Original Article

Figure-4 Patient Positioning Increases Medial Meniscus Extrusion on Ultrasound in Patients With Posterior Medial Meniscus Root Tears of the Knee

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Purpose: To compare the degree of medial meniscal extrusion (MME) between knees with medial meniscus posterior root tear (MMPRT) and degenerative tears of the medial meniscus using ultrasonography (US) in different limb positions and to identify the findings characteristic of MMPRT. **Methods:** The study group comprised 25 subjects with MMPRT (group RT), 25 subjects with degenerative medial meniscal tears (group D), and 25 knees with no abnormalities of the medial meniscus (MM) on magnetic resonance imaging (MRI) (group C) whose age was ≥40 years. MME was evaluated using US in the supine, figure-4, feet-dangling, and standing positions. The MME was evaluated by the actual measurement values and the relative values to the MME in the supine position. The differences in the MME among the 3 groups in each limb position were analyzed using one-way analysis of variance. $P < .05$ was considered significant. **Results:** The actual MME values were largest in group RT in all 4 limb positions. When changing the limb position from the supine to the figure-4, the actual MME increased from 3.8 ± 0.8 mm to 5.5 ± 1.3 mm in group RT, whereas it decreased from 3.4 ± 1.1 mm to 1.8 ± 1.2 mm in group D, showing the most significant difference in MME of the figure-4 position between the 2 groups ($P < .001$). In group RT, 88% of knees had the maximum MME in the figure-4 position. In group D, 60% of knees had the maximum MME in the standing position and only 2 knees (8%) had the maximum MME in the figure-4 position. **Conclusions:** The increase in MME from the supine to the figure-4 position was a characteristic finding of MMPRT but not degenerative tears. **Level of Evidence:** Level III, case−control study.

Medial meniscus posterior root tear (MMPRT) is a result of meniscal degeneration and occurs frequently in middle-aged and older adults.[1] They disrupt the continuity of the circumferential fibers of the meniscus and the hoop mechanism, causing the pathologic extrusion of the meniscus from the joint surface. The radial displacement of the medial meniscus (MM) from the joint surface (medial meniscal extrusion [MME]) progresses and the peak contact pressure of the medial femorotibial joint increases, which is equivalent to total medial meniscectomy.[2] Studies have reported a close relationship between MMPRT and the development of early osteoarthritis (OA)[3] and spontaneous osteonecrosis of the knee.[4,5] OA is a degenerative process of articular cartilage, which has a poor capacity for repair. Hence, it is difficult to control the progress of arthritic changes that have occurred under the current situation without the use of disease-modifying drugs. In the case of MMPRT, correcting the MME by repairing the disrupted posterior root could prevent the development of OA that would occur if the MME was left untreated. Biomechanical cadaveric studies have revealed that the abnormal elevation of joint contact pressure can be restored after MMPRT repair.[2,6] Thus, many basic and clinical studies have increasingly focused on arthroscopic posterior root repair of MMPRT.

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The improvements in the image quality of ultrasonographic imaging equipment has facilitated the use of ultrasonography (US) in the field of orthopaedic surgery, especially in the evaluation of soft tissue trauma and entrapment neuropathy as well as in echo-guided treatment.[7,8] Although US is unable to directly observe the injured site of MMPRT, it can easily evaluate MME. US can also dynamically evaluate the MME under various loading conditions and limb positions. Several studies using US have demonstrated that the MME increases with weight-bearing and the progression of degenerative arthritis.[9-11] However, there are few reports about the US findings of MMPRT.[12]

Meniscal extrusion is not specific for MMPRT and may not even be pathologic. US tends to show a slight extrusion of the meniscus from the tibial joint surface due to weight-bearing, even in healthy volunteers with nonsymptomatic knees.[13] The purpose of this study was to compare the degree of the MME between knees with MMPRT and degenerative tears of the MM using US in different limb positions and to identify the findings characteristic of MMPRT. We hypothesized that MMPRT knees, in which the medial meniscus has lost its attachment to the bone, might exhibit increased meniscal mobility and a different pattern of MME associated with changes in limb position compared with degenerative meniscal tears.

Methods

Subjects

This study was approved by our institutional review board (approval no. 2424). We prospectively collected the data from 31 patients with MMPRT who underwent arthroscopic root repair between June 2020 and August 2022. One patient was excluded due to a partial tear, and 5 patients were excluded due to Kellgren and Lawrence (K-L) grade 3 OA. Consequently, the study group comprised 25 MMPRT knees (group RT) and 25 knees with degenerative MM tears during the same period (group D) in patients aged ≥40 years. The 25 knees with MMPRT included 4 knees in 2 patients with bilateral cases at different times of injury. Specific magnetic resonance imaging (MRI) findings, such as the cleft sign and the ghost sign,[14] were the basis for the diagnosis of MMPRT. The injury type of MMPRT was arthroscopically confirmed; the cases other than the type 2 injuries on LaPrade classification[15] were excluded. The selection of group D was based on the following criteria: patients complaining of medial knee pain with medial joint line tenderness, no obvious traumatic episodes, and radiologic evidence of a meniscal lesion due to degenerative changes on the MRI (eg, horizontal tears and flap tears). Furthermore, 25 knees in subjects older than 40 years with no abnormalities of the MM on MRIs that were performed for reasons other than MM injury were classified as the control group (group C). Group C comprised 10 knees with lateral meniscus lesions, 9 knees with mild arthritis and nonspecific knee pain, 4 knees with trauma other than MM injuries, and 2 knees of healthy volunteers. Subjects with radiologic signs of OA (grade 3 or less) according to the K-L grade were excluded from each group.

