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The Magnetic Resonance Imaging Appearance of Individual Structures of the Posterolateral Knee

A Prospective Study of Normal Knees and Knees with Surgically Verified Grade III Injuries

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ABSTRACT

The purpose of this study was to contrast the magnetic resonance imaging appearance of uninjured components of the posterolateral knee with that of injured structures, and to assess the accuracy of magnetic resonance imaging in identifying posterolateral knee complex injuries. Thin-slice coronal oblique T1-weighted images through the entire fibular head were used to identify the posterolateral structures in seven uninjured knees. The appearance of corresponding grade III injuries to these structures was identified prospectively in 20 patients and verified at the time of surgical reconstruction. The sensitivity, specificity, and accuracy of imaging for the most frequently injured posterolateral knee structures in this series were as follows: iliotibial band-deep layer (91.7%, 100%, and 95%), short head of the biceps femoris-direct arm (81.3%, 100%, and 85%), short head of the biceps femoris-anterior arm (92.9%, 100%, and 95%), midthird lateral capsular ligament-meniscotibial (93.8%, 100%, and 95%), fibular collateral ligament (94.4%, 100%, and 95%), popliteus origin on femur (93.3%, 80%, and 90%), popliteofibular ligament (68.8%, 66.7%, and 68%), and the fabellofibular ligament (85.7%, 85.7%, and 85.7%). Magnetic resonance imaging of the knee was accurate in the identification of these injuries.

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The anatomy of the posterolateral knee is very complex, and the relationships between anatomic components are difficult to understand. Injuries to the posterolateral structures of the knee may result in posterolateral rotatory instability,[2,4,5] which results in significant functional impairment unless correctly diagnosed and treated.[2,4,5,9,11,12,23] Posterolateral rotatory instability is often incorrectly diagnosed and treated on initial evaluation.[5,6,9,11,12] A reliable physical examination of the posterolateral structures of the knee may be difficult to obtain in the initial period after injury. The extent of injuries to these structures can also be difficult to assess on physical examination in patients with chronic knee ligament injuries. Magnetic resonance imaging has the potential to identify injuries to the individual structures of the posterolateral knee. This tool should assist with the management decisions of patients with acute and chronic posterolateral knee injuries.

The appearance of individual anatomic structures of the posterolateral knee on MRI has not been comprehensively addressed to date.[15,19,26] One of our goals was to report on the MRI appearance of posterolateral knee structures and to correlate them with recent reports on the anatomy of the posterolateral knee.[9,10,12,18,20–22] Another goal was to report on the MRI appearance of specific injuries to the posterolateral structures of the knee. The ultimate objective of this study was to determine whether MRI can reliably demonstrate injuries to individual components of the posterolateral knee.

MATERIALS AND METHODS

The appearance of seven uninjured knees was studied on MRI to refine our imaging of the posterolateral aspect of the knee. The criteria for inclusion in the uninjured group included no history of injuries or surgery and a normal physical examination. A standard quadrature knee coil was used for all images. Magnetic resonance imaging of the knee was performed on a 1.5-T MRI unit (Siemens Vision, Erlangen, Germany). The MRI protocol chosen for this study used axial, sagittal, and coronal turbo spin-echo proton-density and T2-weighted sequences (repetition time [TR], 3000 ms; echo times [TE], 16 and 98 ms; slice thickness, 3 mm; slice gap, 0.3 mm; field of view, 25 × 25 cm; matrix, 380 × 512). High-resolution T1-weighted sections (TR, 685 ms; TE, 20 ms; slice thickness, 2 mm; slice gap, 0.2 mm; field of view, 25 × 25 cm; matrix, 350 × 512) were also obtained in the coronal oblique plane angled 30° proximoventrally to lie parallel to the lateral intraarticular portion of the popliteus tendon. All MRI scanning sequences included the entire fibular head and styloid.

The MRI appearance of individual structures at the posterolateral corner of the knee was prospectively collated in 20 patients with grade III posterolateral knee injuries[1] over a 2-year period. There were 7 acute (≤3 weeks from injury) and 13 chronic knee injuries. All MRI scans were read and tabulated before surgery by one musculoskeletal radiologist (TJG). All MRI findings were verified at the time of arthroscopic evaluation and concurrent open surgical reconstruction. In all cases surgery was performed because of the patients' perceived sense of functional instability or a grossly abnormal clinical examination of the knee. Abnormalities in motion testing specific for the posterolateral knee included the posterolateral drawer test, dial tests at 30° and 90° of knee flexion, varus stress test at 30°, posterolateral rotation at 30° (a posterolateral Lachman test), reverse pivot shift, and the external rotation recurvation test.[3,4,6,7,12,23] In addition, when possible, the patient was assessed for a varus-thrust gait pattern.[11,12] Concurrent injuries to other structures of the knee were recorded but are not reported here because they were not relevant to this study.

