A CENTURY OF AJR MEDICAL IMAGING 1906 2006

MRI of the Popliteomeniscal Fasciculi

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OBJECTIVE. The purpose of this study was to further our understanding of the normal appearance of the popliteomeniscal fasciculi (PMF) on MRI after the determination of finely tuned imaging parameters. For this purpose we performed the study in two stages. Stage I was to determine suitable parameters for depicting the popliteomeniscal fasciculi. Stage II was to classify the "normal" image.

CONCLUSION. The findings presented in this article will contribute to the understanding of the normal appearance of the popliteomeniscal fasciculi on MRI, and of the degree of variation of this structure among the population.

According to several anatomic studies [1–3], the popliteomeniscal fasciculi (PMF) function as stabilizers of the lateral meniscus. In 1997, in a biomechanical study using cadaveric knees, Simonian et al. [4] showed the importance of the PMF in this role. In another paper, which was the first that clearly showed the clinical importance of the PMF, these authors presented three cases of hypermobile lateral menisci due to injured PMF [5]. According to that report, PMF injuries were detectable on MRI, a technique that has not been widely accepted. On MRI reports, the PMF are called lateral meniscal fasciculi; it is generally believed that abnormal findings do not necessarily imply derangement of the knee joints [6]. Blankenbaler et al. [7] and De Smet et al. [8] implied the clinical usefulness of findings of "abnormal superior fascicule" but did not refer to the normal appearance of the PMF. Johnson and De Smet [9], in a retrospective study, found that in 64 of 66 knees they could detect both fasciculi on routine MRI examinations. However, in a preliminary study, we were able to detect the PMF in only approximately 60% of the knees examined with routine sagittal and coronal slices in any sequences (data not shown). The lack of knowledge about the MRI appearance of the normal PMF makes it difficult to diagnose injuries to them.

Certain questions remain to be answered. Does every knee have these structures? Are the PMF thick enough to be depicted on routine MRI? The purpose of this study is to elucidate what percentage of knees show the PMF on MRI, not only on routine MRI examination but also on a modified MRI technique that includes optimal MRI sequences and optimized slice angles. Thus, our study consisted of two stages. The first stage was to determine the optimal MRI parameters for depicting the PMF. The MRI sequence, the number of matrices, and the slice thickness were examined in healthy knees from volunteers who consented to the study. Moreover, considering the different orientations of the anteroinferior and posterosuperior fasciculi of the PMF, we also chose to investigate the slice angle parameter. The second stage of the study was to show and classify normal images of the PMF, using the optimal conditions derived from stage I, in healthy knees that had no history of injury or trauma. An improved understanding of the MRI appearance of the normal PMF would increase our knowledge of its structure and might lead to improved diagnosis of PMF injury.

Materials and Methods

All imaging was performed with a Signa Horizon 1.5-T MR scanner (GE Healthcare).

Stage I

The following parameters were examined: MRI sequence, number of matrices, slice thickness, and slice angle with respect to the reference line (Fig. 1). For the assessment of images, using the first three parameters, six orthopedic knee surgeons (three experienced in MRI interpretation of the

Keywords: knee, MRI

DOI:10.2214/AJR.04.0068

Received January 14, 2004; accepted after revision October 19, 2004.

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AJR 2006; 186:460–466

0361–803X/06/1862–460

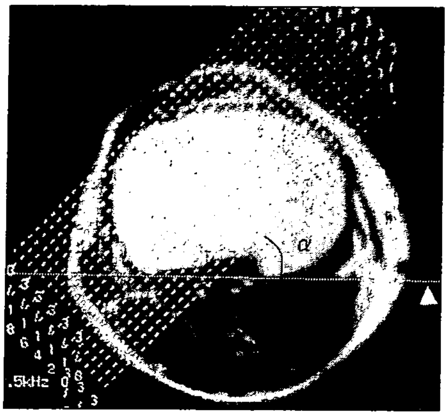

Fig. 1—Slice angle with respect to reference line. Arrowhead indicates reference line, α indicates slice angle.

