Magnetic Resonance Imaging and Arthroscopic Findings of the Popliteomeniscal Fascicles With and Without Recurrent Subluxation of the Lateral Meniscus

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Purpose: The aim of this study was to examine the posterosuperior popliteomeniscal fascicle (sPMF) and anteroinferior popliteomeniscal fascicle (iPMF) by use of magnetic resonance imaging in control knee joints and joints with recurrent subluxation of the lateral meniscus (RSLM) to determine the incidence of abnormal popliteomeniscal fascicles (PMFs) in these groups. Methods: Knee joints were diagnosed with RSLM when there was a history of mechanical locking episodes and when subluxation of the lateral meniscus was recognized on arthroscopy. In this study 238 knee joints were evaluated. The joints were classified into a control group (215 joints), RSLM group (16 joints), and contralateral RSLM group (7 joints). Classification of the sPMF (iPMF) on magnetic resonance imaging was as follows: type I, a tense, low-intensity band ran from the superior (inferior) border of the lateral meniscus to the popliteus tendon; type II, an unclear band ran from the superior (inferior) border of the lateral meniscus; and type III, no band was observed. Types II and III were thought to exhibit abnormal PMFs. The distribution of knee joints among the 3 groups and PMF types was examined. Results: Percentages of abnormal sPMFs and iPMFs were 40% and 26%, respectively, in the control group; 100% and 29%, respectively, in the contralateral RSLM group; and 100% and 100%, respectively, in the RSLM group. A significant difference in the distribution of knee joints by classification of sPMFs was recognized between the control and contralateral RSLM groups (P < .0001). A significant difference in iPMFs was also recognized between the contralateral RSLM and RSLM groups (P = .0005). Conclusions: A significantly high incidence of abnormal sPMFs was found in RSLM and contralateral knees. Thus abnormal sPMFs existed in both knee joints before patients had locking symptoms, suggesting that abnormal sPMFs may be required for locking symptoms. A significantly high incidence of abnormal iPMFs was found only in the knee joints with RSLM. An abnormal iPMF is thus the essential lesion to allow the at-risk lateral meniscus to become unstable beyond the rate of control knees. Level of Evidence: Level III, case-control study.

Recurrent subluxation of the lateral meniscus (RSLM) is characterized by a history of painful locking symptoms and is diagnosed arthroscopically by reproducing subluxation of the lateral menisci without tears or anomalies. However, the causes and pathophysiology of RSLM have not yet been fully elucidated. Several structures control physiologic meniscal movement during knee joint motion. Among them, the popliteomeniscal fascicle (PMF), consisting of the posterosuperior popliteomeniscal fascicle (sPMF) and anteroinferior popliteomeniscal fascicle (iPMF), plays an important role in keeping the lateral meniscus stable. Recurrent subluxation of the lateral meniscus is characterized by a history of painful locking symptoms and is diagnosed arthroscopically by reproducing subluxation of the lateral menisci without tears or anomalies. However, the causes and pathophysiology of RSLM have not yet been fully elucidated. Several structures control physiologic meniscal movement during knee joint motion. Among them, the popliteomeniscal fascicle (PMF), consisting of the posterosuperior popliteomeniscal fascicle (sPMF) and anteroinferior popliteomeniscal fascicle (iPMF), plays an important role in keeping the lateral meniscus stable.1-3 Because the PMF is a primary restraint to anterior displacement of the posterolateral corner of the lateral meniscus at 90° of flexion of the knee joint,4 disruption of the PMF is required for induction of hypermobility of the lateral...
varied, from 55% to 100% in anatomic studies and 50% to 100% in MRI studies. Therefore, when PMF insufficiency is found in a knee joint with RSLM, whether PMF insufficiency is caused by the locking symptoms of the lateral meniscus or has existed before such symptoms occur is unclear, and it is unknown whether PMF insufficiency is a cause of RSLM.