RESULTS

The specific structures of the uninjured knees that were consistently identified on MRI and the best MRI sequencing image(s) for these structures are found in Table 1. A correlation of the MRI and surgical findings in 20 prospective knees is broken down into the 7 acute and 13 chronic injuries and is found in Table 2. The sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of MRI compared with the surgical findings for the 20 knees is listed in Table 3. In general, proton-density MRI sequences demonstrated normal structures best, with well-defined low signal intensity of the ligamentous and tendinous structures. For acute injuries, focal discontinuity and retraction were best demonstrated on proton-density MRI sequences, with concurrent interstitial and localized edema best seen on the T2-weighted sequences. Chronic injuries were best visualized on proton-density images as focal discontinuity or retracted, thickened low signal intensity disruption of the normal MRI appearance of these structures.

TABLE 1
Specific Posterolateral Knee Corner Structures Consistently Identified in Seven Normal Knees

Structure[a]	MRI sequence[b]
ITB-Superficial layer	Coronal
ITB-Deep layer	Coronal
LHBF-Direct arm	Coronal/coronal oblique
LHBF-Anterior arm	Coronal/coronal oblique
SHBF-Direct arm	Coronal/coronal oblique
SHBF-Anterior arm	Coronal
MTL-Meniscotibial	Coronal
Fibular collateral ligament	Axial/coronal/coronal oblique
Popliteus origin-femur	Coronal/coronal oblique
Popliteofibular ligament	Coronal oblique
Lateral gastrocnemius tendon	Sagittal
Fabellofibular ligament	Coronal/coronal oblique

[a] ITB, iliotibial band; LHBF, long head biceps femoris; SHBF, short head biceps femoris; MTL, mid-third lateral capsular ligament.
[b] Sequence with best identification of structures.

Iliotibial Band and its Components

Two layers of the iliotibial band can be visualized with MRI (Tables 1 through 3). The superficial layer is the main tendinous component of the iliotibial band, and it can be seen to insert distally at Gerdy's tubercle.[20,21] This layer is best visualized in the coronal plane (Fig. 1). The superficial layer of the iliotibial band is rarely injured and serves as a good reference point to the lateral knee structures.

The deep layer of the iliotibial band continues in the coronal plane and attaches to the lateral intermuscular septum at the distal femur; it is best visualized on the coronal view (Fig. 1A). Avulsions and interstitial tears of the deep layer of the lateral intermuscular septum are often found in association with posterolateral knee structure injuries and can be visualized on coronal-plane images.

Long Head of the Biceps Femoris Muscle and its Components

The long head of the biceps femoris muscle consists of six components at the knee.[22] Two of these components are tendinous, the direct and anterior arms, while the other four are thin fascial components, the reflected arm, anterior aponeurosis, lateral aponeurosis, and a distal expansion to the lateral gastrocnemius complex. Identification of the direct and anterior tendinous arms was possible with MRI, while the fascial components were not consistently identified (Tables 1 through 3).

The direct arm inserts onto the middle of the posterolateral aspect of the fibular styloid, while the anterior arm has a more complex insertion pattern, including attachments at the far lateral edge of the fibular styloid and fibular head.[22] In addition to the insertion on the fibular head and styloid, the anterior arm also continues anteriorly and distally, where it is separated from the distal quarter of the fibular collateral ligament by a bursa before its termination as an anterior aponeurosis over the ante-

TABLE 2
Correlation of the Normal and Torn MRI Appearance Versus Surgical Verification in 20 Knees (7 Acute and 13 Chronic Injuries) With Grade III Posterolateral Knee Injuries

Structure[a]	MRI appearance		Surgery	
	Normal	Torn	Intact	Torn
Acute injuries				
ITB-Superficial layer	6	1	6	1
ITB-Deep layer	2	5	2	5
LHBF-Direct arm	3	4	4	3
LHBF-Anterior arm	3	4	2	5
SHBF-Direct arm	2	5	0	7
SHBF-Anterior arm	0	7	0	7
MTL-Meniscotibial	1	6	0	7
Fibular collateral ligament	1	6	0	7
Popliteus origin-femur	2	5	3	4
Popliteofibular ligament	1	6	3	4
Lateral gastrocnemius tendon	7	0	7	0
Fabellofibular ligament	0	7	1	6
Chronic injuries				
ITB-Superficial layer	13	0	13	0
ITB-Deep layer	7	6	6	7
LHBF-Direct arm	12	1	10	3
LHBF-Anterior arm	13	0	12	1
SHBF-Direct arm	5	8	4	9
SHBF-Anterior arm	7	6	6	7
MTL-Meniscotibial	4	9	4	9
Fibular collateral ligament	2	11	2	11
Popliteus origin-femur	3	10	2	11
Popliteofibular ligament	6	7	3	10
Lateral gastrocnemius tendon	13	0	12	1
Fabellofibular ligament	7	6	6	7

[a] ITB, iliotibial band; LHBF, long head biceps femoris; SHBF, short head biceps femoris; MTL, mid-third lateral capsular ligament.

