J Orthop Sci (2006) 11:159–166
DOI 10.1007/s00776-005-0988-3

JOURNAL OF
ORTHOPAEDIC SCIENCE

Original article

Endoscopic anterior cruciate ligament reconstruction using a computer-assisted fluoroscopic navigation system

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Abstract

Background. During anterior cruciate ligament (ACL) reconstruction, placement of the reconstructed ligament affects the clinical results. To accomplish accurate and reproducible placement of the tibial bone tunnel, we employed a fluoroscopic navigation system for endoscopic ACL reconstruction. In this study, preciseness of the tibial tunnel placement was evaluated, and the advantages and disadvantages of this navigation system for endoscopic ACL reconstruction are discussed.

Methods. Altogether, 16 knees of 16 patients who had undergone ACL reconstruction using this system (navi group) were evaluated regarding the positioning of the tibial tunnel against Blumensaat's line using X-p and the route of the graft by magnetic resonance imaging (MRI). Another 16 knees of 16 patients who underwent endoscopic ACL reconstruction without the navigation system were the controls (control group).

Results. At the 1-year follow-up, maximally extended lateral knee X-p revealed that the anterior edge of the tibial tunnel and Blumensaat's line were almost aligned and that roof impingement was avoided; the T2-weighted MR images showed that the graft was placed close to and parallel to the intercondylar roof in all the knees of the navi group. The ratio of the distance between Blumensaat's line and the anterior edge of the tibial tunnel at the level of the tibial plateau to the anteroposterior width in fully extended true lateral radiographs was 2.7% ± 3.4% in the navi group and 8.4% ± 7.4% in the control group.

Conclusions. The computer-assisted fluoroscopic navigation system improves accuracy and decreases dispersion of the tibial tunnel placement against Blumensaat's line in single-bundle ACL reconstruction. This innovative device renders the reconstruction procedure more reliable, eliminating the problem of skeletal variation among patients. However, the function of this navigation system for femoral tunnel placement is insufficient at present. Further refinement of the system is necessary, and the method of application requires improvement.

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Received: May 2, 2005 / Accepted: November 8, 2005

Introduction

The current standard surgical procedure for treating the injured anterior cruciate ligament (ACL) is endoscopic reconstruction with autologus tissues. Although the surgery has become a common procedure for orthopedic surgeons, it is not easy to consistently obtain the best possible results. A recent report has shown that nearly 30% of ACL-reconstructed knees had more than 3mm of side-to-side difference even though the surgery was performed by an experienced surgeon.[1] There are various reasons for failure: choice of the graft, graft tension at the time of fixation, method of fixation, and rehabilitation protocols. Among them, proper graft placement is a critical factor for successful reconstruction.[2–4] If a graft is misplaced, it often fails because of roof impingement[5,6] or poor isometry, or it may cause loss of knee motion long after surgery.

The navigation system is a computer-assisted surgery system that has recently been introduced in the operating room. Currently, the most common type of system is an image-guided navigation system based on fluoroscopy or CT images. During surgery, the system indicates the location of the surgical instrument on the images obtained before surgery, eliminating the need for intraoperative image acquisition.

In the field of orthopedic surgery, the method has been used for spinal surgery,[7–11] prosthetic surgery of the hip and knee joints,[12–17] and trauma surgery,[18–20] and successful results have been reported. Its application in ACL reconstruction surgery has also been proposed.[21–24] For ACL surgery, the system is expected to display virtual images of bone tunnels and the graft on radiographic or computed tomography (CT) images before the bone tunnels are drilled, allowing the surgeon to place the graft in the optimal position. However, its feasibility and usefulness in clinical practice has not yet been determined.

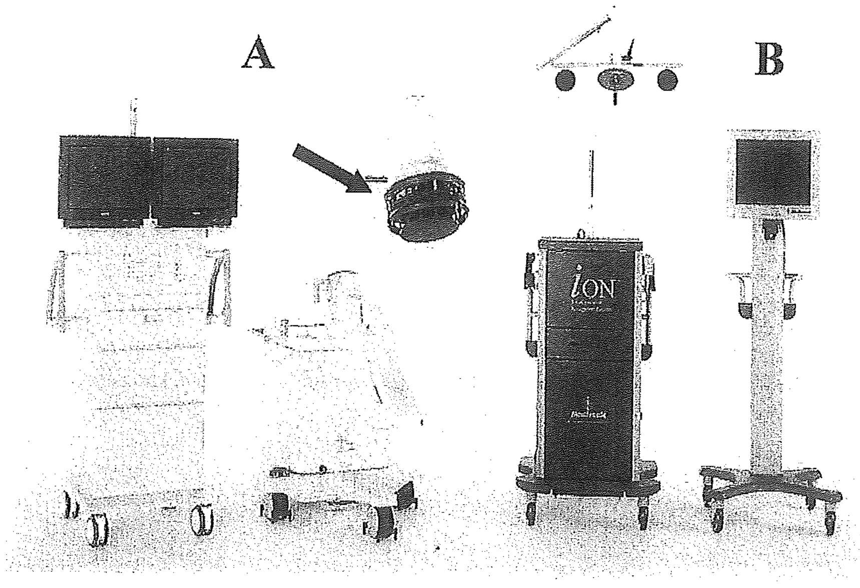

Fig. 1. Configuration of the navigation system used for the study. The system consists of a C-arm fluoroscopy (**A**) with a calibration target (*arrow*) and a core machine equipped with a digitizing camera and a screen for navigation (**B**)

Since October 2001, we have employed a navigation system based on fluoroscopic images for endoscopic ACL reconstruction. Because the system displays the predicted positions of the tibial bone tunnel and the route of the ligament graft in real time before the guide pin is inserted, the surgeon can easily place the graft in the expected, optimal position. We have introduced our endoscopic ACL reconstruction method using a fluoroscopy-based navigation system.[25] In this study the preciseness of the positioning of the tibial tunnel and the graft route were evaluated. The advantages and disadvantages of this navigation system in endoscopic ACL reconstruction are discussed here.

Materials and methods

The study was performed with the approval of the institutional review board, and all patients signed the consent form drafted for the study.

Between October 2001 and April 2003, 17 knees in 17 patients (10 male, 6 female; average age 26.9 ± 9.0 years at the time of surgery) underwent endoscopic ACL reconstruction using the fluoroscopic navigation system by three senior surgeons, and were involved in this study (navi group). Two patients had bilateral ACL injuries, and the other 15 had unilateral injuries. Another 16 patients (12 males, 4 females; average age 29.8 ± 8.9 years at the time of surgery) who underwent ACL reconstruction by the same senior surgeons without using navigation system just before the introduction of this navigation system served as the control group.

Navigation system

A computer-assisted fluoroscopic navigation system (StealthStation iON; Medtronic, Louisville, CO, USA) was used for the study (Fig. 1). This system is composed of a C-arm fluoroscope and a navigation system. The former has a C-arm with calibration target and a fluoroscopic monitor, and the latter has two devices consisting of a core machine with a digitizing camera, which localizes the C-arm calibration target and all of the trackable instruments, and the navigation display. The calibration target features light-emitting diode (LED) tracking to enable the precise localization of the C-arm. Up to four fluoroscopic images can be shown on the navigation display simultaneously, and virtual navigation images are overlaid on these images in a real-time manner. The mean probe tip error of this system was reported to be 0.97 ± 0.40 mm.[11]

Two LED frames (Fig. 2) were sterilized and used for navigation in the surgical field. One frame was attached to a commercially available tibial drill guide (Atlantech Medical Devices, Harrogate, N. Yorkshire, UK) with a universal tool adapter (Fig. 2A), and the other (Fig. 2B) was anchored securely to the midshaft of the tibia by two threaded pins (Fig. 3: reference frame). Fluoroscopic images were then obtained by the fluoroscope, with the calibration target and the reference frame captured simultaneously by the digitizing camera; the images were recorded. Finally, the tibial drill guide with the LED frame (Fig. 2A) was registered to the navigation system. After this step, the system traced LED markers of the ACL tibial guide and the reference

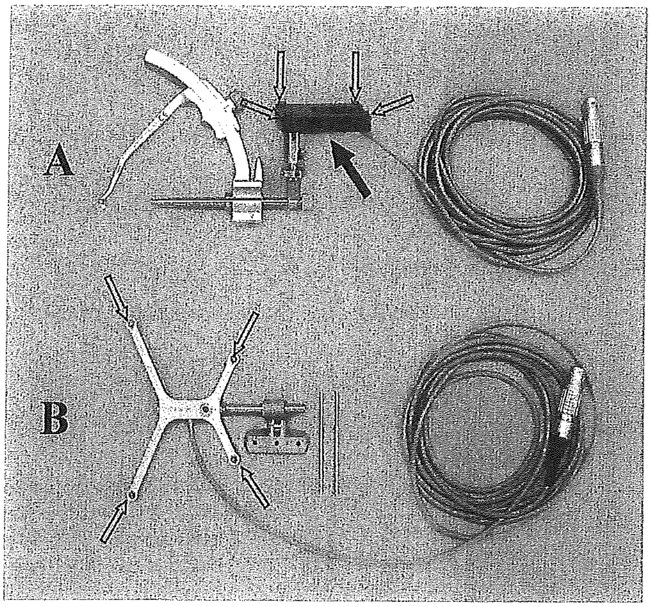

Fig. 2. Surgical instruments used for navigation. A tibial drill guide anchoring an active light-emitting diode (LED) frame (*black arrow*) with a universal tool adapter (**A**) and a reference frame (**B**) carrying active LED markers. The *open arrows* indicate the LED markers