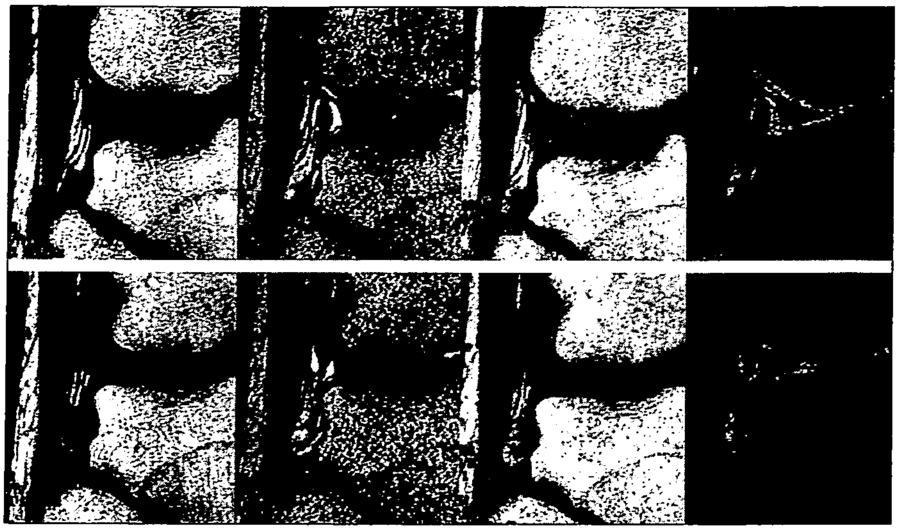

Fig. 2—Effects of MRI sequence for depicting popliteomeniscal fasciculi (PMF). Four sets of sequences were applied for depicting PMF. From left column to right: T1-weighted, T2-weighted, proton density–weighted, and proton fat-saturation images. Posterosuperior fasciculi are depicted in upper four images and anteroinferior fasciculi are depicted in lower four.

knee joint for > 10 years) ranked the sets of images according to the visibility of the PMF in terms of contrast, roughness, and sharpness of images. Two representative healthy knees were used for the assessment of sequence, number of matrices, and slice thickness. A numeric scoring system, ranging from 0 to 3, was used for the evaluation of slice angle as follows: 3 = obvious fasciculi continuity; 2 = fairly certain fasciculi continuity; 1 = uncertain fasciculi continuity; and 0 = fasciculi continuity could not be judged. Examiners were asked to evaluate the images not only by a single representative slice, but also by their ability to reconstruct 3D images of fasciculi from each set of images using the serial images. Six healthy knees with no history of trauma or knee pain were used in the study of slice angle. All six knees were right knees from men with an average age of 35.5 years (range, 28–55 years). Six orthopedic knee surgeons scored the images independently according to these criteria.

MRI sequence—We used four sets of MRI sequences for this study: T1-weighted, T2-weighted, proton density–weighted, and proton fat-saturation. Settings for the T1-weighted images were as follows: spin-echo; TR/TE, 400/minimum; time, 3 min 28 sec for 256 × 256 matrices. For the T2-weighted images, settings were fast spin-echo; 4,000/114; echo-train length, 4; and time, 4 min 24 sec for 256 × 256 matrices.

For the proton density–weighted images, settings were fast spin-echo; 2,000/14; echo-train length, 4; and time, 4 min 24 sec for 256 × 256 matrices. Bandwidth was not manipulated. For proton fat-saturation images, the chemical shift selective (CHESS) method was used and the other parameters were the same as for proton density–weighted images (Fig. 2).

Number of matrices—Three matrices were used: 256 × 128, 256 × 256, and 512 × 256. Examiners ranked three sets of images as described previously. For this portion of the study, the proton density–weighted sequence was used (Fig. 3).

Slice thickness—Slice thicknesses of 2, 3, 4, and 5 mm were studied. Examiners ranked four sets of images as described previously. The interslice gap was 0 mm for all imaging. The proton density–weighted sequence was used for this portion of the study (Fig. 4).