TABLE 3
Sensitivity, Specificity, and Accuracy of MRI Compared with Surgical Findings for 20 Knees With Grade III Posterolateral Knee Injuries

Structure[a]	Sensitivity	Specificity	Accuracy	Positive predictive value	Negative predictive value
ITB-Superficial layer	100	100	100	100	100
ITB-Deep layer	91.7	100	95	100	88.9
LHBF-Direct arm	66.7	92.8	85	80	86.7
LHBF-Anterior arm	66.7	100	90	100	87.5
SHBF-Direct arm	81.3	100	85	100	57.1
SHBF-Anterior arm	92.9	100	95	100	87.7
MTL-Meniscotibial	93.8	100	95	100	80
Fibular collateral ligament	94.4	100	95	100	66.7
Popliteus origin-femur	93.3	80	90	93.3	80
Popliteofibular ligament	68.8	66.7	68	85	44.4
Lateral gastrocnemius tendon	0	100	95	0	95
Fabellofibular ligament	85.7	85.7	85.7	92.3	75

[a] ITB, iliotibial band; LHBF, long head biceps femoris; SHBF, short head biceps femoris; MTL, mid-third lateral capsular ligament.

rior compartment of the leg.[10] Coronal views best demonstrate the direct and anterior arms of the long head of the biceps femoris where they primarily insert onto the posterolateral aspect of the fibular styloid (Fig. 2A).

Avulsions or tears of the direct arm or anterior arm insertion off the fibular styloid can be seen on MRI in the coronal or coronal-oblique plane and demonstrate focal discontinuity, nonvisualization, increased signal intensity, or proximal retraction, occasionally with a concurrent bone avulsion (Fig. 2B). It is also possible to view the injury pattern on axial and sagittal views.

Short Head of the Biceps Femoris Muscle and its Components

The short head of the biceps femoris muscle consists of two tendinous, one muscular, and three fascial insertions at the knee.[21,22] Magnetic resonance imaging demonstrated good visualization of the two tendinous components (the direct and anterior arms) (Tables 1 through 3).

The direct arm inserts on the posterolateral fibular head, just lateral to the tip of the styloid process and medial to the direct arm attachment of the long head of

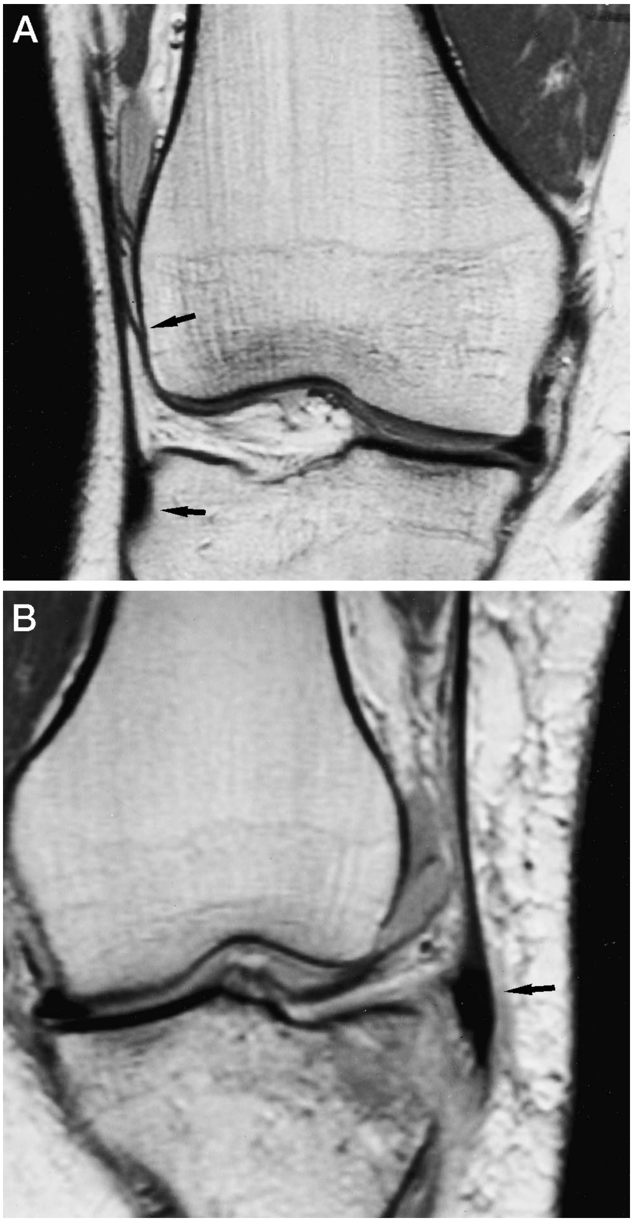

Figure 1. The MRI appearance demonstrating the superficial and deep layers of the iliotibial band (arrows). A, normal superficial and deep layers (coronal view, right knee). B, tear of the superficial layer off Gerdy's tubercle (coronal view, left knee).

