posterior crest originates from the orbital surface of the lacrimal bone. The crests surround the lacrimal fossa, which seats the lacrimal sac.

Figure 8. Normal imaging appearance of the anatomic structures frequently involved in NOE fractures. (a) Coronal CT image shows passage of the right and left nasolacrimal ducts (arrows) from the lacrimal fossae, through the frontal maxillary process, to the inferior meatus, which empties below the inferior turbinate (*). (b, c) Coronal (b) and sagittal (c) CT images show the frontonasal ducts (thin solid arrow = left duct). On each side, the frontonasal duct extends from the frontal sinus floor to the infundibulum of the ostiomeatal complex, a confluence with the ostia of the maxillary sinus (* = left ostium) and the anterior and middle ethmoid air cells. The infundibulum extends posteriorly into the hiatus semilunaris, the final drainage pathway into the nasal cavity (thin open arrow on c). Sagittal CT images have the greatest utility for assessing the patency of the frontonasal duct after NOE fractures.
Grading and Management
Treatment goals involve restoring the preinjury canthal position, nasal projection, lacrimal drainage, and mucociliary clearance (13). Central fragment stability is a key determinant of the treatment plan, and central fragment reduction may be sufficient to restore normal function and aesthetics (14,17); however, management is also guided by the status of the nasolacrimal duct, the frontonasal duct, and the frontal sinuses.

In rare cases, an incompletely fractured central fragment “greensticked” at one of the five cardinal tracts (where the periosteum is still intact) can be nonmobile and nondisplaced, requiring no intervention (17). All other fractures are treated with open reduction and internal fixation (ORIF) (13).

Markowitz-Manson Classification
The Markowitz-Manson classification is universally used for grading the severity of central fragment disruption (19). Grade 1 injuries are single fragments with cardinal tracts forming the perimeter; grade 2 injuries are comminuted but without undermining of the medial canthal tendon insertion; and grade 3 injuries are severely comminuted—either there is avulsion of the medial canthal tendon, or the tendon is attached to a small fragment that cannot be incorporated into stable plate-and-screw fixation (19).

ORIF is performed along three common fixation points: the nasomaxillary buttress, the inferior orbital rim, and the frontomaxillary suture. Additional low-profile plates are sometimes placed across the frontonasal suture to provide dorsal nasal support (Fig 10). Grade 1 fractures may be stable after single-plate fixation of the nasomaxillary buttress with use of a cosmetically favorable transoral incision through the upper gingivobuccal sulcus (Fig 11). If additional fixation is needed, transconjunctival lid incisions provide access to the inferior orbital rim. Figure 12 shows common surgical approaches used for ORIF of midfacial fractures.

Grade 2 injuries with largely intact medial canthal tendon–bearing segments can be reconstructed with plates and screws (Fig 13), which can also be used to bridge short segments of comminution and bone loss (14). Coronal incisions behind the hairline are used for severe NOE fractures because such incisions allow (a) plating of the frontomaxillary junction and frontonasal suture; (b) harvesting of cantilevered dorsal nasal bone grafts from the parietal calvaria; (c) internal orbital reconstruction and
All grade 3 injuries require canthopexy (14,19). Canthopexy involves securing wires to the medial canthal tendon, which are passed contralaterally through drill holes in the lacrimal bones and attached to stable frontal bone or hardware (15) (Fig 14).

Dorsal nasal bone graft augmentation is required in up to 31%–42% of grade 3 fractures because of severe collapse of the cartilage-bone framework of the nose (14,19). Cantilevered grafts affixed to stable bone at the nasofrontal junction or the reconstructed frontal bar (frontal bone and supraorbital rims) restore nasal projection and reduce the perception of telecanthus (14,22) (Fig 15).

Complications include late deformity, which is difficult to correct because of scar contracture (15,16,31). Canthopexy has an unavoidably high failure rate, leading to late telecanthus and globe malposition (16,22,32). Grade 3 injuries are associated with high rates of mucociliary and lacrimal functional impairment (16).

Management of NOE-related frontal sinus and frontonasal duct disruptions is complex and controversial (25). Complications are common with transnasal canthopexy; and (d) wide access to associated ZMC fractures (13,16,22).

Transnasal wire canthopexy is required in more severely comminuted grade 2 injuries in which the medial canthal tendon–bearing segment is too small for stabilization along the three common fixation points (15). All grade 3 injuries require canthopexy (14,19). Canthopexy involves securing wires to the medial canthal tendon, which are passed contralaterally through drill holes in the lacrimal bones and attached to stable frontal bone or hardware (15) (Fig 14).

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Frontal Sinuses and the Frontonasal Duct
both conservative and surgical treatment strategies and can arise days to years after the initial insult (25,29,33,34). Outer table fractures are treated for cosmetic reasons with plates or mesh when there is more than one table width of depression (29,33), whereas the status of the frontonasal duct and the posterior table is predictive of suppurative complications (35). Untreated frontonasal duct obstructions result in mucopyoceles in up to 50% of patients (29,36), which can cause expansile bone remodeling (Fig 16), osteomyelitis, hardware infection, meningitis, and brain abscesses (29,37). Persistent dural disruption with or without frontonasal duct obstruction provides a pathway for intracranial infection (25,29).