Slice angle—Eleven sets of oblique coronal images were taken for each of the six knees. The sets

A B C

Fig. 3—Effects of MRI matrix size on popliteomeniscal fasciculi (PMF) depiction.
A–C, Three sets of matrices applied for depicting PMF were 256 × 128 (**A**), 256 × 256 (**B**), and 512 × 256 (**C**).

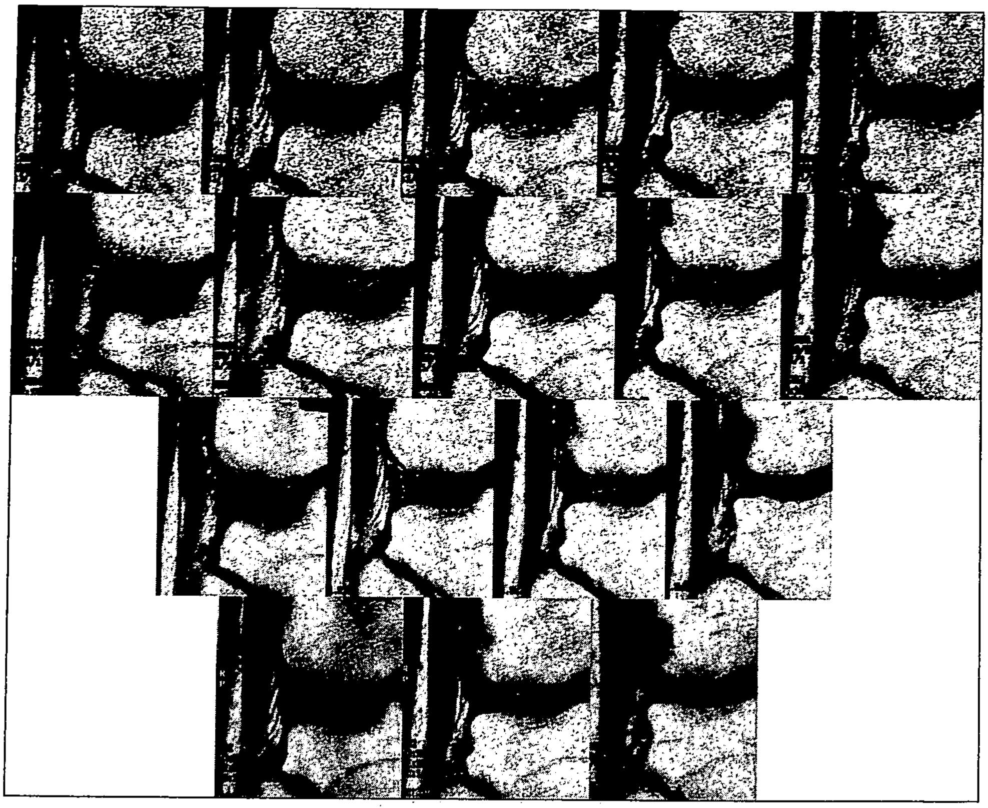

Fig. 4—Effects of slice thickness on popliteomeniscal fasciculi (PMF) depiction. Four sets of slice thickness were used to depict PMF. Images from top row to bottom row show slice thicknesses of 2, 3, 4, and 5 mm, respectively.