In group RT, the date of the medial meniscal root injury was estimated from the date of feeling a popping sensation and enhanced knee pain, and the subjects were divided into 3 groups according to the interval from the injury to the US measurement: within 1 month after injury, 1 to 6 months, and more than 6 months. Of the 11 of 25 knees in group D that underwent arthroscopic meniscal surgery, the subjects were divided into 2 groups according to the morphology of the meniscus injury based on arthroscopic findings: 7 knees with predominantly horizontal tears and 4 knees with flap tears and radial tears extending deep to the periphery of the meniscus.

US Imaging

The MME was evaluated with an ultrasound device (Nobulus, Hitachi Aloka Medical, Tokyo, Japan) using a standardized scanning method with a 5- to 18-MHz linear probe. The medial femoral epicondyle, midportion of the medial joint line, and midportion of the medial joint space were palpated with the knee in full extension in the supine position, and a reference line was drawn parallel to the fiber orientation of the medial collateral ligament (MCL). The linear probe was placed longitudinally along the reference line and an image was acquired of the best delineation of a triangular structure between the medial femoral condyle and the medial tibial plateau in the long-axis view in which the MCL was most clearly visualized. The MME of the bilateral knees was evaluated in the same manner in the following positions in order: figure-4, feet dangling from the edge of the bed, and standing (Fig 1). In figure-4 position, the subjects were instructed to flex the knee approximately 90°.

The MME was measured on dicom files exported from the ultrasound device using an image processing software (Image J 1.52; National Institutes of Health, Bethesda, MD). The MME was defined as the perpendicular distance between the reference line drawn from the medial tibial cortex parallel to the MCL and the outer edge of the MM as previously described[13,16] (Fig 2). To improve the reproducibility of the measurement, whenever a tibial osteophyte was present, the MME was measured with reference to the tangent line to the tibial cortex excluding the osteophytes. An examiner (A.H.) performed US and evaluated the MME in all knees. The MME measurement was repeated after an interval of at least 1 week, and the 2 measurements

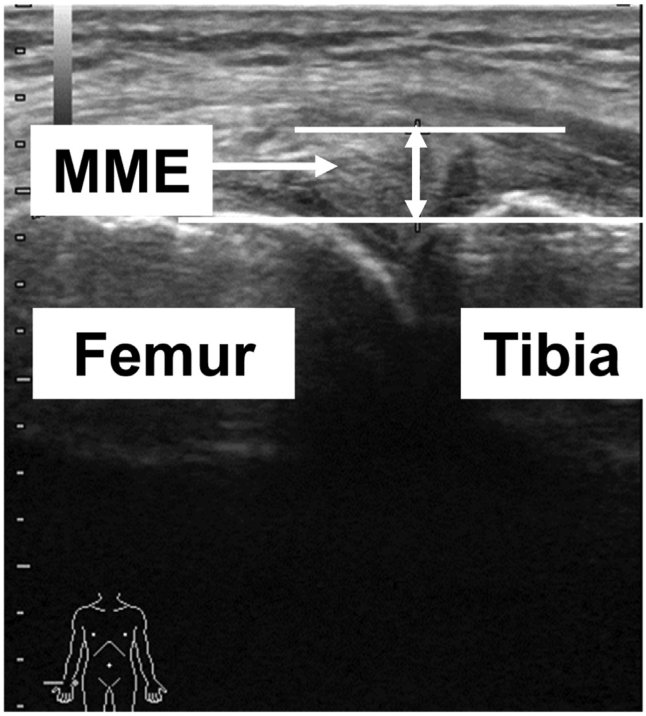

Fig 1. Longitudinal ultrasonographic image of the medial meniscus. The linear probe was placed longitudinally along a reference line drawn parallel to the fiber orientation of the MCL. The MME was measured in the long-axis view in which the MCL was most clearly visualized. The MME was defined as the perpendicular distance from the outer edge of the medial meniscus to the extension of the medial tibial cortex. (MCL, medial collateral ligament; MME, medial meniscal extrusion.)

were averaged. The intraclass correlation coefficient (ICC) was calculated for 10 patients in each group to determine the agreement regarding the ultrasonographic measurement of MME. The MME in each limb position was evaluated using the actual measurement values as well as the values relative to the MME in the supine position (defined as 100%).