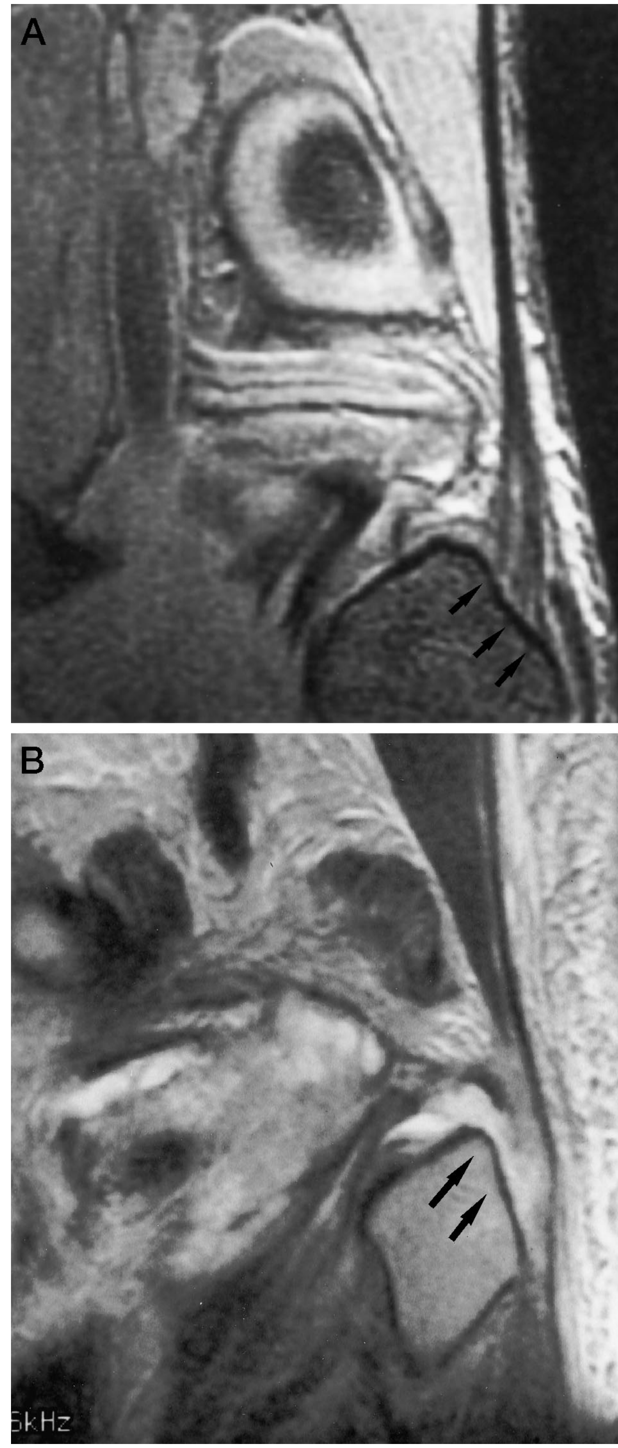

Figure 2. The MRI appearance of the insertion of the direct arms of the short and long heads of the biceps femoris muscle on the posterolateral fibular styloid (arrows). A, normal appearance (coronal view, left knee). B, avulsion of the direct arm off the fibular styloid (coronal view, left knee).

the biceps, and is seen as a low signal intensity band on MRI. The anterior arm passes medial to the fibular collateral ligament and inserts on the posterolateral tibial tuberosity approximately 1 cm posterior to Gerdy's tubercle. The coronal view demonstrates well the direct arm insertion on the fibular styloid (Fig. 2A). The anterior arm of the short head of the biceps femoris muscle is also visualized on the coronal section, where it attaches to the tibia at the same location as the meniscotibial portion of the midthird lateral capsular ligament (see Fig. 4A).

Patterns of injury to the short head of the biceps femoris muscle include avulsion of the direct arm insertion from its attachment just lateral to the tip of the fibular styloid (Fig. 2B) and avulsion of the anterior arm at its insertion posterior to Gerdy's tubercle on the tibia (see Fig. 4B).

Figure 3. The MRI appearance of the popliteus complex (arrows). A, coronal view of an uninjured left knee demonstrating the popliteus origin on the femur. B, coronal view demonstrating the popliteofibular ligament (right knee). C, coronal view, left knee, demonstrating an avulsion of the popliteus tendon origin on the femur. D, coronal view demonstrating an avulsion of the popliteofibular ligament off the posteromedial fibular styloid (left knee).

These can be seen on MRI scans as focal discontinuity, thickening, increased signal intensity, and nonvisualization. The superficial layer of the iliotibial tract, which was rarely found to be injured, may be valuable as a reference point to help identify the anterior arm of the short head of the biceps femoris muscle, as it can be seen on more-anterior coronal images attaching to Gerdy's tubercle. Injury to the anterior arm is frequently associated with a bone or soft tissue avulsion of the meniscotibial portion of the lateral capsule from the tibia (see "Midthird Lateral Capsular Ligament" and "Segond Fracture").

