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Ultrasonographic diagnosis of medial meniscus posterior root tear in early knee osteoarthritis: a comparative study

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Abstract

Introduction This study aimed to detect medial meniscal posterior root tear (MMPRT) diagnostic methods with high sensitivity and specificity using dynamic ultrasonographic evaluation in patients with early knee osteoarthritis (OA) and demonstrate the usefulness of dynamic ultrasonographic medial meniscal extrusion (MME) evaluation in MMPRT diagnosis using a cutoff value.

Materials and methods Between 2018 and 2020, a total of 120 patients were diagnosed with early knee OA using clinical and radiographic findings. Dynamic ultrasonographic evaluations and magnetic resonance imaging were performed in all patients, and 47 patients who had and 73 patients who did not have MMPRT were classified into the MMPRT and non-MMPRT groups, respectively. Age, sex, femorotibial angle, MME of knee extension and flexion, and MME at weight-bearing were compared between the two groups. Additionally, the sensitivity and specificity of significant ultrasonographic findings were calculated using a receiver operating characteristic (ROC) curve.

Results The MMEs under knee extension–flexion and weight-loading in the MMPRT group were significantly larger than those in the non-MMPRT group. ROC curve analysis for each ultrasonographic evaluation condition to diagnose MMPRT indicated that the sensitivity was 72–88% and the specificity was 66–85% when the cutoff values of MME under knee flexion at 0°, 90°, and weight-loading were set at 2.55 mm, 2.00 mm, and 3.55 mm, respectively. The highest sensitivity (88%) and specificity (85%) were exhibited upon > 2 mm MME at a knee flexion of 90° and were the most useful indicators for MME diagnosis.

Conclusions Ultrasonographic MME evaluations for MMPRT diagnosis showed relatively high sensitivity and specificity in patients with early knee OA. Dynamic ultrasonographic MME evaluation may lead to appropriate additional examinations, early diagnosis, and intervention for MMPRT in patients with early knee OA.

Keywords Early knee osteoarthritis · Medial meniscus posterior root tear · Ultrasound · Medial meniscal extrusion

Introduction

A medial meniscal posterior root tear (MMPRT) is a critical medial meniscus injury pattern [1, 2]. Accurate diagnosis is required at the earliest phase of osteoarthritis (OA) possible to prevent progression of OA [3, 4] and to preserve treatment options, such as meniscal repair and rehabilitation [5, 6]. Several characteristic magnetic resonance imaging (MRI) findings for the detection of MMPRT [7–10] have been reported, and high sensitivity (63–100%) and specificity (73–100%) of the characteristic MRI signs for MMPRT have been shown in previous reports [11, 12]. However, MRI has some disadvantages in terms of cost and frequency, although it is useful for diagnosing MMPRT. Owing to these

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disadvantages, MRI has been excluded from the diagnostic criteria for early knee OA, which is often concomitant with MMPRT [13, 14]. Meanwhile, ultrasound evaluation of the medial meniscus is attracting attention as a useful assessment for early knee OA owing to its frequency of use and the possibility of dynamic evaluation [15, 16]. A clinical study in 2021 showed that MMPRT has been present in 25% of consecutive patients with knee early OA, and dynamic medial meniscus screening with ultrasound is useful for performing MRI at an appropriate timing [16]. The validity and accuracy of ultrasound evaluation for medial meniscal extrusion (MME) have been demonstrated in many previous reports using ultrasound and MRI [17, 18]. Although some studies on ultrasonographic evaluation for MMPRT have been reported in recent years [19, 20], no studies have demonstrated high sensitivity and specificity using cutoff values for MMPRT diagnosis, and previous static ultrasound evaluations have not been useful as diagnostic tools in clinical practice. Therefore, the present study aimed to detect MMPRT diagnostic methods with high sensitivity and specificity using dynamic ultrasonographic evaluation in patients with early knee OA. We also sought to demonstrate the usefulness of dynamic ultrasonographic MME evaluation in MMPRT diagnosis using a cutoff value. We hypothesized that dynamic ultrasonographic MME evaluation would show high sensitivity and specificity for assessing MMPRT in patients with early knee OA, which may enable appropriate additional examinations, early diagnosis, and intervention.