Statistical Analysis

Statistical analysis was performed using the SPSS software, version 25 (IBM, Tokyo, Japan). One-way analysis of variance (ANOVA) was used to assess the between-group differences in age and body mass index. Comparison of the ratio of sex and K–L grade in each group was performed using the χ^2 test. The differences in the MME among the 3 groups in each limb position were analyzed using ANOVA. The between-group comparisons of the MME value in each limb position were performed using the Tukey–Kramer test. In group RT and group D, the relationships between K–L grade and actual MME in each limb position were analyzed using 2-way ANOVA.

In group RT, the MME for each limb position was compared within the 3 subgroups based on the differences in the interval from the injury to the US measurement using repeated-measures ANOVA. Similarly, in group D, repeated measures ANOVA was used to compare the MME due to differences in limb position within the 2 subgroups according to the type of degenerative meniscal injury. P values $< .05$ were considered significant.

Results

Of the patients who underwent arthroscopic root repair for MMPRT during the study period, 1 patient was excluded due to a partial tear and 5 patients were excluded due to K-L grade 3 OA. Table 1 shows the detailed characteristics of each group. The mean age of the groups were 65.5 years old (50-80 years) in group RT, 59.2 years old (42-75 years) in group D, and 54.8 years old (42-76 years) in group C. The mean age was significantly greater in group RT and D than in the control group. The distribution of the K-L grade was significantly different between the groups, with group C having a lower K-L grade compared with the other groups. No significant differences in the demographic data were found between group RT and group D.

Reliability of the Ultrasonographic MME Measurement

The intra-rater reliability for the 2 US measurements is shown as the ICC (95% confidence interval). The ICC (1, 1) was 0.847 (0.704-0.924); 0.920 (0.840-0.961); 0.743 (0.527-0.869); and 0.788 (0.600-0.893) for the supine, figure-4, feet-dangling, and standing positions, respectively. The ICC was significant for the measurements in all 4 limb positions ($P < .001$).

MME for Each Limb Position

The mean actual MME was the largest in group RT. The actual MME values were significantly larger in group RT and D than in group C in all 4 limb positions ($P < .001$) (Table 2). There were also significant differences between group RT and D in the actual MME of the figure-4 and feet-dangling positions ($P < .001$). When the limb position was changed from the supine to the figure-4, the actual MME increased from 3.8 ± 0.8 mm to 5.5 ± 1.3 mm in group RT, whereas it decreased from 3.4 ± 1.1 mm to 1.8 ± 1.2 mm in group D and decreased from 2.0 ± 0.7 mm to 0.8 ± 0.5 mm in group C, respectively. Figure 3 shows the typical ultrasonographic images of MMPRT (group RT) and horizontal tear (group D) in the 4 limb positions.

On the basis of the MME in the supine position as a reference, the relative values in each limb position of each subject are shown in Figure 4. The relative mean MME values in the figure-4 and feet-dangling positions decreased in group D and C. In group RT, however, the