Popliteus Complex

Magnetic resonance imaging of the popliteus complex is difficult using standard axial, coronal, and sagittal MRI planes because of its complex anatomy and helicoid course. The popliteus tendon originates on the proximal and anterior aspect of the popliteal groove of the femur.[13] As the popliteus tendon courses distally it has three meniscal fascicles, the anteroinferior, posterosuperior, and posteroinferior popliteomeniscal fascicles, which form a strong attachment to the lateral meniscus around the popliteal hiatus.[18,21] The popliteus tendon at this point curves around the posterolateral aspect of the lateral femoral condyle in a distomedial direction toward its musculotendinous junction. The popliteofibular ligament originates just distal to the popliteomensical fascicles and just proximal to the popliteus musculotendinous junction,[2,4,9,11,21,23] where it blends with a thickening of the posterior joint capsule of the proximal tibiofibular joint and inserts on the posteromedial fibular styloid. The inferior lateral genicular artery is an important landmark in this area as it is always located posterior and proximal to the popliteofibular ligament.[21]

An axial, coronal (Fig. 3A), or coronal-oblique view can be used to assess the popliteus tendon origin on the femur at the popliteal groove. A coronal-oblique view along the

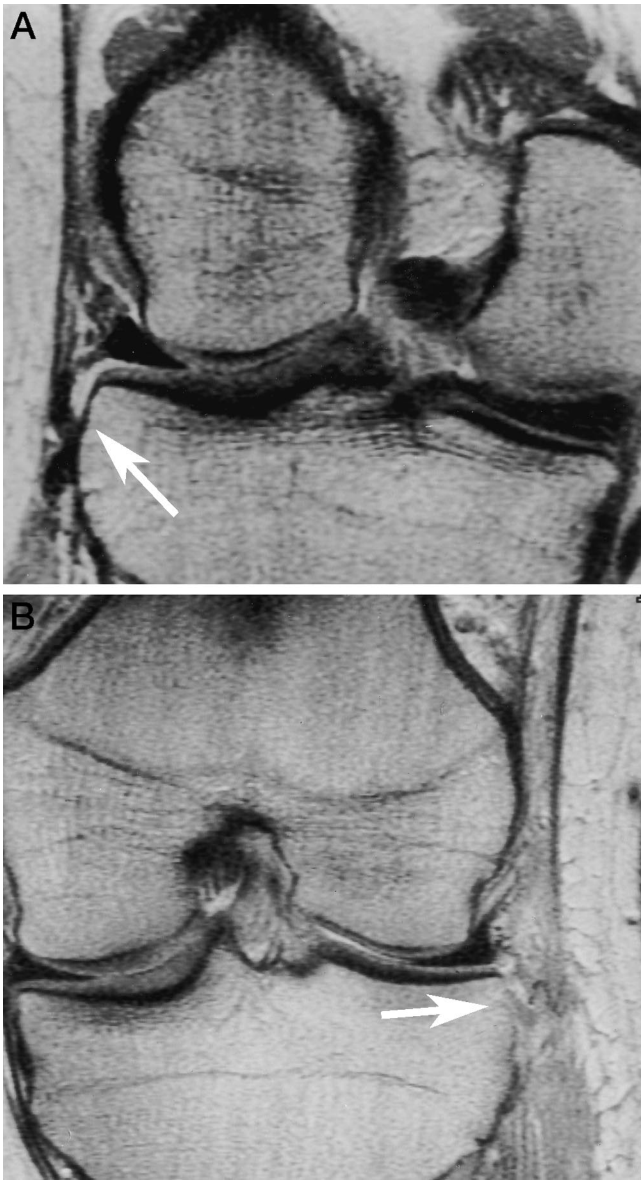

Figure 4. The MRI appearance of the meniscotibial portion of the midthird lateral capsular ligament (arrows). A, uninjured knee demonstrating the meniscotibial ligament and the anterior arm of the short head of the biceps femoris (coronal view, right knee). B, avulsion of the meniscotibial portion of the ligament off the tibia with the anterior arm of the short head of the biceps femoris muscle (coronal view, left knee).

course of the intraarticular popliteus tendon, or a direct-coronal view, can also be used to visualize the popliteus tendon and popliteofibular ligament (Fig. 3B). Injuries to the popliteus origin on the femur or popliteofibular ligament are best visualized on coronal or coronal-oblique views (Fig. 3, C and D) (Tables 1 through 3).