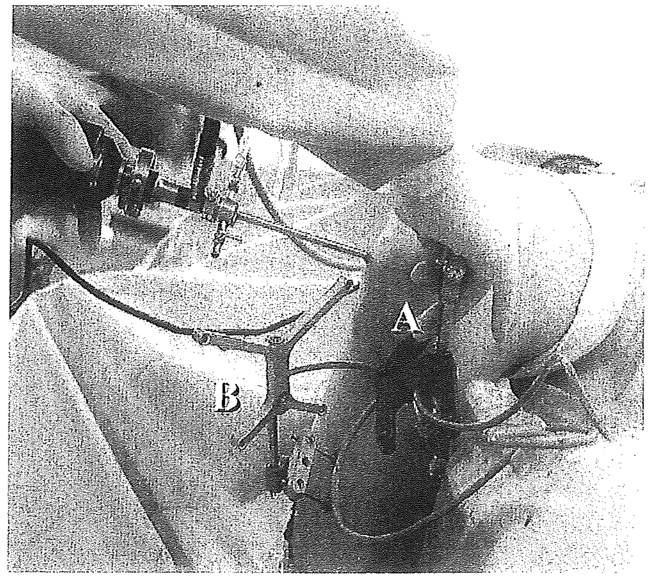

Fig. 3. Operation of the navigation system during surgery. A tibial drill guide (**A**) and reference frame on the tibia (**B**) are seen. Navigation can be performed by concurrently capturing the LED frame of the ACL drill guide (**A**) and the reference frame on the tibia (**B**) with the digitizing camera

frame on the tibia, indicating the virtual bone tunnel and graft route on the navigation images in a real-time manner, regardless of the actual position of the knee being operated on (Fig. 3).

Surgical procedure

Surgery started with endoscopic examination of the joint. Any treatment necessary for the menisci was performed prior to ACL reconstruction. A reference frame was then securely anchored to the midshaft of the tibia, and anteroposterior (AP) and lateral view images of the knee joint were obtained by C-arm fluoroscopy, capturing the calibration target and the reference frame simultaneously by the digitizing camera. To evaluate the risk of roof impingement properly, a lateral view image was obtained in the maximally extended knee position, and rotation of the joint was carefully confirmed by observing the overlap of medial and lateral femoral condyles. Registration of the tibial guide with the LED frame to the navigation system was then performed. Once this registration was completed, further use of fluoroscopy was not necessary for the navigation.

To prepare an ACL graft, semitendinosus and gracilis tendons were harvested and doubled in the middle. The diameter of the graft was measured and put into the navigation system; the system was then able to show the predicted positions of the tibial bone tunnel and the ACL graft route on the navigation images in the predicted graft diameter (Fig. 4). We placed the tibial tunnel where the extension of the anterior tunnel wall would come into line with the intercondylar roof (i.e., Blumensaat's line) (Fig. 4). For this, the position of the bone tunnel should be determined on the lateral knee images obtained at full joint extension in the exact orientation. The navigation system made this possible without changing the knee position or retaking the radiographic images. A guide pin was then driven through the navigated tibial guide. Finally, the tunnel was overreamed in the graft diameter along the guide pin. For the femoral socket, a guide pin was inserted using a size-specific offset aimer (Arthrotek, Warsaw, IN, USA) through the tibial tunnel, and the femoral socket was reamed in the graft diameter. We aimed the insertion point of the femoral guide pin at the 2 o'clock position on the left knee or at the 10 o'clock position on the right knee. After pretensioning, the ACL graft was placed and then fixed with a TransFix system (Arthrex, Naples, FL, USA) in the femoral socket and a spiked washer on the tibia at 20 degrees of knee flexion.

Postoperatively, continuous passive motion (CPM) was started immediately, and weight-bearing was begun as soon as tolerable, usually on the third day after surgery. The patients were encouraged to resume a full range of joint motion including Japanese-style sitting by 12 weeks. Jogging started at the fourth month, and return to full sports activity was permitted after 8 months at the earliest.

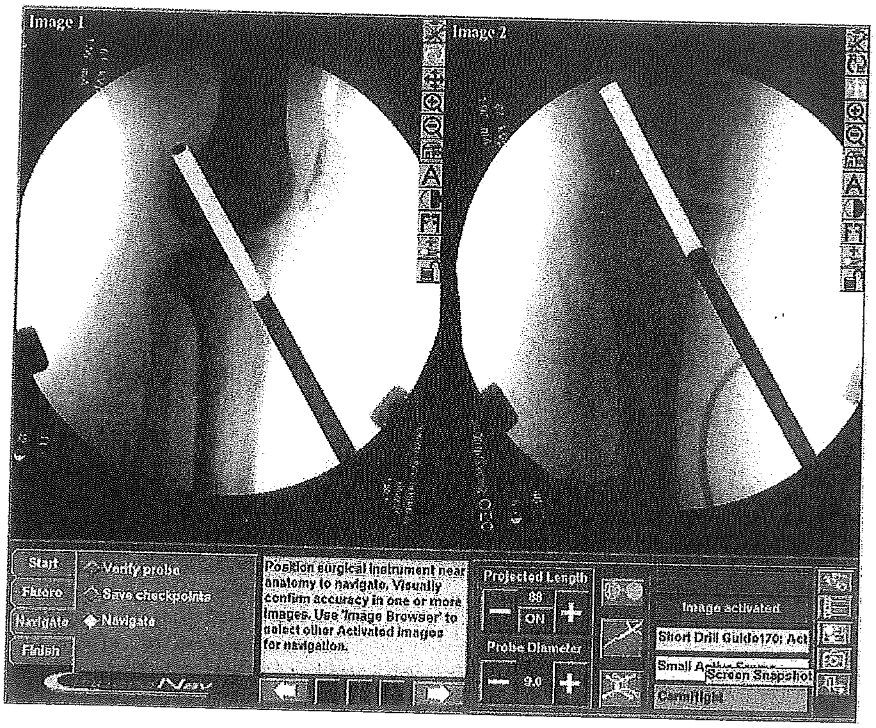

Fig. 4. Display of the navigation images on the navigation screen. Anteroposterior and true lateral images of full joint extension were obtained at the beginning of the surgery, and virtual tibial bone tunnel and the graft route images were then overlaid on the knee images at full joint extension in a real-time manner, irrespective of the actual knee position (e.g., Fig. 3)

Evaluations

The location of the tibial tunnel was evaluated on a lateral-view radiograph 12 months after surgery. The lateral-view radiograph was obtained in the maximally extended knee position, carefully confirming the rotation using a roentgen fluoroscope. On the lateral radiograph, the ratio of the absolute value of the distance between Blumensaat's line and the anterior edge of the tibial tunnel at the level of the tibial plateau to the AP width of the tibial plateau (Fig. 5, %B–A distance) was evaluated, and the absolute value of the angle between Blumensaat's line and the axis of the tibial tunnel (B–T angle) was measured (Fig. 5). Together with the radiographs, T2-weighted MR images were obtained on all knees at full extension, and the location and signal intensity of the grafts were evaluated.

To compare the accuracy of the tibial bone tunnel placement, the %B–A distance and the B–T angle of the patients in the control group was also measured on a lateral-view radiograph taken in the same manner as that of the navi group 12 months after surgery.

In addition, the side-to-side differences of the anterior instability measured by KT-1000/2000 at the 1-year follow-up were compared between the two groups.

Statistical analysis was performed using the Mann-Whitney U-test for the comparison of the two group and the F test for analysis of variance. Statistical significance was defined as $P < 0.05$.

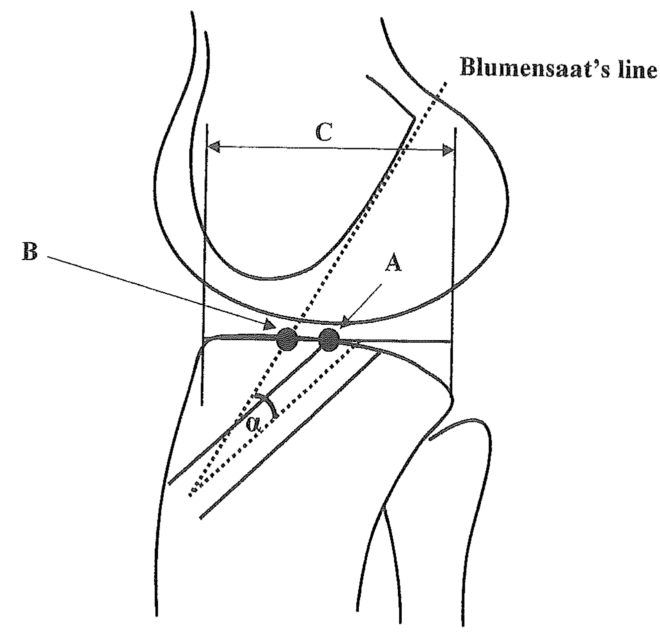

Fig. 5. Radiographic parameters used to evaluate the positioning of the tibial tunnel in this study. The %B–A distance is the ratio of the distance between Blumensaat's line and the anterior edge of the tibial tunnel at the level of the tibial plateau (*B–A*) to the anteroposterior width (*C*). The B–T angle is the angle between Blumensaat's line and the axis of the tibial tunnel (α)