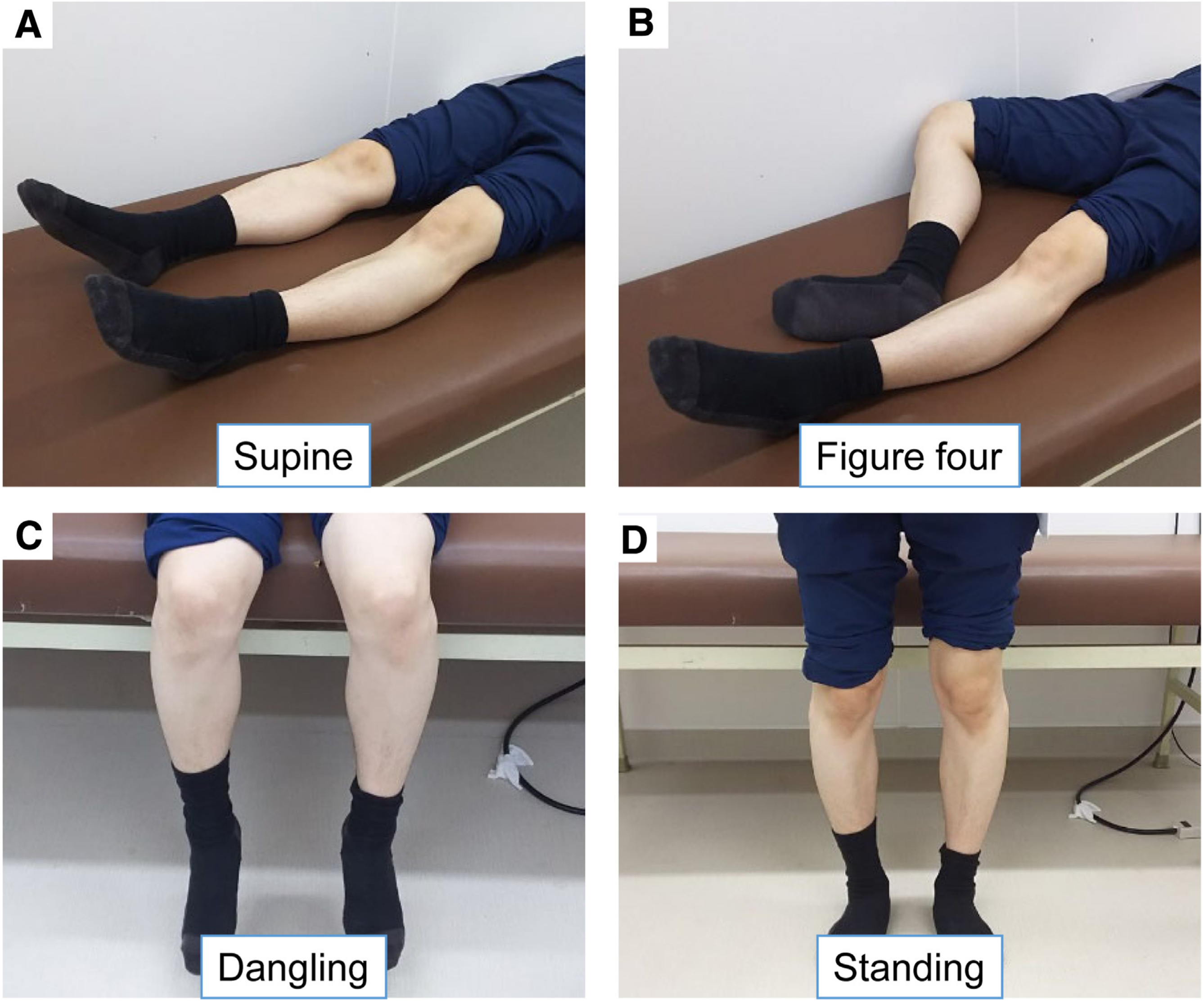

Fig 2. Limb positions for measuring the MME. The MME was evaluated in the same manner in the following positions in order: supine (A), figure-4 (B), feet dangling from the edge of the bed (C), and standing (D). (MME, medial meniscal extrusion.)

Table 1. Basic Characteristics of Each Group

	MMPRT Group (n = 25)	Degenerative MM Tear Group (n = 25)	Control Group (n = 25)
Age, y*	65.5 (50-80)	59.2 (42-75)	54.8 (42-76)
Sex			
Men	7 (28%)	14 (56%)	10 (40%)
Women	18 (72%)	11 (44%)	15 (60%)
BMI	26.4 (18.2-36.7)	26.3 (18-39.9)	23.9 (18.9-27.5)
K-L grade†			
0	1 (4%)	3 (12%)	16 (64%)
1	15 (60%)	10 (40%)	7(28%)
2	9 (36%)	12 (48%)	2 (8%)

NOTE. Data are presented as n, mean (range), or n (%).

NOTE. No significant difference between the groups was detectable for sex and BMI (sex: χ^2 test, $P = .213$, BMI: ANOVA, $P = .066$).

ANOVA, analysis of variance; BMI, body mass index; K-L, Kellgren and Lawrence; MM, medial meniscus; MMPRT, medial meniscus posterior root tear.

*Significantly older than the age in the control group ($P < .05$).

†Significantly greater than the K-L grade in the control group ($P < .05$).

Table 2. Actual MME Value in Each Limb Position

	Supine		Figure-4		Feet-Dangling		Standing	
	MME (Range)	*P* Value	MME (Range)	*P* Value	MME (Range)	*P* Value	MME (Range)	*P* Value
Group RT (n = 25)	3.8* (2.5-5.1)		5.5*† (1.9-8)		2.8*† (0.6-6.3)		4.0* (1.5-6.7)	
Group D (n = 25)	3.4* (1.7-5.8)	.359	1.8* (0.4-5.1)	<.001	1.6* (0-4)	.001	3.6* (1.2-7)	.342
Group C (n = 25)	2.0 (0.7-3.4)	.000	0.8 (0-2.2)	<.001	1.1 (0.1-2.1)	<.001	2.2 (0.8-3.6)	<.001
K-L Grade 0 and 1								
Group RT (n = 16)	3.7 (2.6-5.1)		5.2‡ (1.9-8)		2.8‡ (0.9-6.3)		4.2 (2.4-6.2)	
Group D (n = 13)	3.0 (1.7-5.8)	0.099	1.5 (0.5-2.9)	<.001	1.6 (0.5-3.1)	.018	3.5 (1.6-7)	.178
K-L grade 2								
Group RT (n = 9)	3.9 (2.5-5)		6.1‡ (4.9-7.2)		2.8‡ (0.6-4.6)		3.8 (1.4-6.7)	
Group D (n = 12)	3.8 (1.7-5)	.799	2.2 (0.4-5.1)	<.001	1.7 (0-4)	.058	3.7 (1.2-5.2)	.836

NOTE. Data are shown as average (range).

