Femoral Trochlear Dysplasia: MR Findings

PURPOSE: To establish quantitative and qualitative magnetic resonance (MR) criteria for the diagnosis of trochlear dysplasia.

MATERIALS AND METHODS: MR images were analyzed in 16 consecutive patients with and 23 without trochlear dysplasia. The standard of reference was a true lateral radiograph of the knee. Quantitative and qualitative MR criteria were assessed.

RESULTS: In patients with trochlear dysplasia, the trochlear groove was significantly less deep than that in control subjects. The most accurate measurement was 3 cm above the femorotibial joint space ($P < .001$), where a trochlear depth of 3 mm or less had a sensitivity of 100% and a specificity of 96%. The ventral trochlear prominence between the supratrochlear femoral cortex and the most ventral point of the trochlear floor (midsagittal section) was always larger than 6.9 mm in dysplastic trochleae. A facet ratio of less than 2:5 (medial to lateral) 3 cm above joint space level had a sensitivity of 100% and a specificity of 96%. A nipplelike anterior prominence at the superior end of the femoral trochlea on midsagittal images was a specific (91%) qualitative criterion.

CONCLUSION: Dysplasia of the femoral trochlea can be diagnosed reliably by using quantitative or qualitative criteria on midsagittal or transverse MR images obtained 3 cm above the femorotibial joint space.

Anterior knee pain is one of the most frequent complaints in orthopedics and sports medicine (1). There is a long list of possible differential diagnoses, including femoral trochlear dysplasia. Femoral trochlear dysplasia is a geometric abnormality of the shape and depth of the trochlear groove mainly at its cranial part. This may lead to patellar instability, which in turn results in anterior knee pain. Most magnetic resonance (MR) investigations of anterior knee pain have focused on diagnosing cartilage defects (2) or patellar chondromalacia (3–5), as well as the plica syndrome (6), patellar tendonitis (7,8) or patellar dislocation (9,10). Few MR investigations deal with geometric abnormality of the femoral trochlea (11).

Femoral trochlear dysplasia can be diagnosed by using a true lateral conventional radiograph of the knee (12,13). Two criteria can be used for the diagnosis of trochlear dysplasia: The crossing sign or the sign of the prominent trochlear floor have to be positive. The crossing sign is positive (dysplasia present) when the floor of the trochlear groove crosses the ventral outline of the lateral femoral condyle (13,14). At the level of this crossing, the trochlea is considered flat (12). The ventral prominence of the trochlear floor is measured as the distance between a line drawn through the ventral cortical bone of the femoral shaft and a parallel line defined as the tangent to the most ventral point of the trochlear floor. For the diagnosis of trochlear dysplasia, the prominence has to be more than 3 mm (14,15).

Off-lateral radiographs are commonly encountered instead of true lateral views. In addition, more and more MR examinations have to be performed without the availability of conventional radiographs, which may not have been obtained at all or may not have reached the MR unit at the time of the examination. However, if femoral trochlear dysplasia is not diagnosed during MR imaging, an important cause of anterior knee pain may be missed. The purpose of this investigation was to establish the value of quantitative and qualitative MR criteria for the diagnosis of femoral trochlear dysplasia.
MATERIALS AND METHODS

Patients

MR examinations of 16 knees in 16 patients (six male patients, 10 female patients; mean age, 33 years; age range, 16–59 years) with trochlear dysplasia and 23 knees in 23 patients (11 male patients, 12 female patients; mean age, 37 years; age range, 16–81 years) with normal femoral condyles were included in the investigation. The abnormal cases were selected consecutively in a 1-year period, from March 1998 to February 1999, during which 983 standard MR examinations of the knee were performed. All examination records were checked by two musculoskeletal radiologists (M.Z., J.H.) for the presence of femoral trochlear dysplasia on a true lateral radiograph (Figs 1, 2). The presence of dysplasia was confirmed by means of consensus. Only those cases were included in which a true lateral radiograph was available. The radiograph was accepted as true lateral when the posterior borders of the medial and lateral femoral condyles were superimposed or had a distance of no more than 2 mm. For inclusion, the crossing sign had to be positive (12,13), and the ventral prominence of the trochlear floor had to be more than 3 mm (14,15). All consecutive patients meeting these criteria were included. The control group was consecutively selected out of the same group of patients until a comparable number of subjects was achieved. Inclusion criteria for the control group were no signs of trochlear dysplasia on true lateral radiographs and absence of femoropatellar problems in the history.