Materials and methods

Among all patients with medial knee pain examined between 2018 and 2022, the present study included 120 patients (120 knees) with a K–L grade of 0 or 1 in a standing anteroposterior X-ray view. All the patients were diagnosed with early knee OA [21]. The selection was based on the following three criteria, similar to the study conducted by Luyten et al. [13]: Knee Injury and Osteoarthritis Outcome Score of ≤ 85% in at least two out of four categories, joint line tenderness or crepitus, and a K–L grade of 0 or 1. Additional inclusion criteria were as follows: absence of locking or catching findings that would suggest a symptomatic or traumatic meniscal tear in clinical examination; no history of ipsilateral knee surgery and obvious traumatic accident; absence of lateral pain in the knees or other parts; and absence of inflammatory diseases, as observed by MRI evaluation. The rationale of this study was explained to the patients on the first visit, and MRI, whole-leg standing anteroposterior X-ray, and ultrasonographic evaluation were performed on all participants on the second visit day within 2 weeks of the initial visit. The participants were divided into two groups based on MRI findings: patients who had both white meniscus sign and cleft sign were included in the MMPRT group, and those without medial meniscus tear or with medial meniscus tear excluding MMPRT were classified as the non-MMPRT group. Age, sex, femorotibial angle (FTA), MME of knee extension and flexion, and MME at weight-bearing were compared between the MMPRT and non-MMPRT groups.

This cross-sectional study was approved by the ethics committee of our institution (approval no. 2328). Written informed consent was obtained from all the patients included in this study.

Ultrasonographic evaluation

During ultrasonography, MME at the affected knee with 0° and 90° of flexion in the supine position and at the weight-loading condition with full knee extension in the upright position was evaluated using SNiBLE (KONICA MINOLTA, Tokyo, Japan) with an 18-MHz linear transducer (Fig. 1). MME was evaluated by ultrasound at the medial aspect of the knee using longitudinal sections parallel to the medial collateral ligament (MCL), where the MCL is best depicted (Fig. 2) [22]. Additionally, to ensure the reproducibility of the ultrasonographic evaluation, the top of the femoral medial epicondyle was used as a bony landmark. The femoral medial epicondyle was palpated before the transducer was installed, and the proximal part of the transducer was placed immediately at its top. We were also mindful that the fat between the superficial and deep layers of the MCL was clearly visible and that the MCL was best depicted. MME was defined as the displacement from the margin of the tibial plateau and was measured as the distance (in mm) between the margin of the tibial plateau and the peripheral border of the meniscal body (Fig. 2) [17]. The pictures of the ultrasonographic examination were saved as JPG files, and MME measurements were performed using the ImageJ software (National Institutes of Health, Bethesda, MD, USA). An experienced orthopedic surgeon (KS), with 10 years of experience in performing ultrasound of knee joints, performed all the ultrasonographic medial meniscal assessments. Ultrasonographic MME findings were evaluated twice on the second and third visit days. The mean MME of the two assessments was accepted as the result, and intra-class correlation coefficients under knee flexion at 0° and 90° and weight-loading conditions were also calculated.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences for Windows (version 27.0; IBM Corp., Armonk, NY, USA). Age, sex, FTA, and MMEs on ultrasonography were analyzed using Student's *t* test and chi-squared test between the two groups. To detect useful MME

Fig. 1 Ultrasonographic evaluations at knee flexion angles of (**a**) 0°, (**b**) 90°, and (**c**) weight-loading conditions

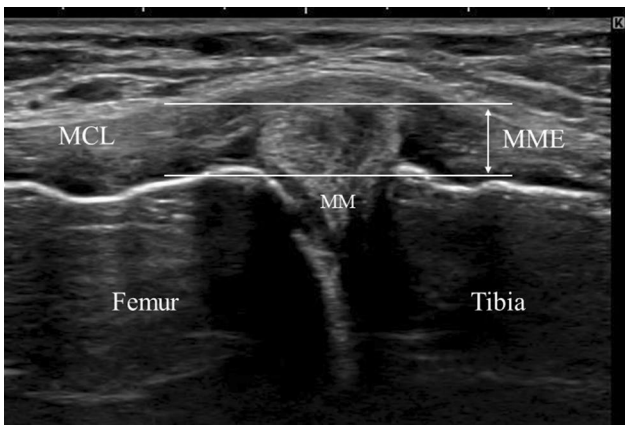

Fig. 2 Methods for evaluating MME via ultrasonography using longitudinal sections parallel to the MCL in MMPRT cases. *MCL* medial collateral ligament, *MME* medial meniscal extrusion, *MM* medial meniscus, *MMPRT* medial meniscus posterior root tear

findings for the diagnosis of MMPRT, the sensitivity and specificity of each ultrasonographic evaluation finding for MMPRT diagnosis were calculated using receiver operating characteristic (ROC) curve analysis. The level of significance for all statistical analyses was set at $\alpha = 0.05$. A post-hoc power analysis for sample size was performed, which revealed an effect size of 0.5, power of 0.85, and α of 0.05. The effect size and power were found to be sufficient.