C, control; D, medial meniscus degenerative tear; MME, medial meniscal extrusion; RT, medial meniscus posterior root tear.

*Significantly greater than the MME of group C ($P < .05$).

†Significantly greater than the MME of group D ($P < .05$).

‡Significantly greater than the MME of group D ($P < .05$).

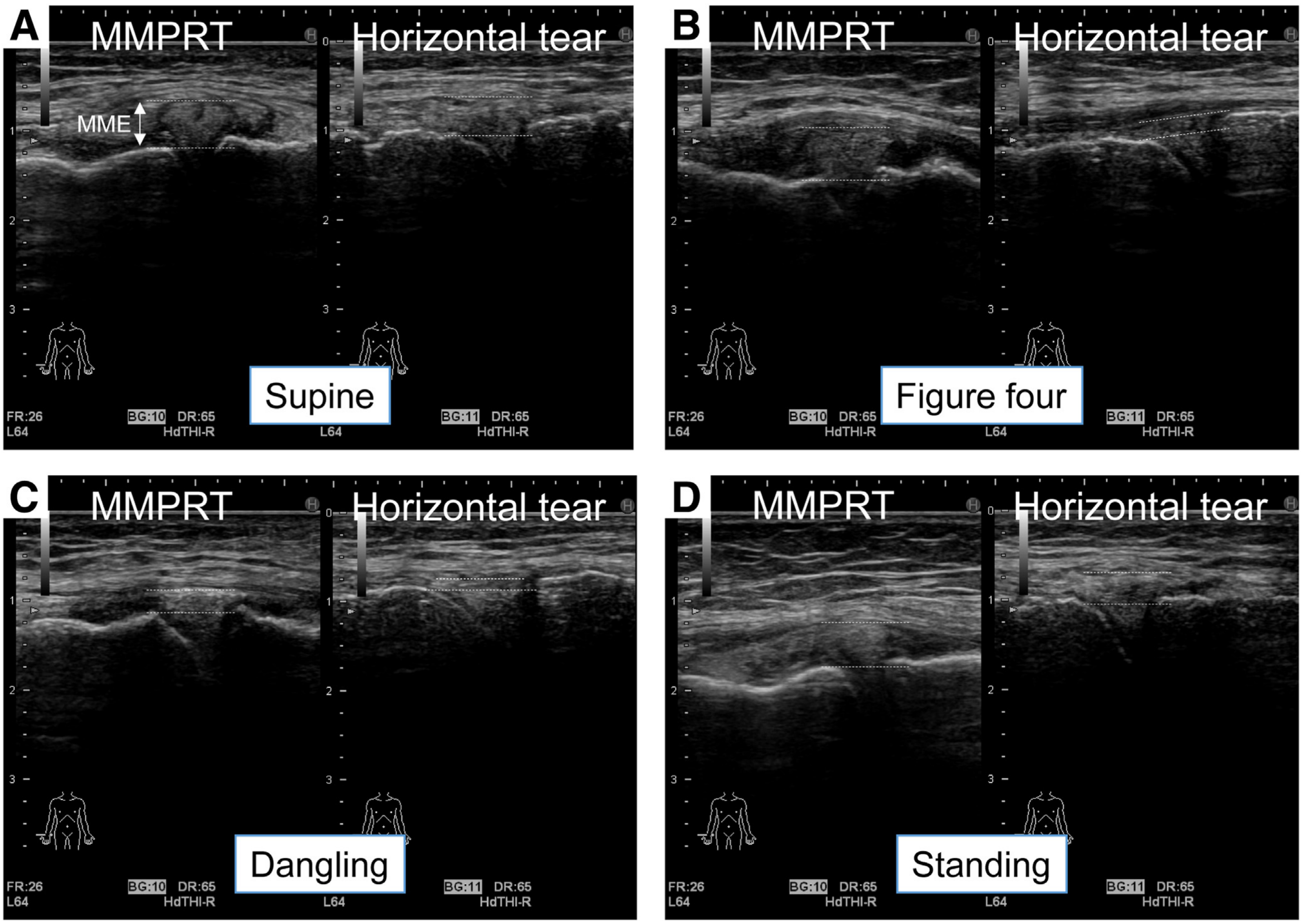

Fig 3. Representative images of the MME in MMPRT and horizontal medial meniscal tear in each limb position. The images in the supine (A), the figure-4 (B), the feet-dangling (C), and the standing (D) position showed the medial meniscus of MMPRT in the left half and horizontal tear in the right half. The MME in MMPRT was larger than that in horizontal medial meniscal tear in the 4 limb positions. In the figure-4 position (B), the MME increased compared with the supine position in MMPRT, whereas the MME decreased in horizontal tear. (MME, medial meniscal extrusion; MMPRT, medial meniscus posterior root tear.)