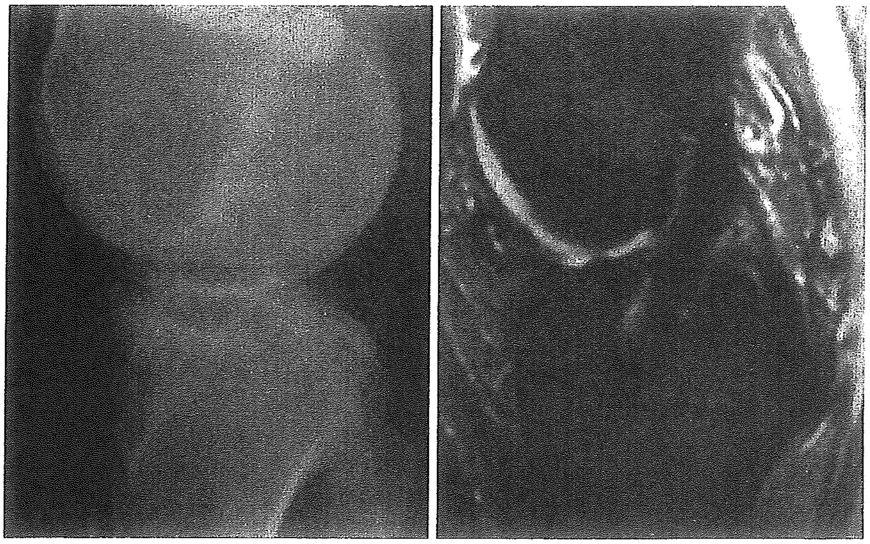

Fig. 6. Lateral radiograph (*left*) and T2-weighted magnetic resonance (MR) image (*right*) at full joint extension of a representative subject obtained 12 months after surgery. Roof impingement was avoided, and the MR image showed that the graft was located close to the intercondylar roof in a parallel orientation

Results

One patient who had a unilateral injury in the navi group was lost to the follow-up, and the remaining 16 knees of the 16 patients in the navi group and 16 knees of the 16 patients in the control group were enrolled in this study. In the navi group, two patients had ACL injuries in their bilateral knees but underwent unilateral reconstruction during the period; another two patients had concomitant meniscus injuries that were treated by partial meniscectomy. Still another patient had a grade III medial collateral ligament (MCL) injury that was repaired using a spiked washer. In the control group, four patients had meniscus injuries, two of which were treated by meniscectomy; and the others were repaired. One of them had a grade III MCL injury that was also repaired using the spiked washer technique. Surgery and the postoperative course were uneventful for all patients in both groups.

At the 1-year follow-up, physical examination revealed that full range of motion had been restored in all of the knees operated on in both groups. On the radiographs, there was no sign of abnormal widening of the tibial tunnels in either group. In the navi group, the lateral radiograph at full extension of the knee showed that the anterior wall of the tibial tunnel was located in line with or slightly behind the extension of the Blumensaat's line at the level of the tibial plateau in all the treated knees (Fig. 6), and successful avoidance of roof impingement was indicated. The %B–A distance and the B–T angle were 2.7% ± 3.4% and 4.8° ± 3.5° in the navi group, and 8.4% ± 7.4% and 6.0° ± 4.7° in the control group. The histogram of the %B–A distance is shown in Fig. 7. The mean and standard deviation of the %B–A distance in the navi group was significantly less than that in the control group ($P = 0.01$, 0.004, respectively) (Table 1).

Avoidance of roof impingement was also confirmed by MRI scans obtained at full extension of the knee in all subjects of the navi group at the 1-year follow-up. A sagittal view of T2-weighted MR images showed that the grafts were placed close to and parallel to the intercondylar roofs as normal anatomy (Fig. 6), and the grafts were depicted as low signal bands in all the patients, suggesting preservation of their structural integrity.

The side-to-side difference of anterior instability was measured in unilateral ACL-injured patients: 14 patients of the navi group and 16 of the control group. The average side-to-side difference was 1.3 ± 2.7 mm in the navi group and 1.3 ± 1.7 mm in the control group. There was no statistical difference between the two groups ($P = 0.95$).

Discussion

Despite their importance to ACL reconstruction, bone tunnels are often misplaced. Although there are several reasons, individual variation in joint geometry is probably a frequent cause of this problem. For example, the intercondylar roof angle varies from 22° to 64°,[26] and the extent of knee hyperextension can differ among individuals.

Because it is impossible to evaluate such variation by arthroscopy, the surgeon often needs to confirm the location of the guide pin by intraoperative radiography or fluoroscopy.[27] However, recognizing the exact pin position is difficult using regular radiography because the radiographs are often obtained in improper orienta-

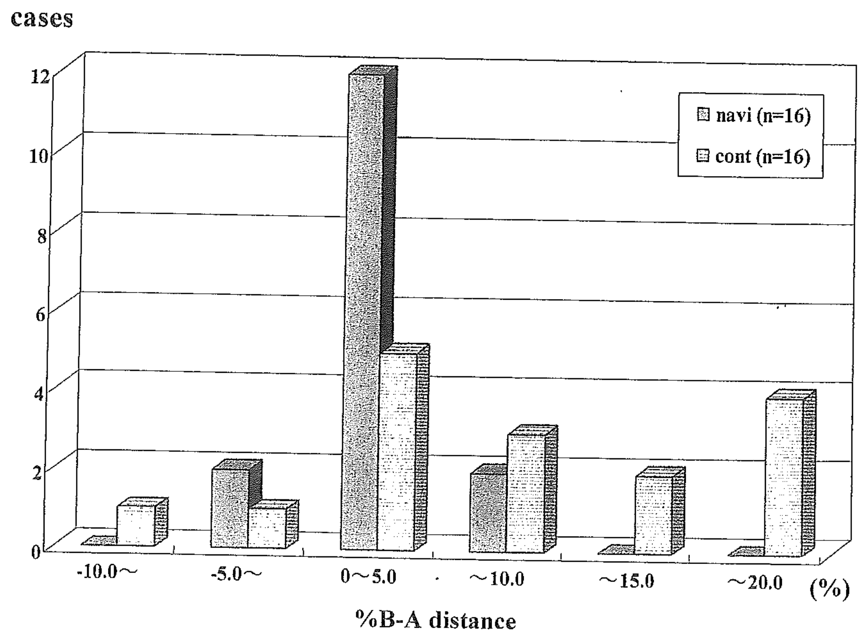

Fig. 7. Histogram of the %B–A distance. *navi*, navigation system; *cont*, controls

Table 1. %B–A distance and the B–T angle of the navigation (navi) and control groups

		Navi (n = 16)	Control (n = 16)	P value
%B–A distance (%)	Mean	2.7	8.4	$^*P = 0.01$
	SD	3.4	7.4	$^*P = 0.004$
B–T angle (degrees)	Mean	4.8	6.0	$P = 0.65$
	SD	3.5	4.7	$P = 0.23$

SD: standard deviation
*Significantly different ($P < 0.05$)

tion. Additionally, because either method shows the position of the guide pin that has already been placed, precise control of guide pin placement is difficult. To make a definitive decision about tibial tunnel placement by intraoperative fluoroscopy, it is necessary to predict the tunnel width of the graft diameter on the guide pin that is already in the tibia. Furthermore, reattempts of guide pin placement for slight transfer is difficult if the target point of the second guide pin is close to the first one. As a result, the surgeon compromises, and the guide pin shows a tendency to be placed posteriorly. With navigation, virtual tunnel placement can be superimposed on the strictly obtained AP and lateral views of the knee joint, and it is displayed in the actual diameter of the graft before guide pin insertion, as shown in Fig. 4. Therefore, strict guide pin placement can be easily accomplished during the first attempt.

Several articles have described the potential advantages of a navigation system for strict placement of the tunnel. Klos et al. developed a system that displays computer graphics of a virtual graft on a fluoroscopic image of the knee joint, and a clinical trial revealed that the technique statistically reduced the variability of ligament placement.[22] One limitation with the system was that it did not have a tracking system for the limb or the surgical instruments, and fluoroscopic images had to be acquired repeatedly during surgery. The virtual images had to be adjusted manually on the computer again when the limb position changed. Several other systems have been attempted on cadavers and plastic models, and accurate tunnel placement has been reported.[21,23,24] However, these methods require CT scanning for preoperative planning[21,23] or multiple intraoperative palpation of anatomical structures and landmarks around the joints.[24] Their value and feasibility have not yet been determined in clinical situations. Compared with these systems, the navigation system used in this study requires image acquisition only once, at the beginning of surgery; once the images have been recorded, operation of the system is simple. Because the virtual images are displayed on the knee images at full joint extension irrespective of the actual knee position, the surgeon does not have to extend the joint even to know the relation between the tunnel and Blumensaat's line during knee extension.