The purpose of this study was to examine PMFs using MRI and arthroscopic examination in control joints, knees with RSLM, and knees contralateral to knees with RSLM to determine what percentage of each group would exhibit abnormal PMFs and whether abnormal PMFs are a cause of RSLM. Our hypothesis was that the asymptomatic knees contralateral to knees with RSLM would exhibit the same percentage of abnormal PMFs as knees with RSLM.

METHODS

The subjects of this study were 142 patients who visited our knee joint clinic between January 2007 and December 2008. More than half of the patients of the knee joint clinic were referred from other clinics, whereas the other patients were referred from other outpatient clinics in our hospital by our colleagues for possible need for surgical intervention. All patients of the knee joint clinic underwent radiographic and MRI examination of both knee joints. We included all of the patients of the knee joint clinic who had atraumatic knee pain in this study. We excluded from this study patients who had a history of apparent injury and those with knee joints with apparent instability. To examine the influence of age on the structure of the PMF, we included patients with medial osteoarthritis of grade 2 or 3 on the Kellgren-Lawrence grading system on radiographic examination. However, we excluded patients with lateral osteoarthritis of the knee joints of grade 2 or higher because lateral osteoarthritis might influence magnetic resonance (MR) findings of PMFs by inducing inflammation around PMFs. Coronal, sagittal, and anteromedial-to-posterolateral directed 45° oblique coronal images were obtained from fully extended knee joints in supinely positioned patients with an MRI system (Signa EXCITE 1.5 T; GE Healthcare, Milwaukee, WI). A series of proton density-weighted images with a 3-mm slice thickness and 256 × 512 matrices were used for 45° oblique coronal views. Of 284 joints, 242 whose MRI studies were sufficiently clear and which did not have a tear or anomaly of the lateral meniscus, or other abnormal findings in the lateral compartment on sagittal and coronal MRI, were used to investigate sPMFs and iPMFs. The reasons for exclusion of 42 joints from this study were discoid meniscus (4 joints), lateral meniscal tear (9 joints), and lack of clarity of 45° oblique coronal images, defined as unclarity of the contours of the lateral femoral condyle and tibial plateau on MR images (29 joints). This study was approved by the institutional review board of the hospital where surgery was performed.

The study population consisted of the following 3 groups. Joints that had no history of catching or locking symptoms and whose contralateral knee joint had no such history either were included in group C. This group consisted of 127 patients (59 male and 68 female patients) with 215 joints (101 male joints and 114 female joints), ranging in age from 11 to 71 years (mean, 34.5 years) and was subdivided by mean age into an A1 subgroup (<34 years) and an A2 subgroup (≥35 years) (Tables 1 and 2). There were 101 asymptomatic joints and 114 affected joints. The diagnoses of affected joints based on clinical and MRI findings included the following: isolated medial meniscal tear (7 joints), cam impingement of the posterior femoral condyle (12 joints), cam impingement of the posterior femoral condyle with medial meniscal tear (25 joints), patellofemoral disorder (29 joints), and unicompartmental medial osteoarthritis (grade 2 or 3) with medial meniscal degeneration or tear (41 joints).

Knee joints were included in group R when they had a history of mechanical locking episodes with pain on the lateral joint line and were diagnosed arthroscopically as having RSLM by reproducing subluxation of the lateral meniscus with the peripheral margin of the posterior segment of the lateral meniscus moving with a probe anteriorly beyond the lateral femoral condyle at 90° of flexion of the knee joint. Group R consisted of 11 patients (1 male and 10 female patients) with 16 knee joints (2 male joints and 14 female joints), ranging in age from 10 to 48 years (mean, 25.3 years) (Tables 1 and 2).

Asymptomatic knee joints contralateral to knees with RSLM were included in group CR. This group consisted of 7 female patients ranging in age from 10 to 48 years (mean, 29.9 years) (Tables 1 and 2). Of 7 knee joints, 6 were from patients in group R. The remaining 1 knee was from a patient with 1 knee
diagnosed with RSLM, as verified by MRI during locking symptoms. Because this patient did not wish to undergo further examination and treatment of the knee with RSLM after reduction of subluxation of the lateral meniscus, this knee with RSLM was not included in group R.