**Preservation of a Functional Safe Sinus**
If the frontonasal duct is obviously disrupted at preoperative CT or if there is uncertainty with regard to patency after evaluation in multiple planes, intraoperative irrigation is performed with methylene blue dye (26). When the dye passes easily, open reduction of the NOE fragment alone is usually sufficient, which allows preservation of a functional “safe sinus” (14,25). If the posterior table is nondisplaced after reduction, CT is performed after surgery, and the patient is monitored expectantly for resolution or recurrence of cerebrospinal fluid rhinorrhea (31,33).

**Frontal Sinus Obliteration and Cranialization**
If failure of dye passage confirms frontonasal duct obstruction but the posterior table is relatively intact, the frontal sinus is obliterated. Involvement of more than 25% of the posterior table has been proposed as a CT-based threshold for performing cranialization (29,36,38). Obliteration and cranialization both involve drilling out all sinus mucosa to create a nonfunctioning safe sinus. The frontonasal duct is sealed with some combination of fascial plugs, pericranium, fibrin glue, or

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**Figure 14.** Left grade 3 NOE fracture in a 33-year-old man after a motor vehicle collision. (a) Postoperative three-dimensional volume-rendered CT image shows that the central fragment is severely comminuted and disorganized, with numerous small fragments only partially incorporated into the nasomaxillary buttress (1) and inferior orbital rim (2) plate fixation. Arrow = canthopexy wire. (b) Coronal thick-slab CT image shows the course of the transnasal canthopexy wire (arrows), which is anchored to the nasomaxillary buttress plate and secured to a screw in the contralateral right frontal bone.

**Figure 15.** Panfacial injuries, including a grade 3 NOE fracture, in a 55-year-old woman after a motor vehicle collision. Three-dimensional volume-rendered CT image shows that dorsal nasal augmentation was performed with a cantilevered bone graft (arrow) fixed with a miniplate to the reconstructed frontal bone.
cancellous bone chips to ensure isolation from the nasal cavity (25,29,31). Obliteration involves packing the frontal sinus with autogenous fat and fascia (Fig 17). Biomaterial such as absorbable gelatin sponge (Gelfoam; Pfizer, New York, NY) can be used to cover small posterior table defects and promote dural closure. Eradication of mucosa and sealing of dura are not possible when there is heavy posterior table comminution at CT, necessitating cranialization (33). This procedure involves posterior table ablation and placement of a pericranial flap between the brain and the anterior table (25,29,33) (Fig 18). Traumatic brain injury requiring frontal craniotomy is a relative indication for cranialization (29).

Preoperative CT has several notable limitations. The amount of anteroposterior displacement of the posterior table does not appear to correlate with the risk of persistent dural defect, because use of ORIF facilitates apposition of the dura, which promotes spontaneous closure (14,29). If cerebrospinal fluid rhinorrhea persists, then cranialization is warranted regardless of the CT appearance. Figure 19 shows an algorithm for the role of CT in surgical decision making for fractures involving the frontonasal duct or frontal sinus posterior tables (36,38). Repeat CT examination at 6-month intervals can be used to monitor for late complications after obliteration or cranialization (29), and a single follow-up CT examination may be performed at 1–3 months after surgery to reassess frontonasal duct patency and sinus aeration if the sinus is preserved (33).

**Nasolacrimal Duct**

Nasolacrimal duct obstruction after NOE fractures usually occurs with delayed treatment (24,39), and early NOE repair greatly reduces the risk (23,24,40). CT evidence of nasolacrimal duct disruption at preoperative imaging is not useful for decision making because patency of the canal is often restored with ORIF (23). Soft-tissue swelling and friability may increase the risk of injury from lacrimal intubation, and no invasive treatment is undertaken in the early postoperative period (23,40).

Even in the presence of severe nasolacrimal duct comminution, patients often develop no symptoms of nasolacrimal duct obstruction (23). Radiologists are frequently unaware that neither pre- nor postoperative CT has much prognostic value for nasolacrimal duct obstruction and that the diagnosis is essentially clinical; chronic epiphora (tearing), dacryocystitis, and recurrent dacycystoceles result not only from disruption of the bone forming the nasolacrimal duct, but also from lacrimal duct or sac scarring, as well as canalicular damage (24,40). Symptoms lasting more than 3–6 months are
assessed by using dacryocystorhinography with a dye marker (40). Confirmed nasolacrimal duct obstruction can be treated with creation of a large (>1 cm) external dacryocystorhinostomy in the frontal maxillary process with temporary stent placement, which is successful in up to 94% of cases (24,40) (Fig 20). The utility of CT is primarily relegated to evaluation of delayed complications such as an infected dacryocystocele (Fig 21).

**Orbital Fractures**

From 10% to 30% of facial fractures involve the orbit (41,42). Orbital fractures are not clinically obvious in unconscious patients with facial swelling (43); and diagnosis, prognostication, and treatment planning rely heavily on the findings at CT (41,42). Orbital fractures can be **pure**, defined as those limited to the internal orbit, or **impure**, defined as those with orbital rim involvement requiring realignment before reconstruction of the internal orbit (41). More than 80% of pure internal orbital fractures are **blow-out** fractures involving the medial wall or orbital floor (44). Lateral wall involvement is a hallmark of ZMC fractures. Roof fractures are impure, are displaced in up to 95% of cases, and are often components of skull base fractures, requiring multidisciplinary facial reconstructive and neurosurgical management, a discussion of which is beyond the scope of this article. A number of references are provided for further reading (45–47).