The results of this study show that the mean and standard deviation of the %B–A distance in the navi group were smaller than those in the control group (Table 1, Fig. 7). Particularly, the significantly decreased standard deviation of the %B–A distance in the navi group was considered more meaningful. This means that not only stricter placement of the tibial tunnel in the navi group against Blumensaat's line but more reproducible placement of the bone tunnel can be accomplished than for that of the control group. In fact, lateral radiography in the fully extended knee position revealed that roof impingement was completely avoided in all knees of the navi group, and the tibial tunnels were placed immediately behind and almost parallel to Blumensaat's lines, whose tilt against the tibial plateau in the sagittal plane at full extension of the knee can vary from person to person. The sagittal view of T2-weighted MR images taken at full extension also showed that the grafts were placed close to and parallel with the intercondylar roofs as normal anatomy. We believe that the tibial tunnel being as anterior as possible and the graft lying close to Blumensaat's line at full knee extension is important for resuming the ligament's function, as it limits anterior instability and hyperextension of the joint.[28,29] Meanwhile, the %B–A distance of the two cases is more than 5%, as shown in Fig. 7. The LED frames attached to both the tibia and the tibial guide are highly sensitive to vibration and movement. This was thought to be due to erroneously touching the LED frames by the surgeon during surgery. Careful handling of the devices is required.

In this series of patients, the navigation system was not used for the femoral tunnel. There were two reasons for this. The first reason concerned the hardware and softwear. In the system we used, preparation for navigation including installing the LED frame into the bone, taking C-arm images used for navigation, and registering of the LED frames, which would have to be repeated for the tibia and femur, respectively. If navigation is planned for both tibia and femur, it would take twice as long to set up. Also, navigation for the femoral tunnel cannot be performed using the tunnel view because of the impossibility of obtaining that image on the operating room table, where we can determine the precise angle and placement of the femoral tunnel instead of the frontal image. The second reason is because precise femoral tunnel placement can be determined using a commercially available femoral offset guide that references definite bony landmarks of the over-the-top position and posterior edge of the lateral femoral condyle after complete removal of ACL remnants and the surrounding soft tissue. Therefore, we believe that using this particular navigation system for the femoral bone tunnel is not mandatory for single-bundle ACL reconstruction. Navigation based on strict lateral and tunnel views will be essential for accurate placement of the femoral tunnel in the next generation of devices.

Issues concerning clinical results, extra work, and surgeons for intraoperative navigation as well as the cost of the navigation system itself are also points of interest. The results of this study showed that there was no statistical difference in the side-to-side difference in anterior instability between the two groups if senior surgeons performed the surgery. Nowadays, however, ACL reconstruction has become a common procedure, so many orthopedic surgeons who sometimes perform arthroscopic surgery but are not familiar with ACL reconstruction sometimes perform this operation. This navigation technique should provide a significant aid for these surgeons.

Extra work for navigation is of course required. After preparation of the graft, two LED frames were anchored to the tibial guide and the midshaft of the tibia, respectively; fluoroscopic images were then obtained and the images recorded for navigation. Finally, the tibial drill guide with the LED frame was registered in the navigation system. These steps were performed during deflation of the tourniquet.

The average surgery time calculated in patients who underwent isolated ACL reconstruction with one senior surgeon without associated meniscus or MCL surgery was 152.7 ± 19.7 min (130–180 min) in the navi group ($n = 7$) and 119.7 ± 7.8 min (112–134 min) in the control group ($n = 6$). Therefore, the intraoperative time extension with fluoroscopic navigation for the tibial tunnel was about 30 min on average in this initial series. However, there was a learning curve regarding handling of the navigation system; when it was first introduced, it took more than an hour to set up, whereas at the end of this patient series setting up took less than 20 min. It has also been reported surgery time with the fluoroscopy-based navigation system for cup implantation in total hip arthroplasty was extended 13 min on average.[16] The involvement of an extra person, who assisted from outside of the operating field but did not have to be a surgeon, was necessary. Therefore, at the minimum, two orthopedic surgeons and an extra person were necessary for the procedure.

The introductory cost of the navigation system used in this study is approximately 30 million yen at listed price. However, the system is versatile; applications of this system in orthopedic surgery are spinal surgery,[10,11] total hip/knee arthroplasty,[16,17] and trauma surgery.[18–20] Once the fluoroscopic navigation system is introduced into the operating room, significant advantages can be enjoyed in an extensive field. Therefore, cost-effectiveness may be move realistic when operations other than ACL reconstruction utilize it.

Conclusions

The computer-assisted fluoroscopic navigation system improves accuracy and decreases dispersion of the tibial tunnel placement against Blumensaat's line in single-bundle ACL reconstruction. This innovative device renders the reconstruction procedure more reliable, eliminating the problem of skeletal variation among patients. However, the function of this navigation system for femoral tunnel placement is insufficient at present. Further refinement of the system is necessary, and the method of application requires improvement.

Acknowledgements. The authors thank Professor Hiroya Sakai, MD, PhD for direction as well as Takumi Nakagawa, MD, PhD, Yoshinari Miyamoto, MD, and Takehiro Matsubara, MD for their assistance with this study.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article, nor have any funds been received in support of this study. The authors declare that this study complies with the laws of Japan.

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Mod Rheumatol (2006) 16:24–29
DOI 10.1007/s10165-005-0450-6

ORIGINAL ARTICLE

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Risk factors for knee osteoarthritis in Japanese men: a case-control study

Received: July 27, 2005 / Accepted: December 13, 2005

Abstract Risk of knee osteoarthritis (OA) was assessed in a population-based case-control study of Japanese men. The study covered three health districts in Wakayama and Osaka prefectures, Japan. Subjects were male individuals ≥45 years old diagnosed radiographically with knee OA, and who did not display any established causes of secondary OA. Controls selected randomly from the general population were individually matched to cases for age, sex, and residential district. Subjects were interviewed using structured questionnaires to determine medical history, physical activity, socio-economic factors, and occupation. Interviews were obtained from 37 cases and 37 controls. In univariate analysis, heaviest weight in the past and physical work such as factory, construction, agricultural, or fishery work as the principal occupation significantly raised the risk of male knee OA ($P < 0.05$). Odds ratios (OR) were determined using conditional logistic regression analysis mutually adjusted for potential risk factors using the results of univariate analysis. Heaviest weight in the past (OR 6.01, 95% confidence interval (CI) 1.18–30.5, $P < 0.05$), past knee injury (OR 6.25, 95% CI 1.13–34.5, $P < 0.05$), and physical work as the principal occupation (OR 6.20, 95% CI 1.40–27.5, $P < 0.05$) represented independent factors associated with knee OA after controlling for other risk factors. Physical work is associated with knee OA, demonstrating the influence of working activity on the development of OA. The present study suggests that risk factors for knee OA in men resemble those in women.

Key words Case control study · Heavy weight · Knee joint · Osteoarthritis (OA)· Physical work

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Introduction

Since osteoarthritis (OA) is a frequent cause of pain and disability in elderly individuals, the recent World Health Organization report on the global burden of disease indicated knee OA as an increasingly important cause of disability in both men and women, suggesting that strategies for preventing OA are urgently required.[1] In Japan, knee OA seems to represent a frequent cause of pain and disability, but few epidemiological studies have examined associated factors.

Several investigations regarding risk factors for hip and knee OA performed in Western populations have suggested obesity, previous injury, polyarticular joint involvement, and occupational activities as important risk factors for the disorder.[2–8] However, few studies of risk factors for OA in Japanese populations have been performed. Our earlier case-control study of hip OA identified some variations in risk factors in Japan.[9] In the previous case-control study of hip OA, occupational lifting was identified as a risk factor and sedentary work as a protective factor for hip OA. In addition, obesity was not identified as a risk factor for Japanese hip OA. For contrast, an identical case-control study was performed for knee OA in women in a Japanese population.[10] In the female study, risk factors of obesity, previous knee injury, and period of total work were identified, and sedentary work as the initial occupation represented a preventive factor.[10] The results from these two investigations suggest various similarities and differences in risk factors between hip and knee OA in Japanese populations.

The present study sought to clarify risk factors for knee OA among men in Japan, by performing a survey identical to that used in the previous female knee OA study. Results for men were compared to those from the female study.[10] Risk factors were then compared between knee OA and hip OA to address differences in risk factors for constitutional and mechanical factors between OA at different sites. Finally, risk factors for knee and hip OA were compared to those identified in a British study[11,12] that used identical methods to the Japanese studies, to clarify differences in risk factors for OA between Japanese and Western populations.

Patients and methods

Methods of data collection in the present study were basically identical to those of the case-control studies for female knee OA and hip OA reported previously.[9,10] A brief summary is provided here. Cases were identified from the registration systems of the six hospitals participating in the study, which were located in three cities in Japan (Wakayama City and Arita City in Wakayama Prefecture, and Sennan City in Osaka Prefecture).

Cases comprised men ≥45 years old who suffered knee pain and walking difficulties, and who were first diagnosed by an orthopedic surgeon as displaying a tibiofemoral joint with radiographic grade of ≥3 on the Kellgren and Lawrence scale[13] within the year preceding the start of the study. Cases with a history of knee injury in the previous year, rheumatoid arthritis, or ankylosing spondylitis were excluded.

For each case, a single control was randomly selected from among men of the same age and district of residence on city registers of the local population, which are updated as residents move into or leave the city. Controls who had suffered knee OA were excluded from the study.

All eligible cases and controls were initially approached using a letter to determine willingness to participate in the study. After providing informed consent, cases and controls were interviewed by the same trained interviewer.