There were 2 knee joints that had a history of locking episodes in deep flexion, but subluxation of the lateral meniscus could not be reproduced at 90° of flexion of the knee joint on arthroscopy. Because these joints and their contralateral knee joints did not meet any inclusion criteria for the 3 groups, they were excluded from this study.

Of 55 patients with 76 joints who underwent arthroscopic examination, 51 patients with 72 joints (40 patients with 56 joints in group C and 11 patients with 16 joints in group R) underwent arthroscopic evaluation of sPMFs. The patients, ranging in age from 13 to 55 years (mean, 29.7 years) were subdivided by mean age into a B1 subgroup (<29 years) and a B2 sub-

### Table 1. Distribution of Knee Joints by Presence or Absence of RSLM, Type of sPMF on MRI, Sex, and Age

<table>
<thead>
<tr>
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<tbody>
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<td></td>
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<td>Female</td>
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<td>A2</td>
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<td>.27§</td>
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</table>

NOTE. Type I indicates that a low-intensity band was clearly depicted with obvious continuity from the lateral meniscus to the popliteus tendon, type II indicates that a band was not clearly depicted or was depicted with discontinuity, and type III indicates that no band was visible.

*Significant difference between subgroups A1 and A2.
†Significant difference between groups C and CR.
‡Significant difference between groups C and R.
§Statistical power of comparison between groups CR and R.

### Table 2. Distribution of Knee Joints by Presence or Absence of RSLM, Type of iPMF on MRI, Sex, and Age

<table>
<thead>
<tr>
<th>Group C</th>
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<td>.37§</td>
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</tbody>
</table>

NOTE. Type I indicates that a low-intensity band was clearly depicted with obvious continuity from the lateral meniscus to the popliteus tendon, type II indicates that a band was not clearly depicted or was depicted with discontinuity, and type III indicates that no band was visible.

*Significant difference between subgroups A1 and A2.
†Significant difference between groups R and C.
‡Significant difference between groups R and CR.
§Statistical power of comparison between groups C and CR.
group (≥30 years) (Table 3). Arthroscopic examination was performed in group C when partial medial meniscectomy, medial meniscal repair, decompression of the medial meniscus, or surgical intervention for patellofemoral joint pain was considered potentially indicated in the affected knee joints. The remaining 54 affected joints and 101 asymptomatic joints in group C underwent MRI examination only. Arthroscopic examination of PMFs was performed through a midpatellar lateral portal with the knee joint fully extended by use of a 30° angled arthroscope. Because the iPMF was usually covered with synovial tissue and it was difficult to clearly differentiate iPMFs from the coronary ligament at full extension of the knee joint, we evaluated only sPMFs arthroscopically. In 4 excluded joints, because the sPMF was completely covered with hypertrophic synovial tissue and could not be seen at all on arthroscopy, classification of the sPMF on arthroscopy was impossible.

MR images of PMFs are shown in Figure 1. Classification of the sPMF and iPMF on MRI and that of the sPMF on arthroscopy are explained in Figures 2, 3, and 4, respectively. In every classification, type I indicates that a tendinous fascicle ran straight from the superior edge of the lateral meniscus in the proximolateral direction, type II indicates that a fascicle ran in a different direction, and type III indicates that no fascicle was recognized.

### Table 3. Distribution of Knee Joints by Presence or Absence of RSLM, Type of sPMF on Arthroscopy, Sex, and Age

<table>
<thead>
<tr>
<th>Group</th>
<th>R</th>
<th>Sex Age</th>
<th>Total</th>
<th>Group</th>
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<tbody>
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<td>Female</td>
<td></td>
</tr>
<tr>
<td>Type I</td>
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<td>14</td>
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<tr>
<td>Type II</td>
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<td>12</td>
<td>8</td>
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</tr>
<tr>
<td>Type III</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
| P value| α = .05 
1 - β | .35  | .93 | < .0001* |

**NOTE.** Type I indicates that a tendinous fascicle ran straight from the superior edge of the lateral meniscus in the proximolateral direction, type II indicates that a fascicle ran in a different direction, and type III indicates that no fascicle was recognized.