**Anatomy**

The orbital surface of the maxilla and the ethmoid bone contribute to the floor and medial wall and articulate with the lacrimal bone in the NOE region (Fig 22a). The medial wall and roof of the maxillary sinus, which is contiguous with the anterior cranial fossa, is composed of thin cortical bone. CT is useful for detection of nasolacrimal duct obstruction, confirming nasolacrimal duct obstruction can be treated with creation of a large (>1 cm) external dacryocystorhinostomy in the frontal maxillary process with temporary stent placement, which is successful in up to 94% of cases (24,40) (Fig 20). The utility of CT is primarily relegated to evaluation of delayed complications such as an infected dacryocystocele (Fig 21).
join at the frontoethmoidal suture, an important landmark for implant positioning and the site of the anterior and posterior ethmoidal artery foramina—two common sources of retrobulbar hematomas (42). The medial wall of the orbit articulates with the orbital floor and the medial wall of the maxillary sinus to form a thick septum called the internal orbital buttress (44). This critical support structure fans out posteriorly into the delicate convex junctional bulge, which maintains forward globe projection (Fig 22b). At the apex, the lesser wing of the sphenoid supports the orbital plate of the palatine bone (Fig 22a), forming the posterior ledge used to seat orbital implants (41).

**CT Evaluation Pearls**
Most suboptimal reconstructions result from failure to appreciate the full extent of injury at CT (41,48). Three-dimensional volume-rendered CT images have little utility owing to volume averaging (42), and the orbit should be evaluated in three orthogonal planes. Coronal CT images have the greatest overall utility for assessing defect size, the direction of fractures, and changes in orbital shape and volume (42,47). Axial and sagittal CT images help delineate the posterior defect margin. CT images with soft-tissue windowing depict the relationship of the extraocular muscles and fibrofatty tissue to fractured segments (41).

**Grading and Management**

**Orbital Blow-out Fractures.**—CT paved the way for a more conservative selective management approach to blow-out fractures, with the rate of orbital exploration decreasing from 90% in 1985 to 30% in 1989 (49–52). Surgical risks and appropriate timing are considered after weighing both CT and clinical findings. Exploration is only appropriate when the risks of long-term complications from nonintervention—namely, enophthalmos, or diplopia and motility restriction—exceed those of surgery (41,42,48,53,54). The rate of occurrence of lid deformities—including ectropion (lid eversion), entropion (lid inversion), and scleral show—is as high as 20% with skin lid incisions and has decreased with transconjunctival incisions but remains nontrivial (42,55). Iatrogenic extraocular muscle injury can cause entrapment and strabismus. Surgical optic nerve injury is rare but devastating (42,48).

Surgical timing for orbital fractures that do not involve major injury to the globe is divided into three categories: (a) immediate repair, (b) semidelayed repair at 7–14 days, and (c) observation, with the possibility of late repair. Semidelayed repair is performed in a critical window after improvement of posttraumatic edema (which limits surgical exposure and increases the risk of globe injury from retraction) but before onset of fibrosis and permanent architectural changes (41,42). Although CT findings associated with major globe injury are not discussed, vision always takes precedence over aesthetics (41,56).Fracture repair may need to be delayed in the setting of major globe injury; for example, corneoscleral lacerations require healing after suture closure to prevent vitreous leak and globe collapse during retraction (41).

**Enophthalmos.**—In orbital blow-out fractures, the bony orbital volume expands as a result of outfracture of the walls and is initially matched...
by volume expansion from hemorrhage and edema of the internal orbital contents, masking all but the most severe cases of enophthalmos (Fig 23). Once the swelling resolves, the contents of the untreated orbit subside to near baseline volume while the walls remain expanded, causing insidious recession of the globe over a period of weeks to months (41,42,44,48,57). Treatment of established enophthalmos is challenging (48). Therefore, in patients at risk for developing noticeable enophthalmos (2–3 mm), reconstruction is performed in a semidelayed fashion before architectural changes have set in, to restore the preinjury orbital shape and volume (41,44,48).

Because the findings at clinical examination during the crucial first 2 weeks after trauma often do not reveal enophthalmos as a complication of a blow-out fracture, CT-based prediction is the cornerstone of surgical decision making (41) (Figs 23, 24). CT features of defects at high risk for clinically important late enophthalmos include (a) a surface area greater than 2 cm², (b) more than 25%–50% orbital floor or medial wall involvement, (c) collapse of the junctional bulge and internal orbital buttress, and (d) soft-tissue herniation with volume displacement greater than 1.5 mL (41,42,44,54,58). A linear relationship between the volume of displaced contents on CT images and the depth of enophthalmos (the “volume-unit principle”) is well documented (44,59–63). Each 1 mL displaced results in 0.8–0.9 mL of enophthalmos (57,60). Rapid volumetric assessment can now complement previously established parameters at the point of care with the use of single-click-access postprocessing software (Fig 24).

