Lateral Meniscus Root Tear and Meniscus Extrusion with Anterior Cruciate Ligament Tear

To retrospectively determine the prevalence of posterior lateral meniscus root tears (LMRTs), as depicted on magnetic resonance (MR) images, in patients with an anterior cruciate ligament (ACL) tear and to investigate the association of LMRTs with lateral meniscus extrusion and other ligament injuries.

Institutional review board approval was obtained; informed consent was not required. This study was HIPAA compliant. MR images were obtained in 174 male and 119 female patients (mean age, 37 years; age range, 16–87 years) and retrospectively reviewed for LMRT, medial meniscus root tear (MMRT), nonroot meniscus tear, meniscus extrusion, and presence of meniscofemoral ligaments (MFLs). The $\chi^2$ and unpaired Student t tests were performed.

In 33 patients, 34 meniscus root tears were identified. An LMRT was present in 26 (9.8%) of 264 patients, and an MMRT was present in eight (3.0%) ($P = .008$). Lateral meniscus extrusion was present in six (23%) of 26 LMRTs and five (2.2%) of 231 patients with normal meniscus roots ($P < .001$). Complex or deep radial tears were found in three of five cases of lateral meniscus extrusion and normal root. The MFL was not observed in five (19%) of 26 studies of an LMRT. Among these 26 studies of an LMRT, lateral meniscus extrusion was identified in three (14%) of 21 cases in which the MFL was intact and in three (60%) of five cases in which the MFL was not identified ($P < .03$). Prevalence of an extruded meniscus was seven (88%) of eight for an MMRT and six (23%) of 26 for an LMRT ($P = .001$).

Prevalence of LMRTs is greater than that of MMRTs in patients with an ACL tear. LMRTs and complex and radial tears are associated with lateral meniscus extrusion; an absent MFL is more prevalent in patients with LMRTs and when the meniscus is extruded.

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The anterior and posterior meniscal roots are the sites where the knee meniscus attaches to the central tibial plateau. While various types of meniscal tears have been described, to our knowledge, tears of the meniscus roots have not been described in a major radiology textbook. In 1994, De Smet and Graf (1) reported a case of posterior lateral meniscus root tear (LMRT) in a larger series of meniscal injuries in patients with an anterior cruciate ligament (ACL) tear. Recently, an abstract described posterior LMRTs in another cohort of patients with ACL tears and suggested a common injury mechanism (2). Other authors have reported an association between medial subluxation or extrusion of the medial meniscus, medial femorotibial osteoarthritis, and posterior meniscal root tear (MMRT) (3,4). Although each meniscus has both an anterior and a posterior root, to our knowledge, only posterior root tears have been reported.

We are unaware of any published reports on posterior LMRTs and lateral extrusion of the lateral meniscus. Thus, the purpose of our study was to retrospectively determine the prevalence of posterior LMRTs, as depicted on magnetic resonance (MR) images, in patients with an ACL tear and to investigate the association of LMRTs with lateral meniscus extrusion and other ligament injuries.

**Materials and Methods**

**Included Studies**

This study was approved by our institutional review board and complied with the Health Insurance Portability and Accountability Act. Informed consent was not required. Reports of all 8540 outpatient 1.0-T MR imaging examinations of the lower extremity performed between January 2000 and June 2004 at our institution were searched for the diagnosis of ACL tear. Our search yielded 297 MR studies of the knee obtained in 293 patients (174 male patients; 119 female patients; mean age, 37 years; age range, 16–87 years). Bilateral ACL tears existed in one male patient and three female patients.

**MR Imaging**

All examinations were performed with a 1.0-T whole-body MR imager (Magnetom Harmony; Siemens Medical Solutions, Erlangen Germany). Patients were examined in the supine position, with their knee in a standard extremity circularly polarized transmit-receive surface coil. Transverse T2-weighted fast spin-echo (SE) (repetition time msec/echo time msec, 4655/96; flip angle, 180°; echo train length, five; section thickness, 4.0 mm; section gap, 1.0 mm; field of view, 180 cm; matrix, 224 × 512; number of signals acquired, two) and sagittal conventional SE intermediate- and T2-weighted (2300/20, 80; section thickness, 3.0 mm; section gap, 1.0 mm; field of view, 160 cm; matrix, 192 × 256; number of signals acquired, one) MR images were obtained in all cases.

During the first 18 months of the study period, (a) coronal intermediate-weighted fast SE and T2-weighted (4083/17, 119; flip angle, 180°; echo train length, five; section thickness, 3.0 mm; section gap, 1.0 mm; field of view, 160 cm; matrix, 215 × 256; number of signals acquired, one), (b) sagittal fast SE intermediate-weighted spectral fat-saturated (2000/12; flip angle, 180°; echo train length, three; section thickness, 3.0 mm; section gap, 1.0 mm; field of view, 160 cm; matrix, 213 × 256; number of signals acquired, one), and (c) sagittal SE T1-weighted (715/20; section thickness, 4.0 mm; section gap, 1.0 mm; field of view, 160 cm; matrix, 256 × 256; number of signals acquired, one) MR images were obtained. During the last 36 months of the study period, coronal intermediate-weighted fast SE fat-saturated (1800/20; section thickness, 3.0 mm; section gap, 1.0 mm; field of view, 160 cm; matrix, 242 × 256; number of signals acquired, one) MR images were obtained.