An identical questionnaire to that used in the British case-control study was used to ascertain risk factors of knee OA.[11,12] The questionnaire was translated and back-translated from Japanese to English. Subjects completed a structured questionnaire that requested details of medical history, socio-economic status and education, cigarette smoking and alcohol consumption, functional status, and lifetime history of leisure activities. Lifetime history of leisure activities included participation in sports such as soccer, swimming, tennis, cricket, and golf, in addition to frequency and duration of less physical activities, such as gardening. Information about eight types of occupational physical activity was requested, namely: standing; sitting; climbing stairs; kneeling; squatting; driving; walking; and heavy lifting. Information on these activities was obtained for the initial job, defined as the earliest job reported, and for the principal job, defined as the job at which the subject had worked longest. For each job, the questionnaire enquired whether work entailed lifting weights (≥10kg, ≥25kg, or ≥50kg) more than once during an average working week. Information regarding use of transport, including frequency and duration of cycling and motorcycling was obtained. Information was also requested on the involvement of other joints, including hands, shoulders, and hips. Furthermore, questions were added about back pain and stiffness, which were not included in the British study. Once heaviest reported weight after 25 years old was obtained, height and weight of each subject was measured at the time of the interview.

After analysis to clarify risk for male knee OA, results were compared between men and published results for women.[10] Risk factors for knee OA and hip OA were also compared to address differences in constitutional and mechanical risk factors between OA at different sites. Finally, risk factors for knee and hip OA were compared to the findings of the British study, which used identical methods to the Japanese studies.

Data were calculated using McNemar's Chi-square test and conditional logistic regression tests for matched sets. Results were summarized as odds ratios (OR) with 95% confidence intervals (CI). Odds ratios were calculated for categories of exposure, and tests of trend were performed across these categories. Statistical analyses were performed using SPSS statistical software (SPSS, Chicago, IL, USA) and the STATA statistical package (STATA, College Station, TX, USA).

Results

A total of 40 men ≥45 years old fulfilled the entry criteria for the study. Among these eligible cases, 37 men (92.5%) agreed to participate after information was provided. Unilateral knee OA ($n = 21$) was more common than bilateral disease ($n = 16$). Among the 21 men with unilateral disease, OA tended to be right-sided ($n = 13$) more often than left-sided (n = 8), but no significant difference was identified.

For controls, we approached age-, sex-, and residence-matched candidates for each case. To recruit the 37 matched controls, we approached 70 subjects (overall response rate 52.9%).

Table 1 shows background characteristics for the 37 case-control pairs in the present study. Mean body weight was significantly greater for cases than for controls ($P < 0.05$). Furthermore, body mass index was significantly higher for cases than for controls ($P < 0.05$). No differences in personal habits such as smoking or drinking were noted between cases and controls.

The association between knee OA and heaviest reported body weight was analyzed. Under univariate analysis, mean heaviest reported body weight for cases was 72.1 kg (standard deviation (SD) = 13.0 kg), significantly higher than that for controls ($P < 0.01$) in men. Odds ratios for heaviest reported body weight were 1.07 (95% CI 1.02–1.13), suggesting that a 1-kg increase in heaviest reported body weight raised the risk of knee OA by 7%.

To more clearly address the influence of heaviest reported weight on development of knee OA, cases were categorized into the following three groups according to the distribution of heaviest reported weight: high, ≥72.0 kg; middle, 61.0–72.0 kg; and low, <61.0 kg. These categories were defined by dividing total distributions into equal thirds. Cases in the high group displayed a >4-fold elevation in risk compared with cases in the low group (OR 4.22, 95% CI 1.13–15.8 for high vs low, $P < 0.05$; OR 1.60, 95% CI 0.50–5.08 for middle vs low, $P = 0.43$) (Fig. 1).

The association between knee OA and history of injury in other joints was calculated. Under univariate analysis, although ORs exceeded a 2-fold increase, no significant difference was observed between cases and controls (OR 2.50, 95% CI 0.78–7.97 for yes vs no, $P = 0.12$).

The association between knee OA and methods of transportation was examined by comparing the frequency of regular bicycle use between cases and controls. Under univariate analysis, while OR was higher for men (OR 2.67, 95% CI 0.71–10.05), no significant differences were noted between cases and controls.

Associations between knee OA and occupational history were analyzed. The most frequent areas of employment for all subjects were factory/construction, agriculture/fishery, clerical/technical, and shop assistant/manager (Table 2). Distributions of initial and principal occupations differed

Table 1. Anthropometric and background characteristics of cases and controls for knee OA in men

	Men	
	Cases	Controls
No. of participants	37	37
Age (years)	70.0 ± 6.6	70.1 ± 7.0
Weight (kg)	64.1 ± 10.7*	59.3 ± 8.7
Height (cm)	162.5 ± 6.9	163.0 ± 6.7
Body mass index (kg/m^2)	24.2 ± 3.4*	22.4 ± 3.8
Heaviest weight in the past (kg)	72.1 ± 13.0**	64.0 ± 9.2
Age at the heaviest weight (years)	57.4 ± 15.1*	51.7 ± 17.8
Current smoking (%)	16 (43.2)	15 (40.5)
Current drinking (≥5 times/week, %)	20 (54.1)	22 (59.5)

Mean ± SD; percentage in parentheses
* $P < 0.05$, ** $P < 0.01$ cases vs controls

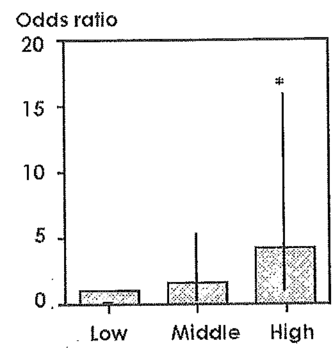

Fig. 1. Association of knee osteoarthritis with heaviest weight in the past. *Low*, lowest 3rd of the heaviest weight category, <61.0 kg; *Middle*, middle 3rd, ≥61.0 kg, <72.0 kg; *High*, highest 3rd, ≥72.0 kg. *Bar* represents 95% confidence interval

Table 2. Occupations reported as initial and principal jobs in men

	Initial occupation				Principal occupation			
	Cases	%	Controls	%	Cases	%	Controls	%
Total	37	100	37	100	37	100	37	100
Factory/construction workers	18	48.6	14	37.8	22	59.5	16	43.2
Agricultural/fishery workers	10	27.0	6	16.2	7	18.9	4	10.8
Clerical workers/technical experts	4	10.8	6	16.2	2	5.4	9	24.3
Shop assistants and managers	2	5.4	9	24.3	2	5.4	6	16.2
Clinical workers	2	5.4	0	0.0	1	2.7	0	0.0
Housekeepers	0	0.0	0	0.0	0	0.0	0	0.0
Hairdressers	0	0.0	0	0.0	0	0.0	0	0.0
Dressmakers	0	0.0	0	0.0	0	0.0	0	0.0
Teachers	0	0.0	0	0.0	2	5.4	0	0.0
Others (soldier, taxi driver, etc.)	1	2.7	2	5.4	1	2.7	2	5.4
No work, no answer	0	0.0	0	0.0	0	0.0	0	0.0

Table 3. Crude and adjusted odds ratios with risk factors for knee osteoarthritis in men

Men	Risk factors	Crude odds ratio (95% CI)	Adjusted odds ratio (95% CI)
Heaviest reported weight[a]	Middle vs Low	1.60 (0.50–5.08)	1.25 (0.29–5.35)
	High vs Low	4.22 (1.13–15.8)*	6.01 (1.18–30.5)*
Past injury of either knee	Yes vs No	2.50 (0.78–7.97)	6.25 (1.13–34.5)*
Occupational factors	Physical work[b] as principal occupation (vs Others)	2.80 (1.01–7.77)*	6.20 (1.40–27.5)*

Adjusted odds ratio refers to values after mutual adjustment for other potential risk estimates
95% CI, 95% confidence interval
[a]Lowest 3rd, <61.0 kg; middle 3rd, ≥61.0 kg, <72.0 kg; highest 3rd, ≥72.0 kg in men
[b]Physical work meaning factory, construction, agriculture or fishery work
$*P < 0.05$

Table 4. Crude and adjusted odds ratios with risk factors for knee osteoarthritis in women (cited from ref. 10)

Women	Risk factors	Crude odds ratio (95% CI)	Adjusted odds ratio (95% CI)
Heaviest reported weight[a]	Middle (vs Low)	1.68 (0.79–3.84)	3.33 (0.95–11.7)
	High (vs Low)	3.10 (1.26–7.98)*	3.92 (1.03–14.8)*
Past injury of either knee	Yes vs No	5.00 (2.44–10.2)*	7.51 (2.40–23.5)**
Transportation	Cycling almost every day for ≥12 months (vs Less)	1.88 (1.02–3.94)*	1.67 (0.61–4.57)
Occupational factors	Physical work[b] as initial occupation (vs Others)	2.54 (1.34–4.82)**	2.08 (0.88–5.61)
	Sitting ≥2 h/day at initial job (vs Less)	0.43 (0.23–0.78)**	0.44 (0.47–1.10)
	No. of jobs (1 job)	1.24 (1.02–1.50)*	0.91 (0.66–1.25)
	Total working period (1 year)	1.05 (1.03–1.07)***	1.05 (1.01–1.08)**

Adjusted odds ratio refers to values after mutual adjustment for other potential risk estimates
95% CI, 95% confidence interval
[a]Lowest 3rd, <55.0 kg; middle 3rd, ≥55.0 kg, <62.0 kg; highest 3rd, ≥62.0 kg in women
[b]Physical work meaning factory, construction, agriculture or fishery work
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$

significantly between cases and controls. Physical work (factory/construction or agriculture/fishery) at the principal job was significantly more common among cases than controls (OR 2.80, 95% CI 1.01–7.77 for yes vs no). Mean age at commencement of the first job was 16.3 years (SD 3.8 years) compared to 16.6 years (SD 4.1 years) for controls, indicating no significant difference between cases and controls. Occupational activities including standing, climbing stairs, kneeling, squatting, driving, walking, sitting, and heavy lifting were not associated with increased risk of knee OA in men.