**Diplopia and Restricted Motility.**—Connective tissue septa and fat invest muscles, forming an interconnected fibrofatty motility apparatus akin to bubble wrap (44,64). In children, self-reducing trapdoor fractures can directly incarcerate and strangulate the inferior rectus muscle, causing muscle necrosis if exploration is not urgently undertaken (65) (Fig 25a); however, in adults, motility restriction is much more often the result of (a) pure fibrofatty tissue entrapment within...
comminuted, mildly displaced (<3 mm) fragments or (b) catching of fibrofatty tissue against a single ledge of a large defect. This catching causes indirect muscle tethering, deviation, and tractional shape change, manifesting as a hooked or kinked appearance at CT (41,44,50,54) (Fig 25b). Complementary physical evidence includes painful restricted eye movement and positive results of a forced duction test, in which the surgeon pulls the anesthetized conjunctiva with forceps to assess for limited globe excursion.

Both CT and clinical findings are nonspecific shortly after trauma; diplopia is usually self-limiting, owing to temporary muscle paresis and contusion, which causes enlargement and rounding at CT (50,54,66). Because muscle incarceration and necrosis are exceedingly rare in adults, there is usually no surgical urgency. Tethering may resolve as the orbital edema improves, and CT findings must be assessed together with the results of serial examinations (41,42,54). Semi-delayed orbital exploration to free tissue is often performed if (a) CT findings are suggestive of incarceration and (b) diplopia or motility fails to improve with observation (41,42,54).

**Reconstruction.**—Medial wall, floor, and combined blow-out fractures vary with respect to their propensity for enophthalmos or entrapment, the optimal surgical approach, the choice of implant, and surgical complications.

Isolated orbital floor and medial wall fractures can be classified as (a) hinged—in which a bent or greensticked portion of the blown-out fragment remains partially attached by way of intact periosteum, or (b) punched out—in which the entire fragment is liberated. Although medial wall fractures are typically large punched-out defects (Fig 25b), floor fractures vary in size and can be minimally displaced and hinged, with a greater tendency toward incarceration. Herniation of orbital contents through large defects is common with fractures in both locations (32,42,44,50,67).

Postoperative CT may identify correctable volume changes or entrapment related to the reconstruction, prompting revision (41,42,48). The implant should ideally bridge the entire defect and rest on all ledges (Fig 23b). Prefabricated implants typically come in two sizes, and selection of the appropriate implant is based on estimation of the defect size with CT. Incomplete defect bridging owing to size mismatch or excessive angulation into the ethmoids or maxillary sinuses can cause orbital volume changes or impingement between mesh and bone ledges (41,42,48) (Fig 26).

Large medial wall defects extending to within 1 cm of the optic canal at CT require careful implant placement to avoid optic nerve impingement (41,42,48,54). Rare postoperative complications include retrobulbar hematoma (68) and orbital cellulitis (69). Implant migration or extrusion is extremely rare (54).

Orbital fractures involve a combination of the orbital floor and medial wall in 10%–27% of patients (44,50) and are associated with higher rates of suboptimal reconstruction (42,70). These combined fractures require a greater degree of exposure and can be accessed through lower lid incisions extended medially behind the canthus and lacrimal sac, or laterally in conjunction with lateral cantholysis (41,48).
Combined medial wall and floor fractures are classified into two types on the basis of the status of the internal orbital buttress at CT (44). Approximately 60% of combined fractures are classified as simple, without internal orbital buttress collapse; and 40% of combined fractures are classified as complex, with internal orbital buttress collapse (44). Defects with internal orbital buttress and junctional bulge collapse result in more profound volume changes and inferior globe malposition, or hypoglobus (41,44) (Fig 27). Buttress collapse results in loss of bone landmarks, which increases the difficulty of reconstruction (48) and necessitates use of implants prefabricated with the convex shape of the bulge.

**ZMC Fractures**

**Anatomy**

The prominent zygomatic bone is involved in 17% of all facial fractures (71,72). The tetrapod-shaped ZMC fragment dissociates from the midface at four major points of failure: (a) the zygomatico-maxillary buttress from the inferior margin of the crest to the inferior orbital rim, (b) the zygomaticosphenoid suture along the lateral orbital wall, (c) the frontozygomatic suture of the lateral orbital rim, and (d) the zygomaticotemporal suture of the zygomatic arch (71–73) (Fig 28).

The zygomatic surface of the orbit contributes to the lateral orbital wall and floor, and rotation of the ZMC fragment in any axis can dramatically change orbital volume (42). ZMC fractures produce facial asymmetry and enophthalmos, which are difficult to correct after development of malunion (52,74). Depressed zygomatic arch fractures can also cause restricted mouth opening from mandibular coronoid impingement (71,75). Complications related to plate fixation such as dehiscence, migration, osteomyelitis, and nonunion occur in less than 4% of midfacial fractures. However, suppurative plate complications are more common along the zygomatico-maxillary and nasomaxillary buttresses, because these structures are approached with an intraoral incision (76) (Fig 29).

**CT Evaluation Pearls**

CT is routinely used for pre- and postoperative assessment of ZMC fractures (52,71,72,77). Axial CT images depict malar retrusion, rotation of the zygomaticosphenoid suture and zygomaticomaxillary buttress, and zygomatic arch fractures (52). The zygomaticosphenoid suture, a component of the lateral wall of the internal orbit, is rarely used as a fixation point; but displacement, telescoping, or angulation at this site is the most sensitive CT indicator of overall ZMC malalignment and orbital volume changes (52,71,77). Although the most common sites of fixation are the zygomatico-maxillary buttress, the frontozygomatic suture, and the inferior orbital rim (Fig 30), surgeons place great emphasis on intraoperative supervision of the zygomaticosphenoid suture. Coronal CT images display internal orbital fractures and volume changes, as well as stepoff and comminution of the inferior orbital rim (74,77) (Fig 28). Three-dimensional volume-rendered CT images
simplify grading of fractures (78) and are used to plan the magnitude and direction of forces needed for disimpaction and reduction of the ZMC, typically with the help of a percutaneous bone traction screw.