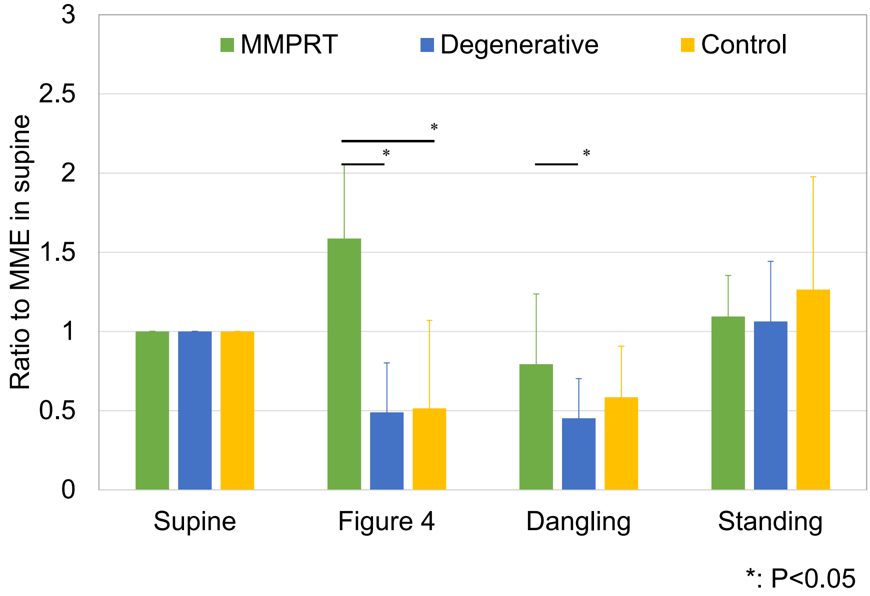

Fig 4. Relative MME value in each limb position versus supine position for all subjects. The amount of the MME in the supine position of each subject was set as 1, whereas the MME in the figure-4, feet-dangling, and standing positions were expressed as relative values to the supine position. The mean MME value was significantly greater in group RT than in group D and C in the figure-4 and feet-dangling positions (D). (group C, control group; group D, knees with degenerative medial meniscal tears; group RT, knees with medial meniscus posterior root tear; MME, medial meniscal extrusion.)

amount of the MME decreased in the feet-dangling position but increased in the figure-4 position. Consequently, the relative MME value was significantly larger in group RT than in group D and C for the figure-4 position ($P < .001$).

Except for group C due to a small number of cases with OA, the relationships between K-L grade and MME in each limb position were evaluated in group RT and D by ANOVA. The MME in the RT group was significantly larger than that in the D group in both K-L grades 0 and 1 ($P < .001$) and K-L grade 2 ($P < .001$) in figure 4 position. In contrast, no statistical difference was found in the MME between K-L grade 0 and 1 and K-L grade 2 in both groups (group RT, $P = .459$; group D, $P = .095$) (Table 2).

In group RT, a significant difference was observed when comparing the MME among the 4 limb positions within 3 subgroups divided by time interval from the injury by ANOVA (≤1 month, $P < .001$; 1-6 months, $P = .002$; ≥6 months, $P < 0.001$). When comparing the MME among the 4 limb positions at each injury time by Tukey's multiple comparison test, the MME in the figure-4 position was larger than that in the other 3 limb positions in the ≤1 month group and in the ≥6 months group (Table 3).

In group D, ANOVA showed significant differences in the actual MME among the 4 limbs in the horizontal tear group ($P < .001$) and in the flap tear group ($P < .001$), and Tukey multiple comparison tests showed significant differences between the MME in the figure-4 position and in the feet-dangling positions and the MME in the supine and in the standing positions in both groups (Table 4).

Limb Position With Maximum MME

Of the 25 knees in group RT, 22 (88%) had the largest amount of MME in the figure-4 position among the 4 limb positions (Table 5). The remaining 3 knees had the largest MME in the standing position, but the differences in the MME between the standing and figure-4 positions were less than 1 mm in 2 of these knees. Meanwhile, In group D, 15 knees (60%) had the maximum MME in the standing position, and only 2 knees (8%) had the maximum MME in the figure-4 position.

Table 3. Results of the Multiple Comparison Test of the Actual MME Values Between Figure-4 and the Other 3 Positions According to the Interval From the Injury to the US Measurement in Group RT

Subgroup	Limb Position	Actual MME	*P* Value
≤1 mo (n = 6)	Supine	3.4 (2.7-4.1)*	.007
	Figure-4	5.4 (4.5-7.2)	–
	Feet-dangling	1.5 (0.6-3.1)*	<.001
	Standing	3.2 (1.5-4.6)*	.003
1-6 mo (n = 11)	Supine	3.9 (2.6-5.1)	.078
	Figure-4	5.3 (1.9-8)	–
	Feet-dangling	2.9 (1.1-6.3)*	.001
	Standing	4.4 (2.4-6.2)	.450
≥6 mo (n = 8)	Supine	3.9 (2.5-5.1)*	.001
	Figure-4	5.9 (4.9-7.1)	–
	Feet-dangling	3.5 (1.7-4.6)*	<.001
	Standing	4.2 (2.7-6.7)*	.006

NOTE. Data are shown as average (range).
MME, medial meniscal extrusion; RT, medial meniscus posterior root tear; US, ultrasonography.
*Significantly smaller than the MME in figure-4 position ($P < .05$).