*Significant difference between groups C and R.

### Statistical Analysis

Interobserver and intraobserver errors for type of sPMF and iPMF on MRI were calculated with κ statistics using 50 knee joints selected at random. To determine interobserver error, classification of PMFs of these 50 joints was performed by 2 teams, each of which consisted of 3 examiners blind to clinical features. To determine intraobserver error, classification of the 50 joints whose MR images were randomly arranged was performed twice by the 3 examiners blind to clinical features, with an interval of 1 month between measurements.

There were 88 patients in group C for whom bilateral MR images were available. The percentage of patients with the same type of PMF classification in both knee joints was determined.

The significance of differences (at $P < .05$) in mean age among the 3 groups, between male and female patients in group C, and between male and female patients who underwent arthroscopic examination in group C were determined. For statistical analysis, analysis of variance with the Scheffé method was used for mean age among the 3 groups and the unpaired t test was used between male and female patients in group C. The distributions of knee joints by group and by PMF type based on MRI and arthroscopy were examined. Moreover, the distribution of knee joints in group C according to sex and PMF type, as well as according to age subgroup and PMF type, was exam-
The $\chi^2$ test was used to examine the distribution of knee joints. A power study was performed when a $P$ value was .05 or higher.

There were 72 knee joints that underwent MRI and arthroscopy. The percentage of knee joints with the same type of MRI classification as arthroscopic classification was determined in groups C and R.

When MRI findings showing both an abnormal sPMF and an abnormal iPMF were used to diagnose RSLM, the sensitivity, specificity, and positive and negative predictive values of this method were calculated.

RESULTS

Interobserver errors for sPMFs and iPMFs were 0.73 and 0.75, respectively. Intraobserver errors for sPMFs and iPMFs were 0.88 and 0.90, respectively.

The percentage of patients with the same type of sPMF classification on MRI between the right and left knee joints was 77%, whereas that for iPMF was 80%.

There was no significant difference in mean age among groups C, CR, and R in patients who underwent MRI or in those who underwent arthroscopy. There was no significant difference in mean age between male and female patients in group C or in patients who underwent arthroscopy in group C. The distributions of knee joints by group and MRI classification of sPMFs are shown in Table 1, whereas those for iPMFs are shown in Table 2. The percentage of abnormal sPMFs was 40% in group C, 29% in subgroup A1, and 49% in subgroup A2. The percentage of abnormal iPMFs was 26% in group C, 15% in subgroup A1, and 35% in subgroup A2. The percentages of abnormal sPMFs and iPMFs in group CR were 100% and 29%, respectively. The percentages of

![Figure 2](image1.png)

**Figure 2.** Classification of sPMFs on MRI. Anteromedial-to-posterolateral 45° oblique coronal images of PMFs of the fully extended knee joints of supinely positioned patients were obtained, and images of left knees were used. (A) In type I a tense, low-intensity band runs from the superior corner of the lateral meniscus in the proximalateral and reaches the superior pole of the popliteus tendon in a straight line (B) or through a detour. (C) In type II a band not clearly depicted runs from the superior corner of the lateral meniscus, or a clearly depicted band runs from the superior corner of the lateral meniscus but does not reach the popliteus tendon. (D) In type III no band runs from the superior corner of the lateral meniscus.