**Facial Asymmetry.**—Moderate-energy trauma (eg, assaults and low-speed motor vehicle collisions) often results in malar retrusion from a combination of internal rotation of the zygomaticomaxillary buttress and posterior displacement of the zygomatic crest. Lateral or medial angulation and offset about the zygomaticosphenoid suture may be seen, depending on the degree of clockwise or counterclockwise rotation in the vertical axis (79), which also causes stepoff and comminution of the inferior orbital rim (73). High-energy injuries, which are typically caused by higher-speed motor vehicle collisions, result in facial widening from posterolateral displacement and external rotation about the zygomaticosphenoid suture (79) (Fig 31).

**Enophthalmos.**—Failure to recognize the need to explore the orbit can result in enophthalmos (52). As in orbital blow-out fractures, increased orbital volume after ZMC fractures results from critically sized defects of the orbital floor that are larger than 2 cm² (71,79), with one major caveat: Reduction of a retruded or internally rotated zygoma into anatomic position may create or enlarge a floor defect, resulting in a mismatch between CT and surgical findings (42,79,80). Floor fractures associated with ZMC fractures displace in three reproducible patterns: Fragments can (a) collapse into the maxillary sinus, creating a defect; (b) fold in a harmonica-like
arrangement; or (c) overlap in a telescoping fashion (79). Folded comminuted fragments collapse into the maxillary sinus during reexpansion (Fig 32), whereas telescoping fragments tend to slide back into near-anatomic position. The risk of defect expansion also increases with posterior malar displacement greater than 1 cm (80). In addition, enophthalmos can result from lateral displacement and angulation of the ZMC in high-energy fractures.

**Grading and Management**

The CT fracture grade and the results of surgical palpation for instability are complementary in predicting the amount of exposure and fixation needed (52,71,81). Ultimately, the determination is made during surgery by the reconstructive surgeon using incremental stability testing, which is commonly performed by applying percutaneous bone screw traction after ORIF of each site (52,77,82). Once the fracture is immobile with firm pressure, no further fixation is necessary because the masseter is weakened after trauma and does not produce enough force to rotate or displace the fragment during healing (52,83).

**Zingg Classification.**—A simple, surgically relevant CT-based grading system introduced by Zingg et al (77) classifies injuries into three basic types, each with its own considerations regarding surgical approach, risks, and benefits. Zingg type A fractures are isolated incomplete fractures involving only one limb of the zygoma. Zingg type B fractures are classic tetrapod fractures, with a completely liberated zygomatic monofragment, and Zingg type C fractures are comminuted.

**Zingg Type A Fractures.**—Zingg type A fractures, which are relatively uncommon, are subdivided into those exclusively involving the zygomatic arch (type A1), the lateral orbital rim or wall (type A2), and the inferior orbital rim (type A3). Type A1 fractures are stable after closed reduction. At CT, the arch often assumes a V shape, with segmentation and depression. Reduction is performed to treat cosmetic deformity or restricted mouth opening (71,77). A percutaneous or transoral bone hook can be used to elevate the fracture back into its original alignment without the need for fixation or splinting, because the periosteum is typically partially intact.

Zingg type A2 and A3 fractures are usually amenable to closed manipulation. Unstable type A2 fragments can be fixed with a single low-profile plate across the frontozygomatic suture.
by way of cosmetically favorable lateral brow incisions or blepharoplasty incisions (along a natural skin crease in the outer third of the upper lid) (42,71). Type A3 fractures are usually stable with closed reduction. If transconjunctival access is required for internal orbit reconstruction, a low-profile plate is sometimes placed along the inferior rim (71).

Zingg Type B Fractures.—A small subset of Zingg type B fractures with minimal displacement or splintering of the tetrapod articulations can often be managed with closed manipulation or percutaneous traction screw reduction alone, provided that the orbital floor does not require exploration (71,77). Overall, up to 17% of ZMC fractures can be treated with closed reduction (52). In general, the risks of aggressive surgical intervention often outweigh the benefits of restoring minor asymmetries in elderly or severely injured patients (71).

Most Zingg type B fractures are unstable and require internal fixation; however, a single point of plate-and-screw fixation is sufficient in 30%–40% of cases (52) (Fig 33). Single-point fixation is performed either across the zygomaticomaxillary buttress with a transoral approach or across the frontozygomatic suture by using a lateral brow incision or blepharoplasty incision. Both sites provide excellent resistance to tensile strain (52,71,84). The zygomaticomaxillary buttress may be favored because the surgery leaves no visible scar, and strong L-shaped plates can span small areas of comminution (52,71,84). On the other hand, access to the frontozygomatic suture allows intraoperative supervision of the zygomaticosphenoid suture, and this site is chosen as the initial fixation site during preplanning if there is evidence of an unstable maxillary fragment or if comminuted zygomaticomaxillary buttress defects are sufficiently large at CT (52,71).