**Image Analysis**

Studies were viewed at a picture archiving and communication system workstation with standard features, including the ability to adjust window and level settings, change the zoom factor, and apply electronic calipers. All studies were reviewed together by two radiologists with subspecialty expertise in musculoskeletal MR imaging (J.M.B., G.A.T.; both with 15 years of experience). MR images of the knee were reviewed for the presence of meniscal root tear, meniscus tear other than root tear, meniscus extrusion, meniscofemoral ligaments (MFLs) of Humphrey and Wrisberg, medial collateral ligament tear, and the extent and location of bone marrow contusions.

Meniscal roots were defined as the last few millimeters of meniscal tissue angling down to the tibial plateau attachment in the intercondylar notch and were visible on both coronal and sagittal MR images (Fig 1). Meniscus root tear was defined as distortion and increased signal intensity within the meniscal root that ex-
tended to the articular surface on the intermediate-weighted, T2-weighted, or intermediate-weighted fast SE fat-suppressed MR images. Nonroot meniscal tear was defined as abnormal globular or linear signal intensity extending to the articular surface on at least two adjacent sections and was characterized according to published criteria (5).

Meniscal extrusion was diagnosed when the longest distance from the peripheral margin of the body of the meniscus between the peripheral margin of the tibial articular cartilage was greater than 1 mm on any of the middle three coronal sections obtained through the meniscal body. If the margin of tibial articular cartilage could not be clearly identified, the point where orthogonal lines drawn tangential to the articular surface and the medial cortex of the tibial plateau intersect on the coronal intermediate-weighted or intermediate-weighted fast SE fat-suppressed images was used instead.

The MFLs were considered absent when they could not be identified on images obtained with any of the performed sequences. Medial collateral ligament tear was diagnosed when the ligament was discontinuous, thick, and hyperintense. Bone marrow contusion was identified as a circumscribed or ill-defined area of increased signal intensity in the subcortical marrow on intermediate-weighted or T2-weighted MR images. Contusions 2 cm in diameter or smaller were classified as “localized,” and those larger than 2 cm in diameter were classified as “extensive.” Studies that showed cartilage loss, joint space narrowing, or osteophytes from femorotibial osteoarthritis were excluded.

Arthroscopic Comparison
An author (J.M.B.) obtained knee arthroscopy data after reviewing images from office medical records, including diagrams and dictated summaries of surgery. Among our group of four referring orthopedic surgeons, only one (M.J.H., 10 years of knee arthroscopy experience) looks for meniscal root tears during routine arthroscopy. Consequently, we have arthroscopic correlation for only those patients referred by this orthopedist.

Statistical Analysis
Differences were evaluated with the χ² test (inferences on proportions) and the unpaired Student t test (comparison of mean distance of meniscus extrusion) by using statistical software (Statview for Windows, version 5.0.1; SAS Institute, Cary, NC). Significance values were calculated with respect to the two-tailed alternative hypothesis. The null hypothesis was rejected if the P value was less than .05.

Results

Final Studies and Root Tears
Thirty-three studies that showed osteoarthritis were excluded. In the remaining 264 studies, 34 meniscus root tears were identified in 33 patients (one patient had a root tear in each knee). This group included 20 male and 13 female patients (mean age, 37 years; age range, 16–62 years). LMRT was identified in 26 (9.8%) of 264 studies, whereas MMRT was found in eight (3.0%) studies (P = .008; Figs 2, 3).

Lateral Meniscus Extrusion
Lateral meniscus extrusion was present in six (23%) of 26 studies in which an LMRT was present and in five (2.2%) of 231 studies in which the lateral meniscus root was normal (P = .001, Fig 2). Of the five studies that showed lateral meniscus extrusion and a normal meniscus root, three showed complex or radial tears of more than 50% of the lateral meniscus thickness, and two showed more superficial meniscal tears (Fig 4).

Of the 26 cases of LMRT, at least one MFL was seen in 21 (81%) studies; both MFLs were absent in the remaining five (19%) studies. Three lateral menisci were extruded in the five cases of LMRT and absent MFLs, whereas only
three lateral menisci were extruded in the 21 cases of LMRT with an intact MFL \((P < .03, \text{Fig } 5)\). In the 231 studies that showed a normal lateral meniscus root, 207 (89.6\%) showed an intact MFL, while the remaining 24 (10.4\%) showed an absent MFL. However, there was no significant difference in the prevalence of an absent MFL between studies with an intact lateral meniscus root and those with an LMRT \((P = .18)\).

Extrusion of the meniscus was identified in seven (88\%) of eight cases of MMRT and in six (23\%) of 26 cases of LMRT \((P = .001)\). The mean extrusion of the meniscus was 3.8 mm \(\pm 1.5\) (standard deviation) for MMRTs compared with 2.6 mm \(\pm 1.2\) for LMRTs \((P = .16)\).