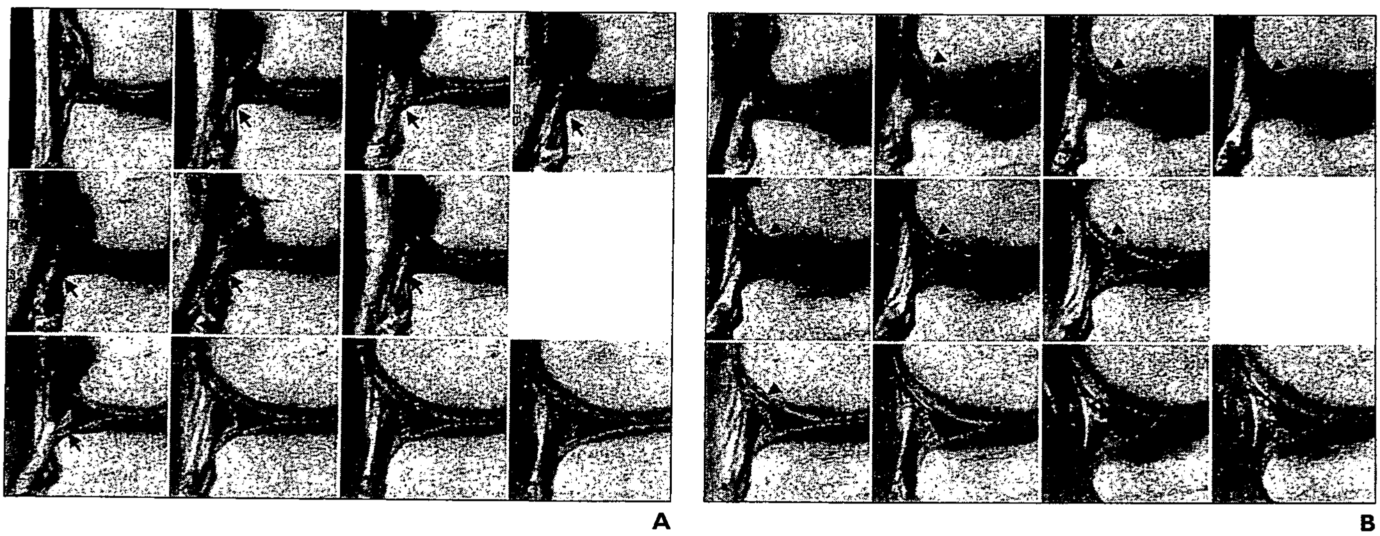

Fig. 5—Effects of obliquity on popliteomeniscal fasciculi (PMF) depiction. Single representative image was selected from each of 11 sets of images from a single knee (10 sets of images were taken at every 10° from 0° to 90°, with respect to reference line, and an additional set of 45° oblique coronal images was taken) to show effects of oblique angle on appearance of PMF.

A and **B**, Images show anteroinferior (*arrows*, **A**) and posterosuperior (*arrowheads*, **B**) fasciculi from various angles.

were taken every 10° from 0° (coronal) to 90° (sagittal) and at 45° to the reference line (Fig. 1). The posterior tangential line to both tibial condyles was used as the reference line. The resulting images were randomly arranged and evaluated. The Tukey-Kramer test was used for statistical analysis, and a p value of less than 0.05 was considered significant. For this study, a proton density–weighted sequence with a 512 × 256 matrix and 3-mm slices was used.