Table 3 shows ORs determined using conditional logistic regression analysis mutually adjusted for potential risk factors. Various risk factors were entered into the conditional logistic model, comprising: heaviest reported weight; previous knee injury; and physical work at the principal occupation in men. Heaviest reported weight in the past (OR 6.01, 95% CI 1.18–30.5, $P < 0.05$), past injury of the knee (OR 6.25, 95% CI 1.13–34.5, $P < 0.05$), and physical work at the principal occupation (OR 6.20, 95% CI 1.40–27.5, $P < 0.05$) represented independent factors associated with knee OA after controlling for other risk factors (Table 3).

Discussion

The results of the present case-control study indicate that heavy weight in the past and previous knee injury are associated with knee OA in men. Also in men, the proportion engaged in physical work (factory, construction, agriculture, or fishery work) was significantly higher among cases than controls. These risk factors for male knee OA are similar to those seen for female OA knees. Although we have already reported the results elsewhere,[10] we briefly compared results for men and women. Table 4 shows ORs in women determined using conditional logistic regression analysis mutually adjusted for potential risk factors. Various risk factors were entered into the conditional logistic model, comprising: heaviest reported weight in the past; previous knee injury; regular bicycle use; physical work in initial occupation; sedentary work in initial occupation; number of jobs; and total working period, summarizing all years of all jobs that subjects worked. Heaviest reported weight in the past, past injury of the knee, and total working period in women represented independent factors associated with knee OA after controlling for other risk factors. The results of the present case-control study indicate that heavy weight in the past and previous knee injury are associated with knee OA in both men and women.

Several limitations apply to the present study. Firstly, this investigation was based on a relatively small number of male cases and controls. Before the start of the research, we had calculated the sample size. We accumulated 155 pairs of cases and controls based on assumed values of a 0.05 level of significance, 80% statistical power, 2.0 risk ratio, and the 30% prevalence of cases. As a result, we succeeded in identifying 160 cases (40 men, 120 women) >45 years old

Table 5. Comparison of risk factors for hip and knee osteoarthritis (OA) in Britain and Japan (combined results for men and women)

	Risk factors	Britain	Japan
Hip OA	Obesity	Yes	No
	Past joint disturbance	Yes	No
	Occupational factors	Yes (lifting)	Yes (lifting)
Knee OA	Obesity	Yes	Yes
	Past joint disturbance	Yes	Yes
	Occupational factors	Yes (kneeling/squatting)	Yes (physical work, working period)

who fulfilled the entry criteria for the study. Of the eligible cases, 138 (86.3%; 37 men, 101 women) agreed to participate. However, the lack of gender balance for cases resulted in a small number of male subjects, which might reduce statistical power, and thus might not have detected other risk factors among lifestyle variables. This could be due to the use of identical case definitions for subject selection as the case-control hip OA and British studies. Cases were defined as those suffering knee pain and walking difficulties, who were first diagnosed by an orthopedic surgeon as displaying a tibiofemoral joint with a radiographic grade of ≥3 on the Kellgren and Lawrence scale. Our previous comparative study of OA in the lumbar spine indicated that OA in the general population tends to display lower prevalence and severity in Japan than in Britain.[14] In addition, the small number of male cases reflects gender differences in prevalence of knee OA in Japan. As a second limitation in the present study, the response rate for controls (52.8%) was lower than that for cases (92.0%). The present results may therefore be subject to some degree of overestimation.

Obesity has previously been shown to display strong associations with risk of knee OA,[2–8] and epidemiological studies performed in Japan have confirmed associations between obesity and knee OA.[15,16] In the present study, a history of heavy weight was shown to exert significant influences on risk of knee OA among men, resembling the results of women,[10] and consistent with previous studies. These findings indicate that the influence of heavy weight on knee OA is consistent across gender in both Japanese and Western populations.

The involvement of other joints is believed to play a role in increased risk of OA. In the British study paralleling the present study, presence of Heberden's node and previous knee injury were both strongly and independently associated with knee OA.[11,12] Although the present study did not seek information regarding the presence of Heberden's node, information was obtained about past history of the involvement of other joints and areas, as diagnosed by a medical doctor, indicating an independent association between previous knee injury and knee OA. In particular, site of knee OA was basically in accordance with the injured site among cases with previous knee injured (right side 91.7%, left side 100%). These findings were again consistent among men and women across Japanese and Western populations.

Mechanical stress represents another factor in the pathogenesis of OA at any joint site. In the present study, although occupational activities of standing, climbing stairs, kneeling, squatting, driving, walking, and heavy lifting were not associated with increased risk of knee OA in men, physical work at the principal occupation raised the risk of knee OA. Physical work represented by factory, construction, agricultural, or fishery work for long periods involved mechanical stress on the knee joints. The previous report utilized conditional logistic regression analysis without physical work, and identified sedentary work as a preventive factor in women.[10] These occupational activities influencing the risk of knee OA suggest that excess stress at the joint raises the risk, while reduced load on the joint decreases risk.

The present case-control study of knee OA paralleled our previous study of hip OA,[9] and was identical in format to some British studies.[17,18] Table 5 summarizes the results of studies using the same methods, indicating differences in risk factors between hip OA and knee OA, and between populations in Britain and Japan. Occupational factors clearly influence the development of both of hip and knee OA in Japan, as in Britain, although differences exist in specific activities exerting influence. Moreover, previous joint injury represented a risk factor for knee OA in Japan, as in the British studies. Conversely, obesity did not represent an independent risk factor for hip OA in Japan, but was a risk factor for both hip and knee OA in the British studies. This may be because local mechanical factors such as acetabular dysplasia might exert stronger influences on hip OA in Japan than other general mechanical factors such as adiposity. However, these results suggest that the pathogenesis of knee OA is similar in Japan and Western countries. Further studies of OA in other sites are required to characterize the risk profile in Japan.

Acknowledgments This research was supported by Grants-in-Aid for Scientific Research A11770200 from the Ministry of Education, Science, Sports and Culture in Japan, the Japan Society for the Promotion of Science, Research Society for Metabolic Bone Diseases, Japan, and the Arthritis Research Campaign, UK. We wish to acknowledge the generosity of surgeons and internists in Saiseikai Wakayama Hospital, Wakayama; Hori Hospital, Sennan; Nishioka Orthopaedic Hospital, Arita; Ryujin Clinic, Wakayama; Tamai Orthopaedic Hospital, Hannan; and Yamamoto Clinic, Shimotsu, Japan; and of Mrs. Sumiko Suzuri for help in locating participants for interviewing. The results of

this study were presented in 2001 at the British Society for Rheumatology XVIIIth Annual General Meeting.

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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.

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

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

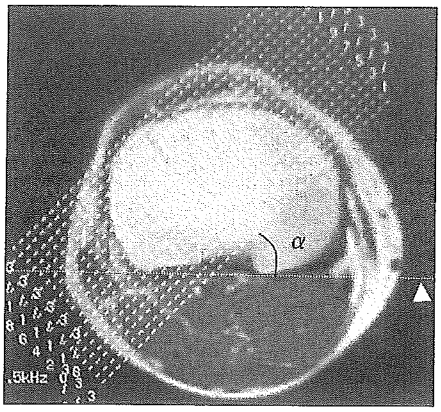


Fig. 1—Slice angle with respect to reference line. Arrowhead indicates reference line, α indicates slice angle.