![Figure 3](image2.png)

**Figure 3.** Classification of iPMFs on MRI. Anteromedial-to-posterolateral 45° oblique coronal images of PMFs of the fully extended knee joints of supinely positioned patients were obtained, and images of left knees were used. (A) In type I a tense, low-intensity band runs from the inferior corner of the lateral meniscus in the distolateral direction and reaches the inferior pole of the popliteus tendon in a straight line (B) or through a detour. (C) In type II a band not clearly depicted runs from the inferior corner of the lateral meniscus, or a clearly depicted band runs from the inferior corner of the lateral meniscus but does not reach the popliteus tendon. (D) In type III no band runs from the inferior corner of the lateral meniscus.
abnormal sPMFs and iPMFs in group R were both 100%.

The distribution of knee joints by group and arthroscopic classification of sPMFs is shown in Table 3. The percentage of abnormal sPMFs was 36% in group C and 100% in group R.

The percentage of knee joints with the same type of MRI and arthroscopic classification was 91% in group C and 100% in group R.

When MRI findings showing both an abnormal sPMF and an abnormal iPMF were used to diagnose RSLM, the sensitivity, specificity, positive predictive value, and negative predictive value were 100%, 83.3%, 30.2%, and 100%, respectively.

**DISCUSSION**

Our hypothesis that the asymptomatic knees contralateral to knees with RSLM exhibit the same percentage of abnormal PMFs as knees with RSLM was supported only in the case of sPMFs but not in that of iPMFs. The type of sPMF in the 2 knee joints in individuals was the same in 77% of cases, whereas that of iPMF was the same in 80%, indicating a high degree of agreement in PMF type between the 2 knee joints. This finding is consistent with the report of Tria et al.9 that the relation between the popliteus tendon and the lateral meniscus in specimens obtained from bilateral dissection of the knee joints exhibited no major asymmetry. The percentage of abnormal sPMFs was 40% in group C and 100% in groups CR and R, and it was significantly higher in groups CR and R (Table 1). Thus the abnormal sPMF was not an effect of locking symptoms but existed in both knee joints before patients had locking symptoms caused by RSLM. An abnormal sPMF thus appears to be required to trigger locking symptoms of RSLM, although the finding that an abnormal sPMF was present in 40% of cases in the control group indicates that an abnormal sPMF alone was not sufficient to induce RSLM. According to reports by Simonian et al.4 and Sussmann et al., a robust iPMF has a greater degree of control over lateral meniscal motion than the sPMF. An abnormal iPMF might thus be required for locking symptoms. However, our findings showed that an abnormal sPMF may be required for them. This discrepancy appears to be because the sPMF is located more posterior than the iPMF, giving the sPMF the advantage of retaining the posterior segment of the lateral meniscus posteriorly. The percentage of abnormal iPMFs was 26% in group C, 29% in group CR, and 100% in group R, with a significantly high incidence of abnormal iPMFs only in group R (Table 2). An abnormal iPMF thus appeared to be an effect of locking of the posterior segment of the lateral meniscus in most cases of RSLM.

Meniscectomy, coronary ligament and meniscocapsular repair, and thermal shrinkage of the posterolateral capsule have thus far been reported as treatments for RSLM.5,16-22 Because an abnormal iPMF is the essential lesion necessary for frank instability of the lateral meniscus, torn coronary ligaments and iPMFs have been repaired for such instability. However, recurrence of locking symptoms has been reported to occur in about 11% to 33% of patients who underwent coronary ligament and meniscocapsular repair or thermal shrinkage of the posterolateral capsule.16,19,21 If torn tissue caused by locking symptoms, including the iPMF and the coronary ligament, is repaired, the knee joint will return to its position before the first locking
symptom. This means that the original factors triggering locking symptoms remain, and recurrence of locking symptoms may occur, because an abnormal iPMF is an effect of locking symptoms. However, if an abnormal sPMF is repaired completely, locking symptoms may disappear permanently because an abnormal sPMF appears to be one of the requirements for induction of locking symptoms.