Midthird Lateral Capsular Ligament

The midthird lateral capsular ligament is a thickening of the lateral capsule of the knee. It attaches to the femur in

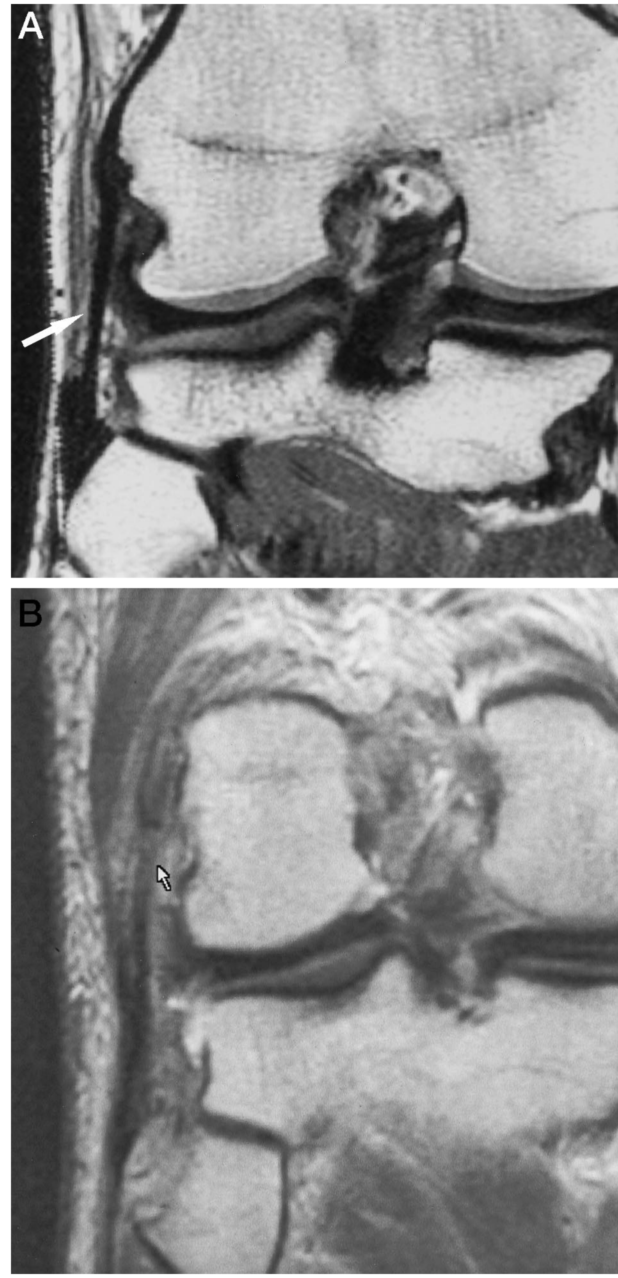

Figure 5. The MRI appearance of the fibular collateral ligament (arrows). A, normal (coronal view, right knee). B, avulsion of the femoral attachment of the fibular collateral ligament (arrow) along with a fibular head avulsion fracture (arcuate fracture) (coronal view, right knee).

the region of the lateral epicondyle, has a capsular attachment to the lateral meniscus, and inserts onto the tibia just distal to the lateral articular cartilage margin between the posterior border of Gerdy's tubercle and the anterior edge of the popliteal hiatus (the anteroinferior popliteomeniscal fascicle).[21] The midthird lateral capsular ligament is best described for both its uninjured and injured states according to its subcomponents, the meniscofemoral and meniscotibial ligaments.[9,12,21] In this study, we found that we could consistently identify the meniscotibial ligament on MRI scans (Tables 1 through 3).

The meniscotibial ligament portion of the midthird lateral capsular ligament is best visualized on the coronal view, where it is seen in relation to the lateral meniscus (Fig. 4A). Injuries to the meniscotibial ligament can be identified on coronal views (Fig. 4B) as focal discontinuity, increased signal intensity and thickening, or nonvisualization of the normal low-intensity signal pattern. Bone avulsion of the meniscotibial ligament portion of the midthird lateral capsular ligament is termed a Segond fracture.[12,16,24,25]

Fibular Collateral Ligament

The fibular collateral ligament attachment on the femur originates between the lateral epicondyle and the supracondylar process. Its main attachment distally is into a groove at the lateral edge of the fibular head, anterior to the fibular styloid.[21] The fibular collateral ligament is best seen on MRI in the axial, coronal, and coronal-oblique views (Tables 1 through 3). It extends obliquely from its femoral attachment near the lateral epicondyle to its fibular attachment adjacent to the fibular attachment of the anterior arm of the long head of the biceps femoris muscle (Fig. 5A). Injuries to the fibular collateral ligament are best seen on MRI in the axial and coronal planes (Fig. 5B). The most common injury patterns included soft tissue avulsion off the insertion on the femur or as a bone avulsion associated with an arcuate fracture of the fibular head (see “Arcuate Fracture”).[11,12,17]

Lateral Gastrocnemius Tendon and Fabellofibular Ligament

The lateral gastrocnemius tendon is located at the far lateral edge of the lateral gastrocnemius muscle-tendon complex. In the region of the fabella, which may be either bony or cartilaginous,[11,21] the lateral gastrocnemius tendon becomes adherent to the posterior capsule of the knee and intimately blends with the meniscofemoral portion of the posterior capsule before inserting just posterior to the fibular collateral ligament attachment on the lateral femoral condyle at the supracondylar process. The lateral gastrocnemius tendon can be well visualized on the sagittal view as a low signal intensity structure at the far lateral edge of the lateral head of the gastrocnemius muscle (Fig. 6) (Tables 1 through 3). Injuries, including complete tears, of this structure were rare. The one case found to be torn at surgery was incorrectly identified as normal on MRI.