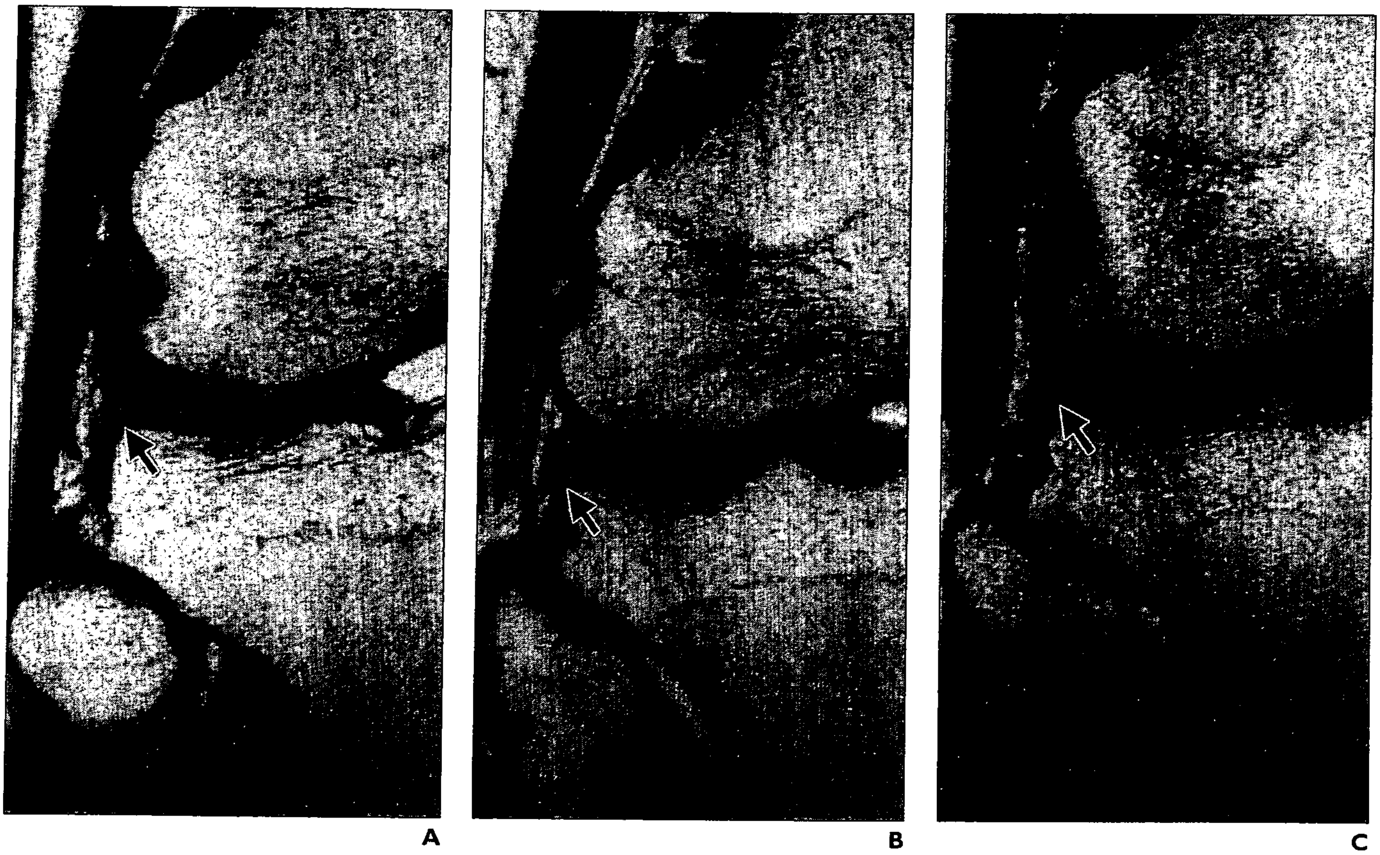

Fig. 6—Classification for depiction of popliteomeniscal fasciculi (PMF).
A–C, Optimal images show depiction of anteroinferior fasciculi (*arrows*) classified A, depicted with obvious continuity and with a low-intensity band (**A**); classified B, depicted with continuity but with ambiguous intensity structure (**B**); and classified C, depicted with discontinuity or not visible in any images (**C**).
(Fig. 6 continues on next page)

Six orthopedic knee surgeons scored each set of images independently on a numeric scale as described previously. A total of 66 sets of images (6 knees × 11 angles) were evaluated (Fig. 5).

Stage II

In stage II, MRI was performed on the right knees of 34 volunteers (33 men and one woman) with an average age of 29.8 years (range, 24–39 years). However, four of the right knees were found to have a history of injury; in those cases, the left knees were used. The optimal MRI conditions derived from stage I were used. All the images were classified according to how the fasciculi were depicted, as follows: A, the fasciculus was depicted with obvious continuity and with a low-intensity band; B, the fasciculus was depicted with continuity but with ambiguous intensity structure; and C, the fasciculus was depicted with discontinuity or was not visible in any of the images (Fig. 6). Three orthopedic surgeons who were also experienced MRI interpreters independently classified the images. Once the first classification process was complete, data from the three examiners were collected. Discrepancies among the examiners were resolved in favor of the majority. If each examiner selected a different classification, a fourth examiner was recruited for a final decision. The anteroinferior fasciculi and the posterosuperior fasciculi were classified separately. For the knees that received B or C for either the anteroinferior or the posterosuperior fasciculi, a second round of MRI (using T2-weighted imaging) was performed.