There were 2 patients excluded who had a history of mechanical locking episodes but in whom subluxation of the lateral meniscus could not be reproduced at 90° of flexion of the knee joint on arthroscopy. In these 2 knee joints, neither medial osteoarthritis nor varus deformity was recognized. Examination of the history of these patients showed that when they had locking symptoms, they did not extend the knee joint but bent deeply and rotated the knee joint internally and externally until the knee joint unlocked. On MRI, the sPMF was type II in 1 case and type III in the other whereas the iPMF was type I in both cases. On arthroscopy, the sPMFs were types II and III, respectively, although the posterior coronary ligament, which was always torn in patients with PMF in this study, was intact in both patients. Therefore the intact coronary ligament and iPMF appear to prevent subluxation of the posterior segment at 90° of flexion of the knee joints. However, the more deeply the knee joint bends, the more slack the coronary ligament becomes as a result of posterior displacement of the lateral meniscus.23,24 Thus the posterior segment of the lateral meniscus appeared to be able to dislocate anteriorly beyond the lateral femoral condyle only in deep flexion without damaging the coronary ligament and iPMF in these 2 patients.

The structure and functions of the PMF in the region of the popliteal hiatus have been described in detail, although no study that we found in the literature examined the biomechanics of the PMF. Cohn and Mainz1 reported that the PMF appears to minimize the expanse of meniscus that is untethered. Stäubli and Rauschning2 reported that the PMF controlled physiologic meniscal play in cooperation with other structures during knee joint motion. Simonia et al.4 objectively evaluated the stability of the lateral meniscus before and after sequential sectioning of the fascicles and found that the mean increase in anterior motion from the intact state was 78%. Oransky et al.5 showed for the first time in human fetuses that as the popliteal bursa enlarges, the popliteus tendon separates from the lateral meniscus and the PMF is formed. Sussmann et al.6 examined the fascicles during embryonic development and concluded that they appeared to provide a vascular supply to the lateral meniscus where it is devoid of capsular attachment. These studies indicate that the intimate structural association between the popliteus tendon and the lateral meniscus keeps the lateral meniscus stable.

The findings of studies of the frequency of PMFs in normal knee joints are still controversial. In anatomic studies many researchers have reported that the PMF was consistently observed, although the PMF was sometimes very thin.1,3,7-9 On the other hand, Tria et al.9 reported that 45% of 40 cadaveric knees showed no attachment of the popliteus tendon to the lateral meniscus, indicating lack of existence of the PMF, and found no evidence that the popliteus tendon plays a role in retraction or protection of the lateral meniscus.

In MRI studies the frequencies of MR visualization of the PMF were determined by Johnson and De Smet10 using sagittal images of knee joints that had neither a history of injury to the lateral compartment nor abnormal findings in the lateral compartment on arthroscopy. They reported that both sPMFs and iPMFs were seen in 97% of patients, and these were better seen on T2-weighted images than on proton-weighted images. Moreover, De Smet et al.11 and Blankenbaker et al.12 reported that the sPMF was normal on MRI in 100% and 97% of control knee joints, respectively. On the other hand, Sakai et al.13 reported that the optimal method for depicting both the sPMF and iPMF on MRI with the same slice angle involves the use of proton density–weighted images and 45° oblique coronal views. They inferred that although more than 88% of sPMFs and 94% of iPMFs in healthy knees of volunteers were visualized, only 50% of sPMFs and 65% of iPMFs had a tense, low-intensity band and consequently appeared normal. Because it is sometimes difficult to differentiate the sPMF from a fascicle at the meniscofemoral capsular attachment and the iPMF from the coronary ligament on sagittal images because the PMF runs in the posterolateral direction, we used 45° oblique coronal images to examine the PMF as accurately as possible.