The indications for the MR examinations in the dysplasia group were femoropatellar pain (n = 7), patellar dislocation (n = 5), knee contusion (n = 2), suspected medial meniscal lesion (n = 1), and abnormal insertion of the quadriceps tendon (n = 1). In the control group, the indications were suspected anterior cruciate ligament tear (n = 8), medial meniscus lesion (n = 4), knee contusion (n = 3), osteoarthritis of the femorotibial joint (n = 2), and a variety of symptoms without clear clinical diagnosis (n = 6).

MR Imaging Protocol

MR imaging was performed with a 1.0-T scanner (Impact Expert; Siemens Medical Systems, Erlangen, Germany). A send-receive circular-polarized extremity coil was used. The imaging protocol included sagittal intermediate-weighted and T2-weighted fast spin-echo images (3,800/17–119 [repetition time msec/echo time msec]; section thickness, 3 mm; intersection gap, 0.3 mm; field of view, 25 cm; matrix, 300 × 512; time of acquisition, 3 minutes 57 seconds), coronal T1-weighted spin-echo images (850/12; section thickness, 3 mm; intersection gap, 0.9 mm; field of view, 16 cm; matrix, 252 × 256; time of acquisition, 3 minutes 38 seconds), and transverse three-dimensional double-echo steady-state gradient-echo images (30/9 and 45; flip angle, 40°; 32 sections with a section thickness of 2.7 mm; field of view, 14 cm; matrix, 256 × 256; one signal acquired; time of acquisition, 4 minutes 8 seconds).

Analysis of MR Images

The MR examinations were evaluated in a blinded fashion with regard to the diagnosis of trochlear dysplasia. All measurements were obtained by a musculoskeletal radiologist (C.W.A.P.) by using the midsagittal and three transverse images (Figs 3, 4).

The midsagittal plane was defined by the deepest point of the trochlea. In the midsagittal plane, the distance between the line paralleling the ventral cortical surface of the distal femur and the most ventral cartilaginous point of the femoral trochlear floor was measured (ventral trochlear prominence, distance X, Fig 3). In this plane, two qualitative criteria were also analyzed. The form of the transition between the anterior femoral cortex to the trochlea was classified as smooth (Fig 3, A) or steplike (Fig 3, B). The presence of any localized nipplelike anterior prominence at the superior border of the femoral trochlea was determined, and the height of the prominence was measured (distance Y; Fig 3, B).

Transverse sections were analyzed 1, 2, and 3 cm above the femorotibial joint space. The distances were always measured to the outermost point of the cartilaginous or osseous surface to ensure analysis of the real joint geometry (11).

The trochlear depth was assessed by measuring the maximal anteroposterior

Figure 1. Diagram and true lateral radiograph of a normal knee in a 42-year-old woman. The floor of the femoral trochlea does not cross the ventral outlines of the femoral condyles. There is no ventral prominence of the trochlear floor. The floor of the trochlea (arrowheads) is always dorsal to the line paralleling the ventral cortical surface of the distal femur.

Figure 2. Diagram and true lateral radiograph of a knee with femoral trochlear dysplasia in a 28-year-old man. Two signs are positive. First, the line (I, arrow) representing the floor of the femoral trochlea crosses the ventral outlines of both femoral condyles. This is a positive crossing sign. Second, there is a ventral prominence of the trochlear floor. The floor of the trochlea is 5 mm ventral to the line paralleling the ventral cortical surface of the distal femur (II, double arrow).
Figure 3. Diagrams of measurements obtained by using midsagittal MR images. A, Normal trochlea; B, Dysplastic trochlea. The midsagittal plane is defined by the deepest point of the trochlea. X is the distance between the line paralleling the ventral cortical surface of the distal femur and the most ventral cartilaginous point of the femoral trochlear floor (ventral trochlear prominence). Distance Y represents the height of a localized nipplelike anterior prominence at the superior border of the femoral trochlea.