Table 4. Comparison of Actual MME in Each Limb Position by Injury Type in Group D

Subgroup	Limb Position	Actual MME	*P* Value
Horizonal (n = 7)	Supine	4 (2.4-5)*	.007
	Figure-4	1.4 (0.4-2.3)	—
	Feet-dangling	1.8 (0.9-3.1)	<.001
	Standing	4.1 (2.5-7)*	.003
Flap (n = 4)	Supine	3.8 (2.2-5.8)*	.078
	Figure-4	1.7 (1.1-2.8)	—
	Feet-dangling	1.9 (0.9-2.7)	.001
	Standing	4.9 (3.9-6.1)*	.450

NOTE. Data are shown as average (range).

D, medial meniscus degenerative tear; MME, medial meniscal extrusion.

*Significantly greater than the MME in figure-4 and feet-dangling position ($P < .05$).

Discussion

The most important finding of this study was that the MME in MMPRT knees was greatly increased from the supine to the figure-4 position, whereas the normal MM and even the degenerated MM were reduced to the joint space and the MME almost disappeared. The MME in the group RT increased even in the early periods after the MMPRT injury, and the MME in the figure-4 position was significantly larger than that in the other 3 positions. The gold standard for the diagnosis of MMPRT is MRI. The characteristic MRI findings of MMPRT, such as the cleft sign and ghost sign, have good sensitivity and specificity.[17,18] However, in some cases, it can be difficult to diagnose MMPRT using MRI due to the unclear delineation of the injured site. Moreover, MRI can rarely be performed during the first visit, and it is not readily available worldwide, which may lead to a delay in diagnosis. In contrast, US can easily and dynamically evaluate body parts. The present results suggest that the evaluation of MME in the figure-4 position and comparison with that in the supine position by US was useful for the early diagnosis of MMPRT.

Studies using open MRI have shown that MMPRT induces the pathological posterior extrusion of the MM in the knee-flexed position,[19-21] Farivar et al.[22] reported in the cadaveric study that the MME measured posterior to the MCL was greater than the MME measured anterior to the MCL at full extension and 30° of knee flexion after dissection of the posterior root of the MM. Therefore, it has been suggested that the meniscal extrusion associated with MMPRT is not simply a medial or posterior displacement from the articular surface, but rather a posteromedial rotational shift around the anterior root that is retained on the tibial plateau. As the knee is also flexed in the figure-4 position, the increase in MME in the figure-4 position observed in the present study seems to be due to the same phenomenon as observed in the abovementioned reports. Contrary to our findings, Masuda et al.[19] observed no significant change in the MME, which was solely a lateral displacement of the MM, between the knee flexion angles of 10° and 90°. A number of previous studies have demonstrated that varus stress applied with the knee induced extrusion of the MM.[23-25] The figure-4 position was considered a knee flexion position with mild varus stress. We assume that the narrowing of the joint space at the posteromedial joint margin in the varus or flexed position have been pushing the meniscus out of the articular surface, resulting in a more prominent MME in this position.

In contrast to MMPRT, the MME was reduced not only in the control group but also in most of the degenerative meniscal tears, regardless of the tear types in the figure-4 position. A study[26] using US to investigate the changes in MME during extension—flexion in early knee OA showed that the MME decreased with flexion in the degenerative meniscal tears because the medial meniscus still retained some hoop function, whereas MME did not change much from extension to flexion in the MMPRT knees, in which the hoop function completely disappeared. We speculate that as the knee was flexed and the posterior displacement of the medial meniscus increased, the hoop stress of the circumferential fibers was increased, resulting in the restriction of the medial extrusion of the meniscus in cases where the posterior root was continuous. In contrast, in knees with degenerated MM or normal MM, or with MMPRT, the amount of MME in the feet-dangling position was minimal despite the knee flexion position. It can be suggested that the opening of the joint space due to gravitational traction force in the feet-dangling position would result in the difference in this study compared with previous reports, indicating that the slight opening or narrowing of the joint space was associated with alterations in the force exerted by the medial femoral condyle to extrude the MM out of the articular surface.

Few previous studies have evaluated the US findings associated with MMPRT. Karpinski et al.[12] used US to compare the MME in the supine and standing positions between knees with MMPRT and healthy knees. They found that dynamic meniscal extrusion (the increase in meniscal extrusion due to weight bearing that is usually

Table 5. Limb Position With Maximum Medial Meniscal Extrusion

	Supine	Figure-4	Feet-Dangling	Standing
Group				
RT (n = 25)		22 (88%)		3 (12%)
D (n = 25)	8 (32%)	2 (8%)		15 (60%)
C (n = 25)	10 (40%)	1 (4%)	1 (4%)	13 (52%)

NOTE. Data are shown as average (range).