The fabellofibular ligament is a thickening of the distal edge of the capsular arm of the short head of the biceps femoris muscle.[11,21] It attaches at the posterolateral aspect of the fabella, or fabella-analog,[21] and inserts just lateral to the tip of the fibular styloid and medial to the direct arm of the short head of the biceps femoris muscle. The fabellofibular ligament is visualized best on the coronal (Fig. 7A) or coronal-oblique views. Injuries to the fabellofibular ligament showed distal avulsion, thickening, increased signal intensity, or nonvisualization. Avulsion of the fabellofibular ligament off the fibular styloid often occurred concurrently with an avulsion of the direct arm of the short head of the biceps femoris muscle (Fig. 7B).

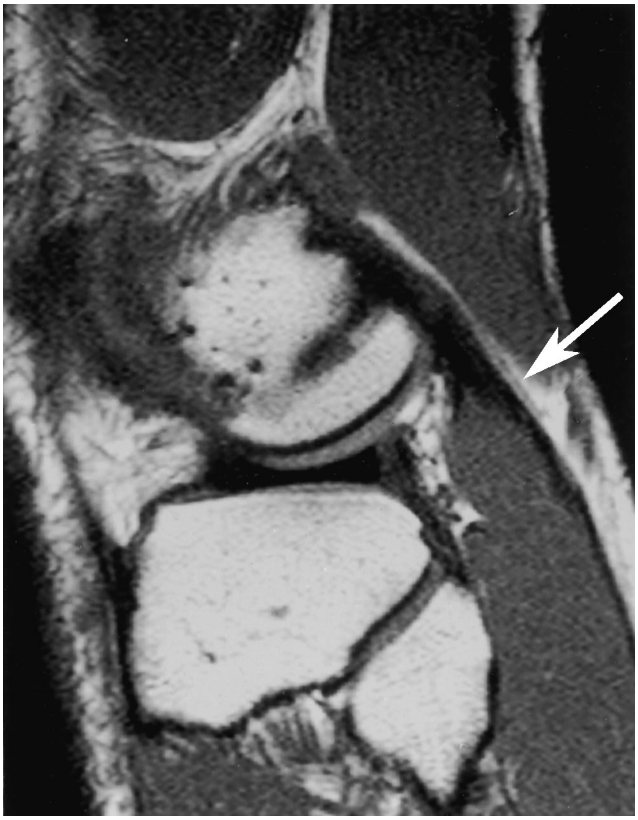

Figure 6. The MRI appearance of the normal lateral gastrocnemius tendon (arrow) (sagittal view, right knee).

Specific Injuries to the Posterolateral Knee

Arcuate Fracture. The arcuate fracture is an avulsion of the fibular head and styloid at the fibular attachment of the posterolateral corner ligamentous structures (anterior and direct arms of the long head of the biceps femoris muscle, direct arm of the short head of the biceps femoris muscle, fabellofibular ligament, fibular collateral ligament, and the popliteofibular ligament).[11,12,17] A bony arcuate fracture is best visualized on plain radiographs, but the extent of associated ligaments attached to this avulsion fracture can be best visualized on MRI in the coronal and sagittal views (Fig. 8).

Segond Fracture. The Segond fracture, often called a lateral capsular (midthird lateral capsular ligament) avulsion fracture, is seen on MRI as a bone avulsion of the meniscotibial portion of the midthird lateral capsular ligament off the tibia and has been found to often include an avulsion of the anterior arm of the short head of the biceps femoris muscle.[11,12,16,22,24,25] Bone avulsion is best identified on plain radiographs. Segond fractures are best vi-