### Additional Tears
In the cohort of 34 meniscus root tears, 28 (82\%) cases were associated with additional meniscal tears; however, there was no significant difference in the type or distribution of these tears in studies that showed MMRTs or LMRTs. There was also no significant difference in the distribution and extent of bone marrow contusion or the prevalence of medial collateral ligament tears.

### Comparison with Arthroscopy
In this study, the orthopedic surgeon (M.J.H.) who routinely evaluates the meniscal roots examined five patients with LMRTs. LMRT was confirmed at arthroscopy in four of these patients; however, in one patient, there was a radial tear with a thickness of more than 50\% adjacent to the root in the lateral meniscus posterior horn.

### Discussion
There is comparatively little written about tears at the anterior or posterior attachment of the meniscus to the central tibia, which is referred to as the root of the meniscus. In a study of 400 patients with a torn ACL, De Smet and Graf (1) reported various types of meniscus tears—including oblique, flap, radial, and bucket-handle tears—and a single posterior LMRT. Kidron and Thein (6) reported that radial root tears could potentially mask larger posterior horn cleavage tears at arthroscopy. In contrast to the number of studies of LMRTs, there have been more investigations of MMRTs, particularly as MMRTs relate to the pathophysiology of medial femorotibial osteoarthritis through meniscus subluxation (3,4). In these studies, researchers postulated that MMRTs, as well as extensive radial and complex tears, disrupt the hoop stress function provided by intact circumferential fiber bundles within the meniscus. This permits radial expansion and displacement of the meniscus from the joint space (ie, subluxation or extru-
As such, axial compressive forces on the knee during weight bearing are transmitted directly to the articular cartilage and may cause premature cartilage degeneration that will lead to osteoarthritis.

In our study, we found that LMRTs were more prevalent than MMRTs in patients with ACL tears and that lateral meniscus extrusion was associated with root, complex, and deep radial tears. However, extrusion of the meniscus was more prevalent in patients with MMRTs than in patients with LMRTs. The medial meniscus is attached firmly to the joint capsule and is also fixed to the inferior margin of the tibial plateau by the coronary ligament (7–9). With the exception of the popliteal hiatus, the lateral meniscus is also firmly attached to the joint capsule by the MFLs, popliteal fascia, and arcuate complex (7,8). However, since more body weight is transmitted through the medial femorotibial joint than through the lateral compartment during ambulation, one might speculate that greater axial forces would preferentially displace the medial meniscus when its root is torn.

We also found that the absence of the MFL is associated with lateral meniscus extrusion when an LMRT occurs. It is plausible that the loss of the MFL anchor contributes to meniscal extrusion. The MFLs are gracile structures that originate at the lateral margin of the posterior femoral condyle and insert on the posterior horn of the lateral meniscus. One MFL courses anterior to the posterior cruciate ligament (ligament of Humphrey), whereas the other MFL courses posterior to the posterior cruciate ligament (ligament of Wrisberg). Thus, none, one, or both of the MFLs may be present.

The function of the MFL is not completely understood. One theory proposes that it acts tangentially to redirect the meniscus away from the tibia and femur during knee flexion to prevent compression injury to the meniscus.
It would be interesting to study meniscal biomechanics when the MFL has been severed; however, to our knowledge, no such investigation has been performed. In our study, the MFL was absent in 10.4% of cases of ACL tear in which the lateral meniscus root was normal and in 19% of cases of ACL tear in which the lateral meniscal root was torn. In a review of published case series comprising 1022 knees, the MFL was absent in 0%–29% of studies (10). Erbagci et al (11) reported that the MFL could not be identified in 18% of MR studies. Thus, the prevalence of MFL absence in our cohort closely follows that reported previously.

There were limitations of our study. We had surgical confirmation for only four of five LMRTs. In one patient, a large radial tear was found in the posterior horn of the lateral meniscus. The absence of surgical confirmation in this patient was a drawback; however, it can be explained: First, initial interpretations of the MR images did not mention the diagnosis of meniscal root tear, so the referring orthopedic surgeon was not forewarned of its presence. Second, the posterior paramedian joint space is not routinely evaluated at arthroscopy, especially when no specific lesion has been described in that region. The exclusion of patients with signs of osteoarthritis might be questioned, since we were evaluating a meniscus tear that might contribute to the development or exacerbation of osteoarthritis. However, we chose to examine knees with ACL tears for LMRTs prior to the development of frank osteoarthritis. Our definition of meniscus extrusion (meniscus displacement ≥ 1 mm) may seem too lax, as some authors define it as meniscus displacement of 3 mm or more (4). However, our intent was to investigate early stages of abnormal biomechanics that might result from a torn meniscus root.

LMRTs occur with ACL tears and may be associated with lateral extrusion of the lateral meniscus. Furthermore, absence of the MFL is more prevalent when the lateral root is torn and the meniscus is extruded.

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References