C, control; D, medial meniscus degenerative tear; RT, medial meniscus posterior root tear.

observed in healthy knees) could not be detected and named this phenomenon the "dead meniscus sign." Although they reported that the dead meniscus sign could be used as a basis to highlight meniscal lesions with a functional reaction of the MM under load, they did not describe the specific mechanism of the dead meniscus sign. The results of our study clarify that the dynamic movement of the meniscus is not necessarily reduced and that the MM in the MMPRT knees was significantly extruded in the figure-4 position, which was opposite to the behavior of the MM in knees with degenerative MM tears. As mentioned above, in a meniscus with a loss of hoop stress due to a posterior root injury, even a slight opening or narrowing of the joint space is expected to have a significant effect on MME. In knees with MMPRT, the MM was already significantly extruded even in the supine position. Therefore, we speculate that the loss of dynamic extrusion as a physiological response to the load occurred because the compression force exerted at the center of the medial tibial plateau due to loading did not effectively act as a force to push the meniscus out of the articular surface.

The results of the present study may also carry implications for the optimal limb positions for pull-out repair. It has been recognized that the correction of MME is insufficient in many cases after posterior root repair alone, even though this procedure has achieved good short-term relief of subjective symptoms.[27-29] Apreliminary study that evaluated the differences in the extent of the reduction of the extruded meniscus depending on the limb position during a surgical procedure of pull-out root repair using US showed that no improvement in the MME was observed in the figure-4 position, regardless of how hard the suture was pulled out.[30] In transtibial pull-out repair, a bony tunnel aperture is likely to be placed proximally medial to the tibia. In this case, it is easy to fix the suture with the knee in the figure-4 position, but the limb position should be subsequently changed.

Limitations

This study has several limitations. First, the ultrasound examinations were performed by only one examiner, as in most previous studies conducting MME assessments by US. As most subjects in group D and all of group C were ambulant and underwent US measurements in routine outpatient settings, it was not practical to use multiple examiners. Thus, all subjects in group RT were also examined by a single examiner for consistency. Second, the reproducibility and accuracy of the measurements may be inferior to those of other imaging modalities, such as MRI, because even a slight change in the way the US probe is applied causes a great difference in the images. Although it is difficult to directly assess meniscal injury by US examination, the usefulness of ultrasound in measuring the meniscal extrusion has been demonstrated in a number of papers.[10,11,13,31] In the systematic review of MME measurements in MMPRT,[32] the pooled MME was 3.9 mm in 10 previous studies that measured the MME in full extension using MRI with the MCL as a landmark to acquire coronal images for MME measurements, which was similar to the present results, and the previous report showed no significant difference between the measurement results of MRI and US.[12,16] The greatest ICC value in the present study was 0.920 in the figure-4 position and the lowest was 0.743 in the feet-dangling position; these are comparable to those reported in previous studies.[13,33] Furthermore, the MME in the figure-4 position of group RT was different by more than 3 mm compared with that in group D and C. This was considered a useful finding with a diagnostic value that outweighed the difficulty of measurement accuracy. Third, some of the analyses, in particular many of the subgroup analyses, were underpowered due to insufficient sample sizes, which may have led to false negatives. The power of the ANOVA for MME in the supine and standing positions was 0.23. We calculated the required sample size based on the effect size obtained from the analysis and it was determined that a total of approximately 125 samples with a minimum of 40 cases in each group would be required to increase the power to 0.8 in this analysis. In contrast, the power of the ANOVA for MME in the figure-4 and the feet-dangling positions was high, 1 and 0.9, respectively, and the total sample size of 75 cases in this study was considered adequate. Fourth, the degree of MM degeneration in group D was not consistent, and group C (the control group) included only 2 knees of healthy subjects and did not have uniform knee conditions within the group. Although no apparent abnormalities were observed in the MRI findings of the MM in group C, some degree of meniscal degeneration is possible. In addition, group C was not comparable to the other 2 groups in terms of age and the distribution of the K—L grades. These differences of basic characteristics were considered to contribute to a significant difference in the MME in group C compared with that in group RT and D when comparing MME in each of 4 limb positions. However, as noted previously, the most important finding of this study was that when the limb position was changed from the supine to the figure-4, the MME in MMPRT knees was increased by an average of 1.8 mm, whereas the MME in group D and C decreased by an average of 1.5 mm. Even in the case of flap injuries in group D, where the tear tends to reach the most peripheral circumferential fibers and the hoop function of the MM would be compromised, the MME in the figure-4 position was significantly lower than that in the supine and standing positions, as was the case with the horizontal tears and the control group indicating that the behavior of the MM showed contrasting changes. That is, in the figure-4 position, the MME seemed to be determined by whether anchoring to the medial tibial plateau at the meniscal root was maintained, regardless of the degree of meniscal degeneration.

Conclusions

The increase in MME from the supine to the figure-4 position was a characteristic finding of MMPRT, but not degenerative tears.

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