Type B fractures with splintering and displacement
at CT often require fixation at both sites. The inferior orbital rim is not a first choice for fixation owing to comminution in up to 60% of cases and the need for lid incisions (52) but is used as a third fixation point if additional fixation is needed on the basis of incremental intraoperative stability testing (72,85). In general, CT aids in planning the least surgical exposure that is necessary, which reduces the risk of iatrogenic lid deformities, scarring, soft-tissue droop or hollowing, and plate prominence (52,71,86).

Zingg Type C Fractures.—All Zingg type C fractures require ORIF with liberal exposure (77). Many comminuted type C fractures can be sufficiently stabilized with three plates (Fig 31b), and reduction of the zygomatic arch is usually achieved indirectly with ORIF of the common fixation points or percutaneously (52,77). When coronal incisions are required for other indications, the arch can be used as a fourth point of fixation; however, dissection can result in temporal hollowing or facial nerve injury (52,71,85). When associated NOE fractures go unrecognized at preoperative CT, the ZMC may be positioned too far laterally, which results in widening of the midface (85).

Le Fort Maxillary Occlusal Segment Fractures

Le Fort Nomenclature: Past and Present
The current Le Fort nomenclature is a simplification of a wide variety of fracture patterns described by René Le Fort in his series of cadaver experiments (87). Le Fort 1 fractures involve the lateral and medial walls of the maxillary sinus, propagating posteriorly from the piriform aperture. Le Fort 2 fractures involve the frontonasal suture, the inferior orbital rim and floor, and the maxillary sinuses, forming a pyramidal shape. The Le Fort 3 fracture level extends horizontally from the frontonasal suture to the frontozygomatic suture and zygomatic arches (Fig 34a). It is widely taught that all three patterns converge through the pterygoid plates (Fig 34b), resulting in dissociation of the involved midfacial segment, and that if the pterygoid plates are intact, a Le Fort fracture is excluded (88). Le Fort 1, 2, and 3 fractures are conceptualized as a “floating palate,” a “floating maxilla,” and “craniofacial dissociation,” respectively (89,90). Before the advent of CT and rigid fixation with titanium hardware, points of fixation beyond the highest Le Fort level were used for closed compression with suspension wires (31,91). The face would have an elongated appearance from undercompression or a characteristic “balloon face” morphology (91,92) from overcompression and the inability to control width or anteroposterior projection.

Le Fort Fractures in Contemporary Practice
With the evolution of subunit-specific principles for midfacial fracture reconstruction, emphasis on the highest Le Fort level is anachronistic. Overemphasis of the Le Fort classification system leads to radiology reports that are laundry lists of involved levels and buttresses, findings which are of limited value in surgical planning.
Upper Le Fort level fractures are commonly permutations of NOE, ZMC, and orbital fractures that are addressed individually (31) (Fig 35). Suggestions for subunit-specific assessment and reporting are presented in the Table.

The occlusion-bearing fragment represents an independently managed subunit consisting of the palate, alveolus, and maxillary dentition and is liberated from the upper midfacial subunits at the lowest Le Fort level. The primary management goal for occlusion-bearing maxillary fractures is to prevent handicapping malocclusions by restoring the pretrauma alignment of the maxillary and mandibular dental arches (the occlusion) by using maxillomandibular fixation with arch bars and wires (93). Even 2–3-mm malocclusions result in impairment, whereas 2–3-mm bone gaps along the maxillary buttresses are of little clinical consequence (94). Fixation of the occlusion-bearing fragment to the reconstructed upper midface along the four maxillary buttresses is therefore performed as the last step in surgical sequencing after maxillomandibular fixation is established and palatal fractures are controlled (Figs 35b, 36) (31).

CT Evaluation Pearls
Malocclusion occurs in 8%–20% of Le Fort maxillary fractures (94). Three-dimensional volume-rendered CT images may reveal gross malocclusions such as abnormal inclination of the dental arches, open bite, premature dental contact, and maxillary intrusion with prognathism; however, assessment of occlusion is primarily clinical. After surgical correction, orthodontic resurfacing can be used for minor occlusal problems; major occlusal problems after healing require delayed Le Fort 1 osteotomy (31,95,96). The didactic emphasis on “floating fractures” that extend completely through the pterygoid plates fails to capture the utility of CT for discriminating between (a) completely liberated occlusion-bearing Le Fort fragments that can be passively mobilized and (b) incomplete, greensticked, and impacted fractures. Incomplete fractures may necessitate disimpaction or completion osteotomy (93,94,97,98) and have become more common with mandatory seat-belt laws (92).