Results

Stage I

MRI sequence—Four of the six examiners ranked proton density–weighted images in first place and T2- weighted images in second place. The other two examiners ranked T2-weighted images in first place. On the basis of these results, we chose proton density–weighted images for use in further studies.

Number of matrices—Using the proton density–weighted images, all six examiners ranked the 512 × 256 matrix in first place.

Slice thickness—Using proton density–weighted sequences, three examiners ranked the 3-mm slice and three ranked the 4-mm slice in first place. The 2-mm slice was ranked in fourth place by all examiners. Although the sharpness and clarity of the images were better in the thicker slice, we chose the 3-mm slice to use in further studies. This choice was based on the consideration that a thinner slice would be better for judging the continuity of the fasciculi.

Slice angle—For the anteroinferior fasciculi, images taken at 45° or 50° received the highest scores, which were significantly higher than scores for images taken at 80° and 90°. Scores for images from 0° to 30° tended to be higher than those from 80° or 90°. Therefore, coronal slices are better than sagittal slices for the detection of the anteroinferior fasciculi. This is reasonable considering that these fasciculi run more or less parallel to our reference line.

For the posterosuperior fasciculi, images from 45° or 50° again gave the best results.

Fig. 6 (continued)—Classification for depiction of popliteomeniscal fasciculi (PMF).
D–F, Optimal images show depiction of posterosuperior fasciculi (*arrowheads*) classified A, depicted with obvious continuity and with a low-intensity band (**D**); classified B, depicted with continuity but with ambiguous intensity structure (**E**); and classified C, depicted with discontinuity or not visible in any images (**F**).

The scores from 45° and 50° were significantly higher than those from 10° or 20°. Scores from 80° or 90° tended to be higher than those from 0° to 30°. Sagittal slices, therefore, depicted these fasciculi better than coronal slices. Again, the pathway of these fasciculi would account for this result, because the posterosuperior fasciculi run more or less vertical to our reference line.

Combining these two results, 45° or 50° was the best angle for imaging both the anteroinferior fasciculi and the posterosuperior fasciculi (Fig. 7).

Stage II

Using the optimal MRI parameters established in stage I, proton density–weighted (fast spin-echo; 2,000/14; echo-train length, 4; and time, 4 min 24 sec) images were used for stage II, using a 45° angle, 3-mm slices, and a 512 × 256 matrix. All the images were classified as A, B, or C according to the pattern of how the fasciculi were depicted, as described previously.

Sixteen knees received two As for both fasciculi, and the other 18 knees received B or C for both or either of their fasciculi. T2-weighted images using a 45° angle were applied to those 18 knees because we thought that the magic angle phenomenon might give rise to a type B or C evaluation [10]. As a result, all classifications were the same regardless of whether proton density–weighted or T2-weighted conditions were used, except for a single posterosuperior fasciculus that was type A on T2-weighted imaging but type B on proton density–weighted imaging. This fasciculus was then classified as type A. The results of classification are presented in Table 1. If we were to consider that only the type A classification corresponds to firm connective tissue that could be called fasciculus, 64.7% (22/34) of knees would have anteroinferior fasciculi and 50.0% (17/34) of knees would have posterosuperior fasciculi. However, if we were to consider that both type A and type B classifications correspond to the existence of fasciculi, 94.1% (32/34) of knees would have anteroinferior fasciculi and 88.2% (30/34) of knees would have posterosuperior fasciculi (Table 1).