Statistical Analysis
The two groups were analyzed by using an unpaired Student t test. Sensitivity, specificity, accuracy, and negative and positive predictive values were calculated for the qualitative criteria and for different cutoff values of the quantitative measurements. A P value less than .05 was considered to indicate a statistically significant difference.

RESULTS
The ventral trochlear prominence (distance X, Fig 3) between the line paralleling the anterior femoral cortex and the most ventral point of the trochlear floor as measured in the midsagittal plane was always larger than 6.9 mm in dysplastic condyles (mean, 9.3 mm; range, 6.9–15.5 mm) (Table 1). In the control population, the mean was 5.0 mm, with a range of

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Trochlear Dysplasia</th>
<th>Normal Knees</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventral trochlear prominence (mm)</td>
<td>9.3</td>
<td>5.0</td>
<td>&lt;.001</td>
</tr>
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<td>Trochlear depth (mm)</td>
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<td>9.0</td>
<td>.008</td>
</tr>
<tr>
<td></td>
<td>3.6</td>
<td>6.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>−0.6</td>
<td>5.2</td>
<td>&lt;.001</td>
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<td>Facet asymmetry</td>
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<td>80</td>
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<tr>
<td></td>
<td>45</td>
<td>65</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>12</td>
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<td>.68</td>
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<td></td>
<td>91</td>
<td>93</td>
<td>.21</td>
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<td>Lateralization of patella (mm)</td>
<td>7.7</td>
<td>2.5</td>
<td>&lt;.001</td>
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<tr>
<td>Nipple (mm)</td>
<td>1.8</td>
<td>0.1</td>
<td>&lt;.001</td>
</tr>
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</table>

*The P value refers to the results of the Student t test.
† Data were obtained 1, 2, or 3 cm above the femorotibial joint level.
‡ Data are the percentage of medial to lateral facets.
§ Data are the percentage of lateral to medial condyles (anteroposterior distance).
0–10.5 mm. When the value was greater than 8 mm, the ventral trochlear prominence on sagittal MR images had a sensitivity of 75% and a specificity of 83% for the diagnosis of trochlear dysplasia (Figs 5–7).

The trochlear groove was significantly less deep in dysplastic knees when compared with depth in the control population. The most relevant difference was found on transverse images 3 cm above the femorotibial joint space—in dysplastic knees (mean, −0.6 mm; range, −6.5 to −2.7 mm) and in the control population (mean, 5.2 mm; range, 2.4–10.5 mm; P > .001) (Figs 8–10). Negative values are encountered when the trochlear
groove is anteriorly convex. When a cut-off of 3 mm was chosen for trochlear depth, MR imaging had a sensitivity of 100% and a specificity of 96% for trochlear dysplasia (Table 2).

Trochlear articular facet asymmetry was significantly increased in dysplastic knees (distances f and g, Fig 4). Three centimeters above knee joint space, the width of the medial facet was 12% that of the lateral facet (range, 0%–40%; medial-to-lateral ratio, 2:5). In the control population, the mean was 57%, (range, 17%–93%; P, .001) (Table 1). With a cutoff of 40%, this MR sign of trochlear dysplasia had a sensitivity of 100% and a specificity of 96% (Table 2).

Another significant criterion was the degree of patellar lateralization. Patellar lateralization had a mean of 7.7 mm (range, 0–16.2 mm) in dysplastic knees and 2.5 mm (range, 0–11.2 mm; P, .001) in the control population (Table 1). Patellar lateralization of more than 6 mm had a sensitivity of 75% and a specificity of 83% for trochlear dysplasia (Table 2).

Qualitative criteria analyzed on mid-sagittal images included the presence of a nipplelike anterior prominence at the superior border of the trochlea and the form of the transition zone from the ventral femoral cortical bone to the trochlea (Figs 5–7). A nipple at the superior border of the femoral trochlea was present in 11 (69%) of 16 cases of dysplasia but in only two (9%) of 23 control cases (P < .001). A sharp steplike transition zone was encountered in 13 (81%) of 16 dysplastic knees, whereas the normal knees had predominately smooth transition zones (21 [91%] of 23, P < .001) (Table 2).