Incomplete Fractures.—Between 9% and 20% of maxillary occlusion-bearing segment Le Fort fractures are incomplete (93,98). Coronal CT images may demonstrate subtle incomplete or greensticked hairline fractures through the thin walls of the maxillary sinuses and palatal vault that may bend or buckle, and the piriform aperture or pterygoid plates may remain largely intact (31,93,94) (Fig 37). Many patients with these incomplete fractures have malocclusions, and the maxillary fragment cannot be easily mobilized or repositioned (93,94,97). The higher the fracture level, the more excessive the force needed to disimpact the maxillary fragment, resulting in a greater risk of propagation into the skull base,
Figure 35. Upper Le Fort level fractures in a 58-year-old man with facial fractures after falling from a roof. (a) Three-dimensional volume-rendered CT image shows that the patient sustained a mandibular parasymphyseal fracture (thin white arrow) and dissociation of the Le Fort I maxillary occlusion-bearing fragment (arrowhead), which is inclined anteriorly and superiorly owing to the pull of the pterygoid muscles. Note comminution and tooth loss of the anterior maxillary dental alveoli. In the upper midface, a type B fracture of the left zygoma (thick white arrow) and bilateral grade 1 NOE fractures (thick black arrow) are depicted. (b) Postoperative three-dimensional volume-rendered CT image after sequential panfacial fracture reduction and fixation shows that initially the mandibular parasymphysis was reduced by using two lag screws (arrows). The mandible served as a template for establishing the correct maxillary incline and occlusion. Maxillomandibular fixation was achieved with arch bars (bracket) and interdental wires (wires subsequently removed). After reduction of the occlusion, the grade 1 NOE fractures were secured with nasomaxillary buttress plates (1, 2), and the left ZMC fracture was reduced along the frontozygomatic suture (3). The upper midfacial (NOE and ZMC) fractures were reconnected to the lower midfacial segment with a nasomaxillary buttress plate on the right side (1) and bilateral zygomaticomaxillary buttress plates (4, 5) as the last step of the fixation. A nasomaxillary buttress plate was not used on the left owing to comminution and bone loss in this area.

<table>
<thead>
<tr>
<th>Key Elements of CT Assessment and Reporting of Midfacial Subunit Fractures</th>
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<tbody>
<tr>
<td><strong>Nasoseptal fractures</strong></td>
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<tr>
<td>Image review</td>
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<tr>
<td>25% of nasal bone fractures are missed on axial images.</td>
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<tr>
<td>Sagittal images are 85%–99% sensitive for minimally displaced and transversely oriented fractures.</td>
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<td>Anterior nasal spine fractures are a marker of septal cartilage fracture-dislocation.</td>
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<td>The bony nasal septum should be assessed for bowing on coronal images and for telescoping and/or comminution on axial images.</td>
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<tr>
<td>Reporting</td>
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<tr>
<td>Fractures of the bony nasal pyramid underestimate the degree of injury to the cartilaginous septum.</td>
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<tr>
<td>Follow-up with speculum examination is warranted for all fractures because of the risk of septal cartilage fractures and septal hematomas.</td>
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<tr>
<td><strong>NOE fractures</strong></td>
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<tr>
<td>Image review</td>
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<tr>
<td>NOE fractures involve at least four of the five cardinal tracts; NOE fragment conceptualization is difficult; three-dimensional volume-rendered images are essential.</td>
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<tr>
<td>The medial orbit and floor are volume averaged with three-dimensional volume-rendered images and are best assessed on coronal images.</td>
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<tr>
<td>Sagittal images provide the most accurate assessment of the frontonasal ducts.</td>
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<td>Intrusion of the nasal dorsum into the anterior ethmoids is also highly suggestive of frontonasal duct obstruction.</td>
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(Continues)
### Key Elements of CT Assessment and Reporting of Midfacial Subunit Fractures (continued)

#### Reporting
- Although medial canthal tendon status is only assessed indirectly, Markowitz-Manson grading at CT helps guide management.
- Suspected frontonasal duct obstruction at CT should be emphasized because intraoperative dye irrigation may be required.
- Comment on the degree of posterior table comminution; sinus preservation may be feasible with less than 25% involvement.
- Avoid drawing conclusions about nasolacrimal duct patency; disruption of the nasolacrimal duct poorly predicts impaired lacrimal drainage.

#### Orbital blow-out fractures

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<tr>
<th>Reporting</th>
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<tr>
<td>Comment on high-risk CT features for noticeable (&gt;2–3 mm) late enophthalmos: defect size more than 25%–50% of the orbital floor; internal orbital buttress collapse; and soft-tissue herniation greater than 1.5 mL.</td>
</tr>
<tr>
<td>Know that CT findings of entrapment are often false-positive findings in adults.</td>
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<td>Comment on implant positioning at postoperative CT; implant angulation can cause enophthalmos and incarceration.</td>
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#### ZMC fractures

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<tr>
<td>Failure to anticipate floor defect expansion is a major cause of late enophthalmos after ZMC reduction.</td>
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<tr>
<td>Fragments folded in a harmonica-like arrangement tend to collapse during reduction, expanding the floor defect.</td>
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<tr>
<td>CT-based grading with the Zingg classification as a framework is helpful in guiding management.</td>
</tr>
<tr>
<td>Single plate-and-screw fixation is sufficient to stabilize 30%–40% of minimally displaced Zingg type B (monofragment) fractures.</td>
</tr>
<tr>
<td>Isolated incomplete (Zingg type A) fractures are often amenable to closed reduction; these fractures are uncommon.</td>
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<tr>
<td>All Zingg type C (comminuted) fractures require ORIF, usually with three-point fixation.</td>
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#### Occlusion-bearing maxillary and palatal fractures

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<tr>
<td>Incomplete, impacted, or severely comminuted maxillary fractures are the most difficult to manage.</td>
</tr>
<tr>
<td>Type 3 (comminuted) palatal fractures require long periods of maxillomandibular fixation and may benefit from stabilization with splints.</td>
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<tr>
<td>Comment on palatal comminution with bone loss; mucoperiosteal flaps may be needed to prevent fistula formation.</td>
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optic nerve injury, and carotid-cavernous fistulas (93,94,99,100). Completion of nonreducible fractures by Le Fort 1 osteotomy may be necessary to safely achieve passive occlusion (93).