Discussion

Abnormal findings of PMF on MRI do not necessarily imply derangement of the knee joint [11]. On the other hand, several reports have indicated the clinical importance of an abnormal image of PMF on MRI [5, 7, 8]. Evidently, one cause of this discrepancy is the lack of knowledge about the normal appearance of PMF on MRI. Therefore, we investigated suitable MRI parameters for depicting the PMF. We found that, because of the course followed by the two fasciculi of the PMF, oblique coronal images are superior to sagittal and coronal images, which are the most routinely used slices in clinical assessment, for depicting both fasciculi. We therefore concluded that a 45° or 50° slice angle with the posterior tibial condylar line as a standard of reference is desirable for depicting both fasciculi at the same time. In addition, that angle

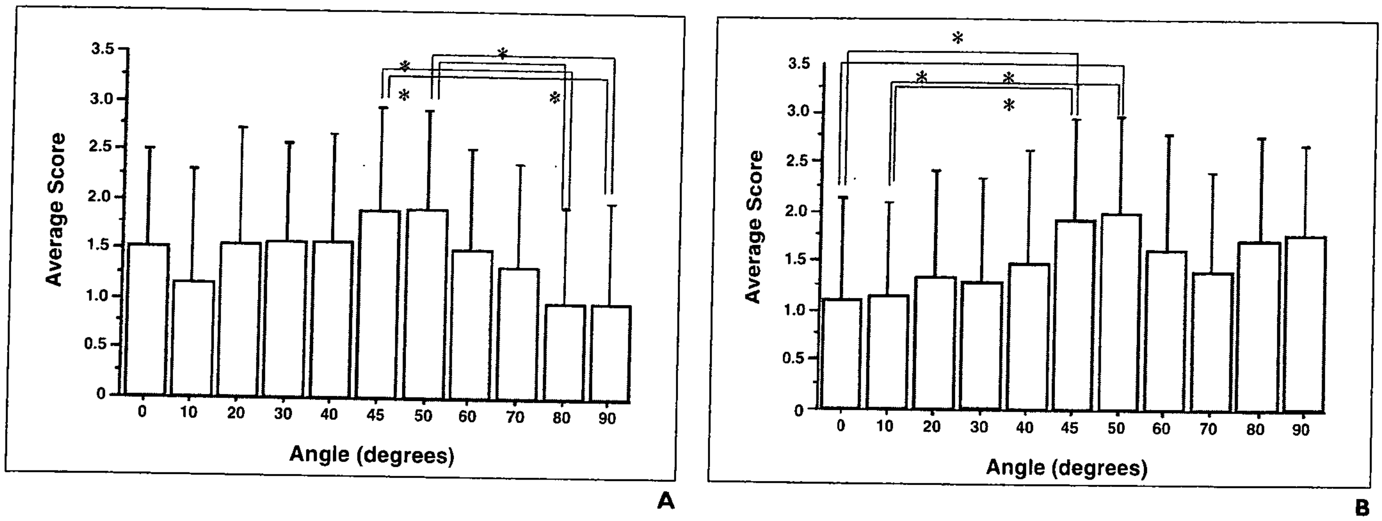

Fig. 7—Graphs show scores for depicting fasciculi as a function of angle.
A and B, Average score for depicting anteroinferior (A) and posterosuperior (B) fasciculi as a function of angle. Best angle for imaging both fasciculi was between 45° and 50°. Asterisks indicate statistical significance ($p < 0.05$).

TABLE 1: Classification of Images for Depicting Popliteomeniscal Fasciculi in 34 Knees

Classification	Meaning	Anteroinferior	Posterosuperior
A	Depicted with obvious continuity	22	17
B	Depicted with continuity	10	13
C	Depicted with discontinuity or not visible	2	4

aids the understanding of the 3D character of structures in this popliteal hiatus area. In summary, we suggest that the optimal parameters for the depiction of the PMF on MRI are as follows: proton-density weighting with a 3-mm slice thickness, 256 × 512-matrix, and 45° oblique coronal images. Preferably, T2-weighted, 45° oblique coronal images should be obtained as well to avoid misreading caused by the magic angle phenomenon as a result of the low TE in proton density–weighted imaging; this artifact seemed to occur in only one of 34 posterosuperior fasciculi and in none of anteroinferior fasciculi in our series.