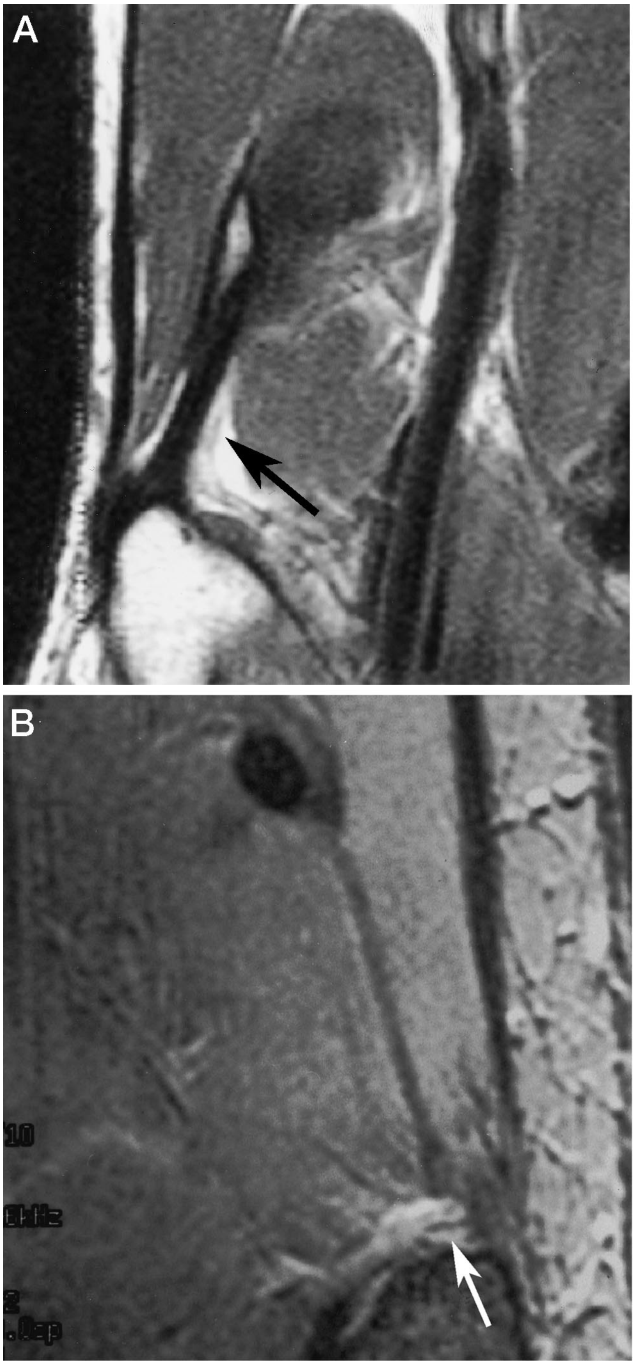

Figure 7. The MRI appearance of the fabellofibular ligament (arrows). A, normal (coronal view, right knee). B, avulsion of the fabellofibular ligament off its attachment on the posterolateral fibular styloid (coronal view, right knee).

sualized on MRI on the coronal view (Fig. 9), but they can be visualized on the axial view as well.[24] In addition, we have noted that soft tissue avulsion injuries, which we have termed "soft tissue Segond injuries," may occur and can be visualized as a high signal intensity disruption with proximal retraction or thickening and redundancy of

Figure 8. The MRI appearance of the arcuate avulsion fracture of the fibular head (arrow) (coronal view, left knee).

Figure 9. The MRI appearance of the Segond avulsion fracture (arrow) (coronal view, right knee).

the normal low signal conjoined tibial attachment of the anterior arm of the short head of the biceps femoris muscle and the meniscotibial portion of the midthird lateral capsular ligament with consistency on MRI scans (Fig. 4B).

DISCUSSION

There is a paucity of information describing and summarizing the MRI appearance of the normal anatomy and injured individual components of the posterolateral knee. Previous studies do not give the information necessary to aid in determining the integrity of the individual components of the posterolateral knee or to aid in the identification of individual structures that may need to be surgically repaired.[15,19,26] Information concerning the individual structures of the posterolateral knee may be crucial with respect to surgical repair, as patients with grade III injuries to the posterolateral corner of the knee have poor functional results[8] and untreated grade III posterolateral complex injuries have been suggested to be a significant cause of ACL graft failure.[11,14] In this study we were able to demonstrate that the MRI protocol we presented yields accurate visualization of the majority of the complex individual components of the posterolateral knee as well as injuries to these structures. We believe that MRI of the posterolateral knee is a useful adjunct to the surgeon in the diagnosis of grade III injuries to the posterolateral knee when the diagnosis may be in doubt.

Because of the relatively small number of knees in this study, a direct comparison between acute and chronic knee injuries was not performed. There were no obvious differences demonstrated between the acute and chronic knee injuries in our ability to correctly diagnose torn structures on MRI (Table 2).

In summary, this study does not identify those patients with posterolateral knee injuries who need surgery. Its purpose was to aid the clinician in the understanding of this complex rotatory instability problem and aid in determining the pattern of injury present. Ideally, one should rely on the physical examination to achieve a diagnosis. In complex cases, especially in the acutely injured painful knee, it has been recognized that a good physical examination may not be obtainable. In these cases, when posterolateral rotatory instability is suspected, we believe that the MRI techniques we have outlined to visualize specific injuries of the posterolateral knee will consistently allow identification of the majority of these injured structures. We also recommend that a specific MRI protocol, which includes the entire fibular head and styloid on all imaging sequences, be used to best identify these structures when a posterolateral knee injury is being evaluated on MRI.

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