Results

Of the 120 patients, 47 were included in the MMPRT and 73 in the non-MMPRT group. In the non-MMPRT group, 20 no meniscus tear cases, 50 degenerative or horizontal medial meniscus tear cases, and 3 cases of longitudinal medial meniscal tears were detected by MRI. However, tears of the medial meniscus that directly affect meniscal hoop function, such as MMPRT or radial tears, were absent. No significant differences were observed in the average age, sex, or FTA between the two groups (Table 1). The MMEs under knee flexion at 0° and 90° were significantly larger in the MMPRT group than in the non-MMPRT group. Similarly, MME under the weight-loading condition in the MMPRT group was significantly greater than that in the non-MMPRT group. From 0° to 90° of knee flexion, MME values decreased by 0.5 ± 0.6 mm in the MMPRT group and 1.2 ± 0.8 mm in the non-MMPRT group, and significant differences were revealed between the two groups ($P < 0.01$). However, no significant changes were detected in MME from unloaded to loaded conditions between the two groups.

The MME evaluation items that showed significant differences between the two groups were evaluated using ROC curve analysis to characterize the diagnostic ability of ultrasound for MME (Table 2). ROC curve analysis indicated that when the cutoff values of MME under knee flexion at 0° and 90° were set at 2.55 mm and 2.00 mm, the sensitivity

Table 1 Data comparison between the two groups

	MMPRT ($n=47$)	Non-MMPRT ($n=73$)	*P*-value
Age (years)	64.1 ± 8.5	62.4 ± 10.1	0.92
Sex (female/male)	31:16	41:32	0.34
FTA (degree)	176.6 ± 2.3	175.3 ± 2.1	0.06
MME at knee flexion 0° (mm)	3.8 ± 1.1	2.4 ± 1.0	< 0.01
MME at knee flexion 90° (mm)	3.2 ± 1.2	1.1 ± 0.9	< 0.01
MME under weight-loading (mm)	4.4 ± 1.2	3.0 ± 1.0	< 0.01
Change in MME from 0° to 90° knee flexion (mm)	0.5 ± 0.5	1.2 ± 0.8	< 0.01
Change in MME from unloaded to loading (mm)	0.7 ± 0.5	0.8 ± 0.6	0.74

FTA femorotibial angle, *MME* medial meniscal extrusion, *MMPRT* medial meniscus posterior root tear

Table 2 ROC curve analysis result for the evaluation of the diagnostic ability of MME using ultrasound

	MME evaluation conditions			
	Flexion 0°	Flexion 90°	Weight-loading	Change from 0° to 90°
Cutoff value (mm)	2.55	2	3.55	0.95
Sensitivity (%)	88	88	72	83
Specificity (%)	69	85	79	66
AUC	0.824	0.906	0.809	0.759
95% CI	0.723–0.925	0.821–0.992	0.821–0.992	0.673–0.846

MME medial meniscal extrusion, *AUC* area under the curve, *CI* confidence interval, *ROC* receiver operating characteristic

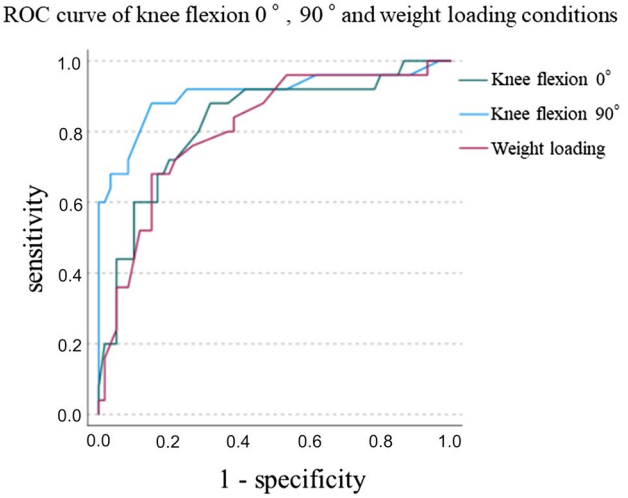

Fig. 3 The result of the ROC curve analysis for MMPRT diagnosis regarding MME evaluation under flexion of 0°, 90°, and weight-loading conditions. *ROC* receiver operating characteristic, *MMPRT* medial meniscus posterior root tear, *MME* medial meniscal extrusion