There was no significant difference with regard to the relation of the antero-posterior diameters of the femoral condyles (femoral condyle asymmetry, distances a and b, Fig 4), the absolute and relative lateral widths of the femoral head and the femoral joint cartilage (distances c and h, Fig 4), and the distance between the deepest point of the trochlear floor and the posterior femoral border (distance d, Fig 4).

### DISCUSSION

Anterior knee pain is a common problem in orthopedics and sports medicine. A large number of diagnoses with different therapeutic consequences have to be considered. Patellar chondromalacia and patellofemoral osteoarthritis are the most important entities. Femoral trochlear dysplasia is considered less commonly as a differential diagnosis. If present, it may lead to patellar instability and patellofemoral maltracking, which are possible causes for patellofemoral osteoarthritis (14).

Most treatment concepts concentrate on reducing maltracking or instability of the patella during knee motion. Physical therapy with training of the vastus medialis muscle is the first option (18). Surgical procedures include the release of the lateral patellar retinaculum, reconstruction of the medial femoropatellar liga ment, or moving the tibial tuberosity medially. Trochleoplasty refers to remodeling of the trochlear groove and reduces the ventral prominence of the trochlear floor. This is a difficult surgical procedure and is rarely performed (19). Diagnosis of trochlear dysplasia at MR imaging can help to initiate proper treatment in patients with anterior knee pain.

In our study, seven of 16 patients with trochlear dysplasia had anterior knee pain as the main clinical symptom. Five

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### TABLE 2

<table>
<thead>
<tr>
<th>Criterion</th>
<th>No. of Cases</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
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<tbody>
<tr>
<td>Ventral trochlear prominence greater than 8 mm</td>
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<td>75</td>
<td>83</td>
<td>79</td>
<td>75</td>
<td>83</td>
</tr>
<tr>
<td>Trochlear depth less than 3 mm*</td>
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<td>100</td>
<td>96</td>
<td>97</td>
<td>94</td>
<td>100</td>
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<td>Face asymmetry less than 40%†</td>
<td>16</td>
<td>100</td>
<td>96</td>
<td>97</td>
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<td>100</td>
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<tr>
<td>Patellar lateralization greater than 6 mm</td>
<td>12</td>
<td>75</td>
<td>83</td>
<td>79</td>
<td>75</td>
<td>83</td>
</tr>
<tr>
<td>Nipple positive</td>
<td>11</td>
<td>69</td>
<td>91</td>
<td>82</td>
<td>85</td>
<td>81</td>
</tr>
<tr>
<td>Sharp steplike transition zone</td>
<td>13</td>
<td>81</td>
<td>91</td>
<td>87</td>
<td>87</td>
<td>88</td>
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</tbody>
</table>

* Data were obtained 3 cm above the femorotibial joint level.
† Data are the percentage of medial to lateral facets.
of 16 patients with femoral trochlear dysplasia presented clinically with patellar instability. The diagnosis of acute patellar dislocation is easy in the presence of a characteristic history or an MR examination performed immediately after acute trauma. However, the history and clinical signs can be misleading, and the diagnosis of patellar dislocation or patellar instability may be missed (9). MR imaging may miss the diagnosis of patellar dislocation when the typical bone bruise and soft-tissue hematoma are no longer present. In the presence of trochlear dysplasia, subtle scarring of the medial femoropatellar ligament or residual bone changes at the medial patellar border of the lateral femoral condyle may be diagnosed more confidently.

The prevalence of femoral trochlear dysplasia was low in our series: 16 dysplasias (2%) in 983 consecutive MR examinations. However, the prevalence is underestimated because strictly lateral conventional radiographs were commonly not available. On the other hand, our prevalence of femoral trochlear dysplasia is comparable to that in a previous series (three [0.7%] of 420 cases) (13).