We also studied normal images of the PMF using healthy knees with no history of trauma or injury. On the basis of these studies, we infer that the anteroinferior fasciculi were lacking in 5.9% of the knees examined, and that the posterosuperior fasciculi were lacking in 11.8%, if only a classification of C corresponds to absence of fasciculi. If, however, we assume that a classification of B also implies the absence of PMF, then the percentage of knees lacking those structures increases to 35.3% for anteroinferior and 50.0% for posterosuperior fasciculi. We emphasize that classification was not based on a single slice but on a series of images.

In 1999, Johnson and De Smet [9] described the detection of both types of fasciculi in 64 of 66 knees on routine MRI examinations. They found that only 3% of knees lacked PMF, which is lower than our result, particularly if we consider only type A to correspond to what could be called fasciculi. Two possible reasons might explain this discrepancy. One is the different conditions used for MRI. Johnson and De Smet [9] as well as Crues et al. [12] recommended T-2 weighted imaging, but under these conditions it seems to be difficult to tell whether the depicted structure is a loose connective tissue like synovia or tense tissue that could be called fasciculi. These authors [9, 12] also said that joint effusion would work as contrast media, but they did not refer to the intensity of the fasciculi themselves. In contrast, we used proton density–weighted imaging and could therefore distinguish loose tissue from collagenous tissue. Although we did not have any histologic data, our assumptions are as follows: classification A corresponds to collagenous tissue, classification B to scarce collagenous tissue or loose connective tissue, and classification C to the absence of the structure. Johnson and De Smet may have observed a mix of types A and B in their study. The second possible reason for the discrepancy in the results is a difference in the ethnic makeup of the subjects. Although Johnson and De Smet did not report on the ethnic background of their subjects, their study was done in a clinical hospital in the United States, whereas all volunteers in our study were Japanese.

A variety of percentages for the presence or absence of PMF in the knees of the population has been reported in dissection studies [1, 2, 13, 14]. Tria et al. [13] reported that 18 of 40 cadaveric knees had an isolated insertion of the popliteus tendon to the lateral femoral condyle with no connection to the lateral meniscus. Munshi et al. [14] reported that seven of seven cadaveric knees had both fasciculi and that these were detectable in corresponding MR images. However, it would be better to try to obtain the percentages via noninvasive examination of this rather vulnerable tissue. Kimura et al. [15, 16], in their arthroscopic research work, referred to the floor of the popliteus hiatus (presumably including the anteroinferior fasciculi of the PMF) and reported that 79% of knees lacked this structure. Although those authors did not distinguish the anteroinferior fasciculi of PMF from the coronary ligament, their articles revealed the existence of variability in the anatomy of the popliteal hiatus area.

Sussmann et al. [17] studied the developmental features of PMF using fetal knee specimens and described the histologic characters of the two fasciculi. Those authors described the anteroinferior fasciculi as more robust and shorter than the posterosuperior fasciculi because the period of elongation during development was longer in the posterosuperior fasciculi. This supports our finding that the percentage of type B cases was higher when examining the posterosuperior fasciculi because type B has less collagenous tissue.

A posterolateral meniscal lesion always impedes accurate diagnosis on MRI [18, 19]. One cause of this is the existence of PMF. Although the number of healthy volunteers might be too small to generalize to the general population, our findings will contribute to understanding of the normal appearance of the PMF and will help to determine the proportion of variation in this structure on MRI.

In conclusion, the optimal method for depicting PMF on MRI is the use of proton density–weighted images of 3-mm slice thickness, 256 × 512-matrices, and 45° oblique coronal views. Preferably, T2-weighted, 45° images should be obtained as well. We also inferred from this study that about 30% of healthy knees lack the anteroinferior fasciculi of the PMF and about 50% lack the posterosuperior fasciculi, if we consider PMF to be present only when depicted as a tense low-intensity band on MRI. Even when we defined the existence of PMF by the presence of any structure on MRI, 5–12% of healthy knees may still lack the PMF. Finally, our findings, as presented in this article, will contribute to understanding of the normal appearance of the PMF on MRI, and of the proportion of variation of this structure among the population.

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