Sakai et al.13 classified the PMF based on the combination of clarity and continuity of the PMF from the lateral meniscus to the popliteus tendon on MRI. However, because we planned to compare the findings on MRI with those on arthroscopy, we simplified their classification of PMFs. PMFs that were clear and combination of clarity and continuity of the PMF from the lateral meniscus to the popliteus tendon on MRI. However, because we planned to compare the findings on MRI with those on arthroscopy, we simplified their classification of PMFs. PMFs that were clear and exhibited continuity were considered type I, whereas PMFs that could not be seen at all on MRI were considered type III. PMFs that did not meet the criteria for type I or III were considered type II. In our study the percentages of visible sPMFs and iPMFs,
that is, type I or II, in the control group were 96% and 99%, respectively. The percentages of normal sPMFs and iPMFs, that is, type I, in the control group were 60% and 74%, respectively, with no significant difference between the findings of Sakai et al. and our findings.

In arthroscopic studies, Stäubli and Birrer\(^2\) reported that the incidence of structural lesions of the sPMF in control knees was 4.7%, whereas in our study the incidence of abnormal sPMFs was 36% (Table 3). The reason for this discrepancy appears to be that we regarded the sPMF as abnormal when the anterior portion of the sPMF, which has been described as a crescent-shaped insertion\(^1\) and which usually abuts the portion of the sPMF, which has been described as a crescent-shaped insertion\(^1\) and which usually abuts the posteromedial surface of the popliteus tendon (Figs 4A and 4B), is absent, whereas Stäubli and Birrer appear to have regarded it as normal in this condition. Their performance of arthroscopic examination through an anterolateral portal with the knee in 20° of flexion might also have contributed to this discrepancy. They also reported the incidence of structural lesions of the iPMF. However, because we could not always clearly identify the iPMF on arthroscopy because of coverage of it by the synovium, we did not evaluate the iPMF arthroscopically.

There is no clear definition of the normal PMF on MRI and arthroscopy. We believe that on MRI, the normal PMF should be depicted as a tense, low-intensity band connecting the lateral meniscus to the popliteus tendon, although about one-third of asymptomatic individuals will have abnormal PMFs. We ensured that MR images depicting the popliteus tendon at the same level or just slightly distal to the lateral meniscus were used to evaluate PMFs, although our classification of PMFs was based on a series of images. We paid special attention to the direction of the sPMF, that is, that the sPMF became proximal as it ran from the lateral meniscus to the popliteus tendon. Therefore a low-intensity band running distally from the lateral meniscus to the posterior capsule on MRI was not considered a normal sPMF and was classified as type II. On arthroscopy, a normal sPMF is clearly seen inserting into the proximal corner of the posterolateral portion of the lateral meniscus. However, the site of insertion of the sPMF on the popliteus tendon cannot be seen through a midpatellar lateral portal\(^1\) because it is located on the posterolateral side of the popliteus tendon. If we had used a 70° angled arthroscope or a posterior trans-septal portal,\(^2\) we might have been able to observe the insertion site more precisely. We therefore regarded the normal sPMF as a tense, tendinous fascicle running straight in the proximolateral direction with its anterior border abutting the posteromedial surface of the popliteus tendon (Figs 4A and 4B). Fascicles running in different directions, such as that of the meniscofemoral capsular attachment, were not considered normal sPMFs and were classified as type II (Fig 4C). Because the images of PMFs obtained from 45° oblique coronal images\(^1\) were very similar to those obtained from arthroscopy using the midpatellar lateral portal,\(^1\) it was very easy to compare the findings of MRI with those of arthroscopy. By use of these methods of MRI and arthroscopy to evaluate PMFs, the percentage of knee joints with the same type of MRI and arthroscopic classification was greater than 90%. The high incidence of abnormal sPMFs on 45° oblique coronal images compared with those on sagittal images was thus supported by the results of arthroscopic examination using MRI and arthroscopic classification described in this study.