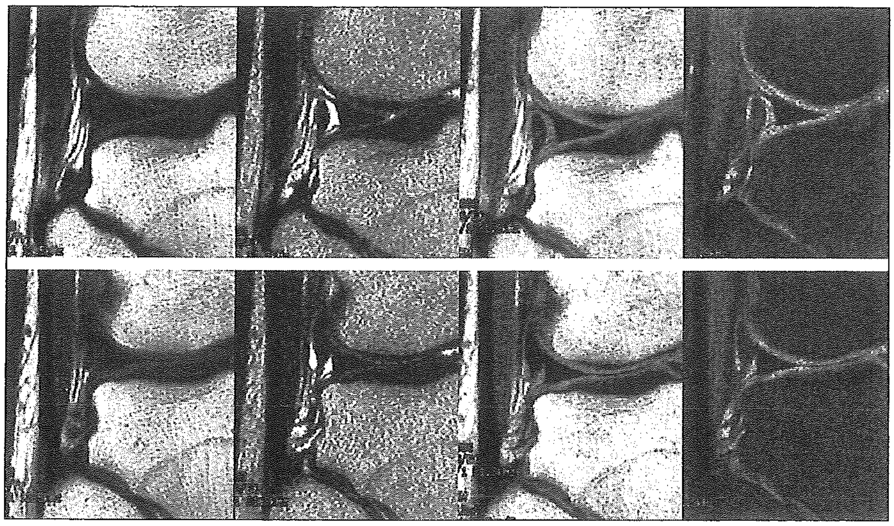


Fig. 2—Effects of MRI sequence for depicting popliteomeniscal fasciculi (PMF). Four sets of sequences were applied for depicting PMF. From left column to right: T1-weighted, T2-weighted, proton density–weighted, and proton fat-saturation images. Posterosuperior fasciculi are depicted in upper four images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

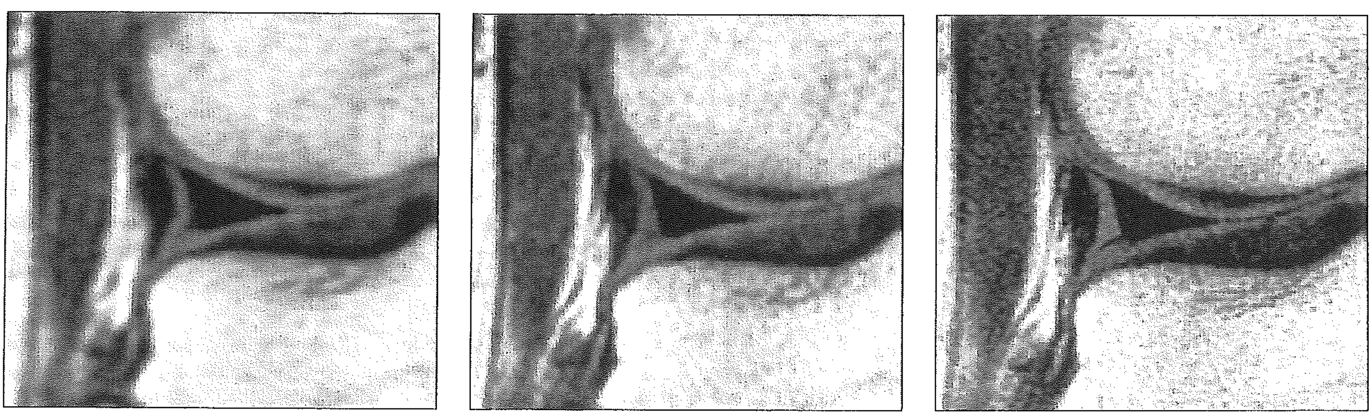
MRI sequence—We used four sets of MRI sequences for this study: T1-weighted, T2-weighted, proton density–weighted, and proton fat-saturation. Settings for the T1-weighted images were as follows: spin-echo; TR/TE, 400/minimum; time, 3 min 28 sec for 256 × 256 matrices. For the T2-weighted images, settings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

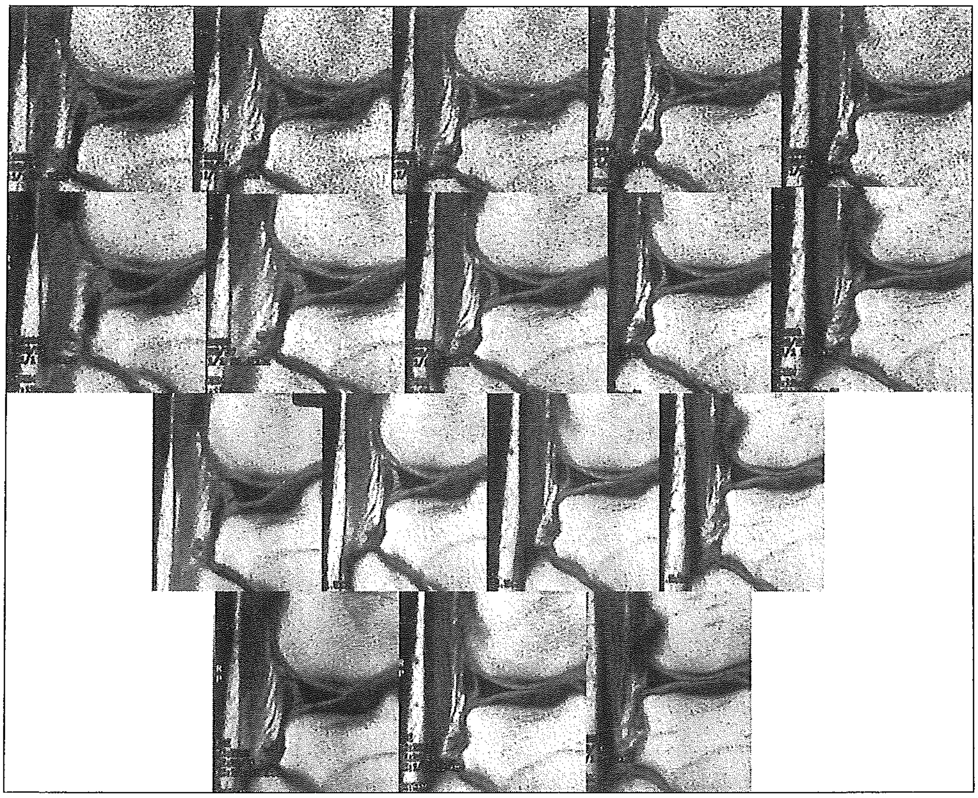


Fig. 4—Effects of slice thickness on popliteomeniscal fasciculi (PMF) depiction. Four sets of slice thickness were used to depict PMF. Images from top row to bottom row show slice thicknesses of 2, 3, 4, and 5 mm, respectively.

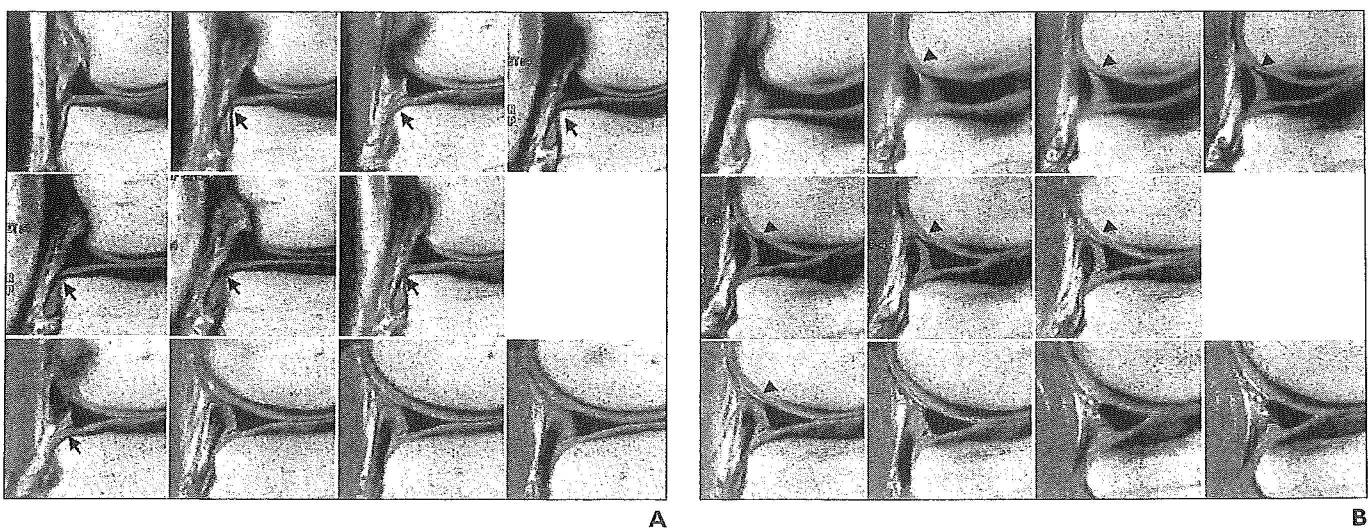


Fig. 5—Effects of obliquity on popliteomeniscal fasciculi (PMF) depiction. Single representative image was selected from each of 11 sets of images from a single knee (10 sets of images were taken at every 10° from 0° to 90°, with respect to reference line, and an additional set of 45° oblique coronal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