The analysis of femoropatellar disorders historically has concentrated on abnormalities of the patellar shape (20). Later, a large variety of different measurements were advocated for characterization of trochlear abnormalities. Most of these measurements are based on transverse radiographs of the knee at approximately 30° (20°–55°) of flexion: The sulcus angle or trochlear angle is defined by the intersection of the lines connecting the highest point of the femoral condyles to the deepest point of the trochlear groove and is normally 141°–143° (21). The lateral-medial femoral facet ratio normally has a value of 1–3:1 (22). A value greater than 1.75 is considered diagnostic for dysplasia (22). The femoropatellar congruence angle is determined by bisecting the sulcus angle to establish a reference line and then projecting a second line from the apex of the sulcus to the lowest point on the articular ridge of the patella (23). A value of more than 16° is associated with femoropatellar disorders. The lateral patellofemoral angle is defined by lines parallel to the lateral facet of the patella and through the ventral outlines of the femoral condyles describing the patellar tilt (24). If the lines are parallel or converge laterally, a tendency toward subluxation or dislocation is suspected.

All these measurements are not able to demonstrate the trochlear groove in the crucial cranial zone of the trochlea. Our results confirm that insufficiency of the trochlear depth is particularly significant in the proximal aspect of the femoral trochlea (17) (Fig 10). On a true lateral radiograph, diagnosis of an insufficient depth of the proximal femoral trochlea is reliable with use of the crossing sign (13–15). At this level, the crossing of the line representing the trochlear groove with the ventral outline of the femoral condyles is a sign of trochlear dysplasia (12). The mean trochlear depth in normal knees 3 cm above femorotibial joint level was 5.2 mm in our study. This is in good correlation (5.9 mm) with results of a previously published series (12) in which true lateral radiographs were evaluated. Our value for the dysplasia group was slightly lower (~0.6 mm compared with 2.7 mm). This difference is probably due to the fact that our measurements included the cartilaginous surface.

Many previous computed tomographic investigations have been focused on centering of the patella with or without flexion of the knee and with or without isometric quadriceps contraction (25,26). Kinematic MR imaging has been used to assess tracking abnormalities of the patella. These investigations focus on the relationship of the patella to the trochlear groove (27,28). Few investigations have used the sagittal plane for the evaluation of the patellofemoral joint (29). Our results indicate that the mid-sagittal plane provides valuable information about the geometry of the patellofemoral joint. The advantage of MR images over conventional radiographs is the depiction of the cartilaginous joint surface and, therefore, the assessment of the real geometric joint configuration (11).

The ventral trochlear prominence can be measured as the distance between the line paralleling the ventral supratrochlear femoral cortex and the most ventral point of the trochlear groove. A value of more than 8 mm has a sensitivity of 75% and a specificity of 83% for the diagnosis of trochlear dysplasia. Therefore, the mid-sagittal plane probably should be included in the examination of patients suspected of having dysplasia.

In further evaluating this imaging plane, we detected a nipple at the superluminal border of the femoral trochlea in 11 (69%) of 16 patients with dysplasia but in only two (9%) of 23 in the control group. The meaning of this sign is not clear. The presence is not linked to age. A nipple has a high specificity (91%) for the presence of femoral trochlear dysplasia, especially if the height of the nippelike prominence is larger than 2 mm. This sign is reliable only in the absence of osteoarthrosis of the femoropatellar joint because there is often chronic physeal disruption at the same position. Another qualitative criterion was a step-like transition zone (Figs 3, B; 6, 7) between the anterior femoral cortex and the trochlea in 13 (81%) of 16 patients with dysplastic knees compared with two (9%) of 23 patients in the control group. This sign was also specific (91%). The presence of these qualitative signs should raise suspicion for trochlear dysplasia. Measurement of ventral trochlear prominence on midsagittal images and measurement of trochlear depth and facet asymmetry on transverse images 3 cm above the joint space confirm the diagnosis of femoral trochlear dysplasia.

This study was performed retrospectively. As a study limitation, we have to acknowledge that the accuracy of MR imaging for trochlear dysplasia may be lower in a prospective series, because in the control group without dysplasia no borderline cases were included.

In summary, dysplasia of the femoral trochlea can be diagnosed reliably on midsagittal and transverse MR images 3 cm above the femorotibial joint space by using either quantitative or qualitative criteria.

References
8. McLoughlin RF, Raber EL, Vellet AD, Wiley JP, Bray RC. Patellar tendinitis: MR imaging features, with suggested pathogene-