Female patients were found to be more predisposed to RSLM than male patients in this study, although there were no significant differences in distribution of knee joints by MRI classification of sPMFs and iPMFs between male and female patients in the control group. Therefore not only abnormal sPMFs but other intrinsic or extrinsic factors to which female patients are predisposed appear to induce RSLM.\(^2\) The knee joints of the subjects aged 35 years or older were more likely to have abnormal PMFs on MRI than those of subjects aged less than 35 years. Gupte et al.,\(^2\) in a study of the anterior and posterior meniscofemoral ligaments in 84 fresh-frozen knees, reported that both ligaments were more likely to be present in younger specimens, and they speculated that both ligaments may normally be present at birth and disappear after injury and degeneration. Although the location of the PMFs and that of the meniscofemoral ligaments differ considerably, they are attached to the posterior half of the lateral meniscus and control meniscal movement.\(^3\) Therefore repetitive submaximal trauma caused by varus knees with unicompartmental medial osteoarthritis and/or aging might have influenced the structure or properties of PMFs. We found no difference in the distribution of knee joints on arthroscopic classification of sPMFs between age subgroups (Table 3), probably because the number of patients undergoing arthroscopic examination was relatively small and we performed arthroscopic examination on relatively young patients in this study.

There are several limitations to this study. First, this study was retrospective, although all patients who met the inclusion criterion for this study were included. Second, the inclusion criterion for this study was
atraumatic knee pain in patients referred to our knee joint clinic for potential surgical intervention. Because many orthopaedists referred patients to the clinic with different criteria regarding need for surgical intervention, we could not provide 1 precise inclusion criterion regarding symptoms. Third, about 10% of knee joints were excluded from this study because of lack of clarity of 45° oblique coronal images, defined as unclarity of the contours of the lateral femoral condyle and tibial plateau. We found unclarity in 45° images, although the coronal and sagittal images were somewhat unclear as well. The 45° images appeared to be more sensitive to patient movement during MR examination than the coronal and sagittal images. If we had included these unclear MR images in this study, the percentage of knee joints with abnormal PMFs might have increased by about 10%. Fourth, the numbers of knee joints in groups CR and R were small. This may have been the reason for our lack of findings of a significant difference ($P = .66$ and $\beta = .73$) between groups CR and R in the distribution of knee joints on MRI classification of sPMFs. Fifth, because more than half of the patients with RSLM were referred from other clinics, the true positive predictive value of our method of diagnosis of RSLM might be less than 30%. Moreover, because the percentage of knees with abnormal PMFs increases with age, more individuals should be diagnosed with RSLM using our method among the older population. However, RSLM usually occurs in younger patients. Therefore it may be that predictive values should have been calculated in younger and older patients separately if the number of subjects in this study had been much larger. Sixth, RSLM can be caused by trauma, because the PMF was found to be torn in about half of knee joints with anterior cruciate ligament injury and about 80% of knees with grade 3 posterolateral complex injuries. Therefore other factors involved in the pathophysiology of locking of the lateral meniscus should have been examined, including knee joints with RSLM caused by trauma or joint laxity. However, had we enlarged our study in this fashion, factors related to concomitant injury or instability might have complicated the results. We, therefore, excluded knee joints with a history of injury or joint laxity to simplify this study. Seventh, because our MRI and arthroscopic classification of PMFs was based on the morphology of the PMF, it is unclear how accurately we were able to evaluate the function of the PMF, which keeps the posterior segment of the lateral meniscus from dislocating anteriorly. Because type II sPMFs included a variety of fascicles, there may have been large differences in function among such fascicles. A fascicle might function as a checkrein to subluxation of the lateral meniscus even though it attaches to the posterior capsule instead of the popliteus tendon. Comparative study between the morphology of PMFs and the degree of instability of the posterior segment of the lateral meniscus measured by use of a force-displacement recorder on arthroscopy might solve this problem.

CONCLUSIONS

A significantly high incidence of abnormal sPMFs was found in RSLM and contralateral knees. Thus abnormal sPMFs existed in both knee joints before patients had locking symptoms, suggesting that abnormal sPMFs may be required for locking symptoms. A significantly high incidence of abnormal iPMFs was found only in the knee joints with RSLM. An abnormal iPMF is thus the essential lesion to allow the at-risk lateral meniscus to become unstable beyond the rate of control knees.

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