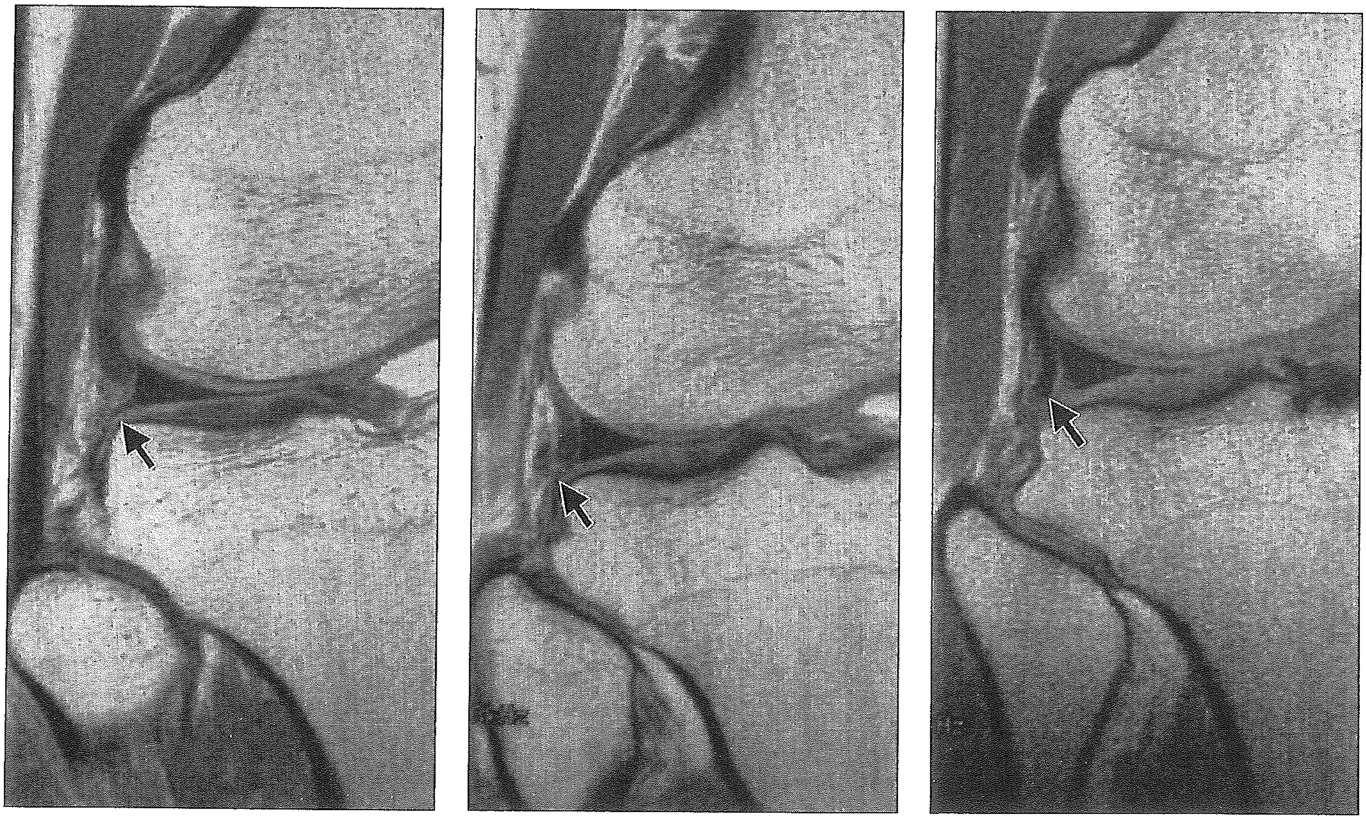


Fig. 6—Classification for depiction of popliteomeniscal fasciculi (PMF).
A–C, Optimal images show depiction of anteroinferior fasciculi (*arrows*) classified A, depicted with obvious continuity and with a low-intensity band (**A**); classified B, depicted with continuity but with ambiguous intensity 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

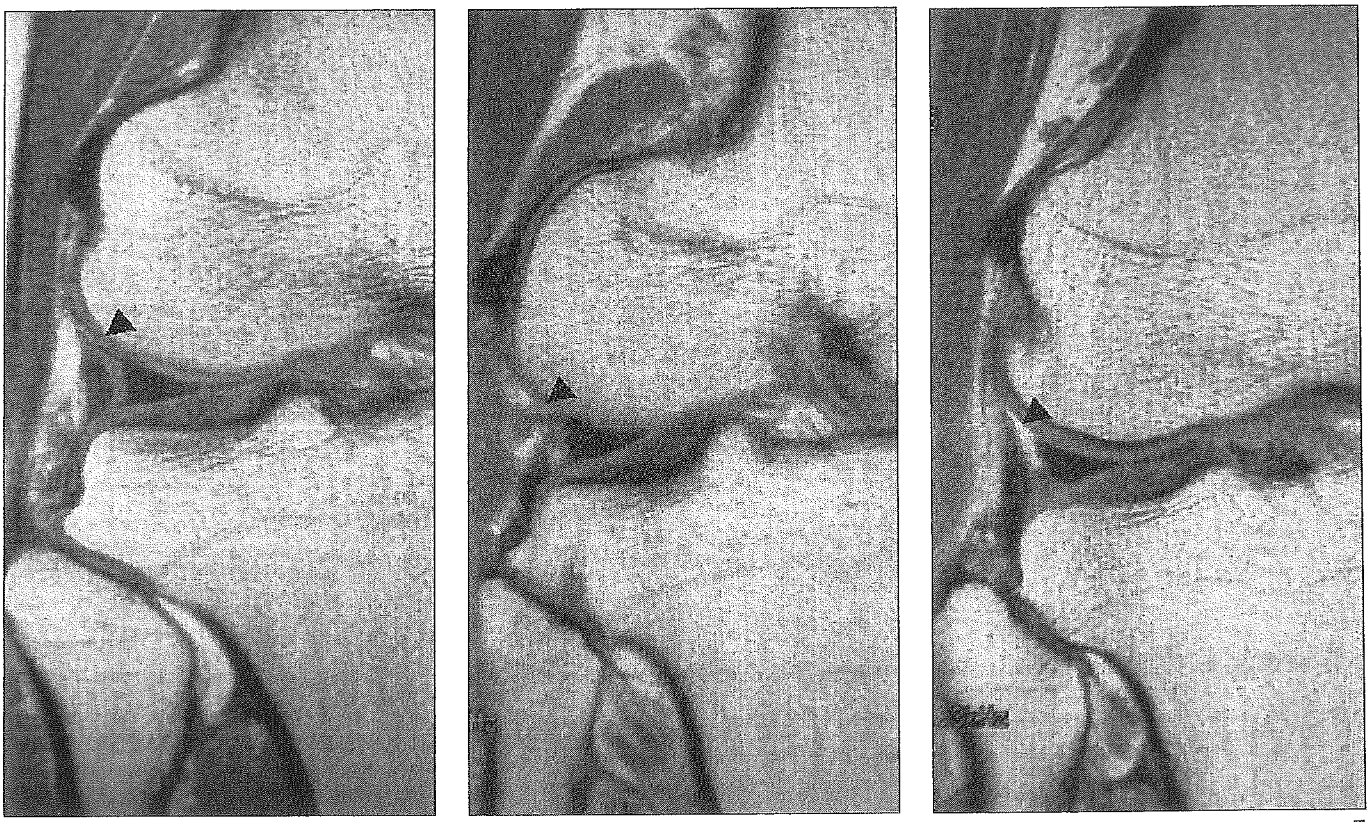
MRI sequence—Four of the six examiners ranked proton density–weighted images in first place and T2- weighted images in second place. The other two examiners ranked T2-weighted images in first place. On the basis of these results, we chose proton density–weighted images for use in further studies.

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.



D E F

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

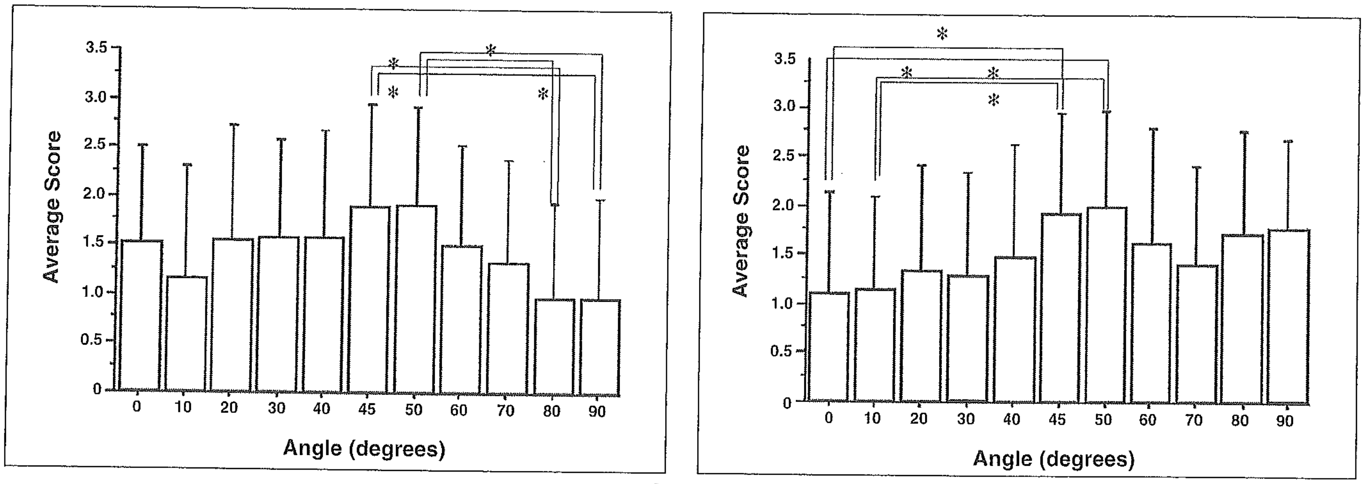


Fig. 7—Graphs show scores for depicting fasciculi as a function of angle.
A and **B**, Average score for depicting anteroinferior (**A**) and posterosuperior (**B**) fasciculi as a function of angle. Best angle for imaging both fasciculi was between 45° and 50°. Asterisks indicate statistical significance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

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 de-