**Impacted Fractures.**—Because of its thin walls and air-filled cavities, the maxilla may crumple, resulting in retrusion and impaction of the maxillary buttresses and pterygoid plates (Fig 37b). Mobilization of a retruded impacted maxilla may require extreme amounts of force, incurring additional risk of iatrogenic injury (31,93). Use of maxillomandibular fixation when the maxilla is not completely disimpacted and mobilized can force the mandibular condyles posteriorly and inferiorly. Prognathism or anterior open bite may be apparent on postoperative CT images after the mandible returns to its normal position (93,94) (Fig 38).

**Comminuted Fractures.**—Comminution can make passive mobilization into the proper occlusal relationship easier for the reconstructive surgeon because there are fewer bone and soft-tissue attachments; however, these comminuted fractures may also be more difficult to stabilize with arch bars (94). Pull by the pterygoid muscles results in anterior-superior incline of the retruded maxilla (Fig 35a). The reconstructive surgeon may need to reposition a superiorly inclined anterior maxilla with disimpaction forceps (94).

**Mandible Fractures.**—The principles guiding mandibular reconstruction are complex (75). With regard to midfacial fractures, the mandibular dental arch serves as a template for restoring pretrauma maxillary projection, incline, and occlusion (31) and must be either intact or
reconstructed before maxillomandibular fixation is secured (94) (Fig 35b). Bilateral subcondylar fractures can alter mandibular height and are repaired first, to prevent abnormal dental inclination (31,91).

Palatal Fractures.—Up to one-half of Le Fort fractures have associated fractures of the hard palate (95). Sagittal palate fractures can result in palatal collapse and buccal flaring of the hemi–Le Fort fracture segments (101) (Fig 39). These features make surgical control more difficult (94). In such cases, maxillomandibular fixation plays a crucial role in stabilizing palatal fractures and counteracting buccal torque (101).

Chen et al (95) described three major patterns of palatal fractures. Type 1 fractures, accounting for more than 90% of cases, are sagittally oriented, beginning at the maxillary alveolus and propagating in paramedian or para-alveolar locations (Fig 40a). Type 2 fractures have a transverse orientation, dividing the hard palate in the coronal plane (Fig 40b). Type 3 fractures are complex and comminuted (Fig 40c). Type 2 and 3 fractures are rare, with each type accounting for 4%–5% of cases. Definitive diagnosis is made with axial and coronal CT images (95). Management of all three fracture types requires mobilization of the occlusion, followed by maxillomandibular fixation. For type 1 and 2 fractures, maxillomandibular fixation is needed for up to 2 weeks, whereas type 3 fractures require maxillomandibular fixation for periods of 4–5 weeks and may benefit from stabilization with a splint (31,95). Sagittal and transverse palatal fractures may be sufficiently stabilized indirectly with maxillary buttress fixation. Plate-and-screw fixation transversely along the alveolar ridge may also aid in achieving positional control and stability (31,95) (Fig 40a). Comminuted palatal fractures have a high incidence of malocclusion, nonunion, and tooth loss (95,102); and oroantral or oronasal fistulas may rarely occur (96). To prevent fistula formation, palatal defects with considerable bone loss are closed at the time of surgery by using mucoperiosteal flaps (95).

Conclusion
To add value to the multidisciplinary care of patients with midfacial fractures, radiologists should strive to familiarize themselves with the complex interplay between patterns and grades of injury on CT images and at clinical and intraoperative assessment, as well as the risk-benefit considerations for each midfacial subunit—all of which are important for synthesizing individualized treatment plans aimed at maximizing aesthetic and functional outcome and minimizing complications.

References
Figure 40. Palatal fractures in three different patients. (a) Panfacial fractures in a 35-year-old man after impact with a wall during a motorcycle collision (same patient as in Fig 37). Axial thick-slab CT image shows a left type 1 paramedian fracture of the hard palate (thick open arrow). After occlusal reduction with maxillomandibular fixation, plate-and-screw fixation was performed along the alveolar ridge just below the piriform aperture to stabilize and reduce the palate (thin solid arrow) before maxillary buttress fixation. (b) Facial fractures in a 57-year-old man after an assault. Sagittal thick-slab CT image shows an uncommon type 2 transverse fracture of the posterior hard palate (thin solid arrow), together with a Le Fort level 1 maxillary occlusal segment fracture (thick open arrows). The occlusal fragment was stabilized with maxillary buttress ORIF, and the palatal fracture was managed with a period of maxillomandibular fixation. (c) Facial fractures in a 58-year-old man after falling from a roof (same patient as in Fig 35). Axial thick-slab CT image shows a comminuted type 3 palatal fracture, with right and left para-alveolar components (arrows). Communion and tooth loss of the anterior aspect of the alveolar process are also depicted. The palatal fractures were stabilized with maxillomandibular fixation and indirectly reduced and fixed with maxillary buttress plates and screws, as shown in Figure 35.