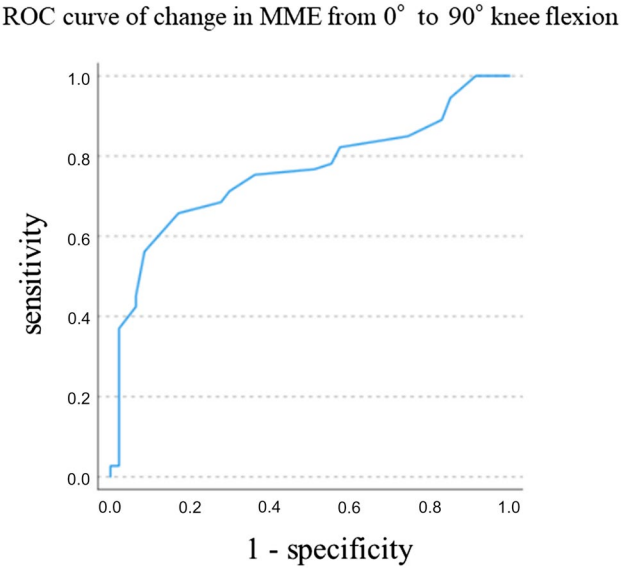

Fig. 4 The result of the ROC curve analysis for MMPRT diagnosis regarding the amount of MME change from knee extension to flexion. *ROC* receiver operating characteristic, *MMPRT* medial meniscus posterior root tear, *MME* medial meniscal extrusion

was 88% and the specificities were 69% and 85%, respectively (AUC = 0.82 and AUC = 0.91, respectively, Fig. 3). Similarly, when the cutoff value of MME during weight-loading was set at 3.55 mm, the sensitivity was 72%, and the specificity was 79% (AUC = 0.81, Fig. 3). Regarding the amount of the MME change from knee extension to flexion, when the cutoff value was set at 0.95 mm, the sensitivity was 83%, and the specificity was 66% (AUC = 0.76, Fig. 4). An MME of > 2 mm at a knee flexion of 90° showed the highest sensitivity and specificity and was the most useful indicator for MME diagnosis. For ultrasonographic assessment, the intra-class correlation coefficients under knee flexion at 0°,

90°, and weight-loading conditions were 0.908, 0.887, and 0.901, respectively.

Discussion

In this study on early knee OA, we evaluated the dynamics of the medial meniscus during knee flexion–extension and weight-loading, as measured using ultrasonography. Most importantly, our analysis revealed that dynamic MME evaluation in early knee OA cases had good sensitivity and specificity for MMPRT diagnosis. The criteria for suspecting MMPRT were MME of 2.55 mm in the knee at 0° flexion (sensitivity: 88%, specificity: 69%), MME of 2 mm in the knee at 90° flexion (sensitivity: 88%, specificity: 85%), MME of 3.55 mm in weigh-loading condition (sensitivity: 72%, specificity: 79%), and MME change of 0.95 mm during knee flexion–extension (sensitivity: 83%, specificity: 66%). MME of > 2 mm under a knee flexion of 90° showed both high sensitivity and specificity and was considered the most useful finding for MME diagnosis. The results showed that dynamic MME evaluation using ultrasound is a useful first-line screening tool for MMPRT diagnosis.

MME with MMPRT correlates with the disease duration and grows larger by the day if the tear is left untreated [23, 24]. Therefore, medial meniscus posterior root repair and/or medial meniscus centralization should be performed as soon as possible to restore medial function and improve MME with surgical treatment [4, 25]. Although the relationship between MMPRT and MME has been reported previously, the value of MME as a diagnostic indicator for MMPRT using MRI is not very high. Choi et al. [11] reported in 2013 that the sensitivity and specificity of MME for diagnosing MMPRT were 63.3% and 90%, respectively. The sensitivity was relatively low compared to that of other MRI findings. Furthermore, Lerer et al. [26] reported that an MME of ≥ 3 mm was considered abnormal—only 79% of MMPRT cases were found to fit the criteria. Based on these previous reports using MRI, to make the MME assessment more sensitive as a screening test, this study performed a dynamic evaluation and calculated the most appropriate cutoff value for the evaluated conditions. From our results, ultrasonographic MME evaluation under a knee flexion of 90° showed the highest sensitivity and specificity among the different assessment conditions. The medial meniscus has been reported to undergo backward translation owing to knee flexion [27], which can be detected via ultrasonography as medial meniscal movement into the joint when the hoop function of the medial meniscus is normal [16]. In contrast, in MMPRT knees, the meniscus moves posteromedially due to the loss of hoop function, and the MME remains. This abnormal medial meniscal movement during knee flexion was reported in a previous study using MRI [28]. Ultrasound could detect the meniscal abnormality easily in this study as the small amount of MME changed from knee extension to flexion. However, the sensitivity and specificity of each ultrasonographic MME evaluation are insufficient. Therefore, a combination of these different evaluation conditions may be needed for screening with even higher sensitivity and specificity.

In contrast, it has been reported that the medial meniscus has some hoop function even after a longitudinal tear or partial meniscectomy, whereas its hoop function disappears with a complete radial tear, which is included in the medial meniscus posterior root tear [29, 30]. In this study, the non-MMPRT group showed smaller MME than the MMPRT group, as in previous studies, although 53 of 73 patients had meniscal tears, except for MMPRT and radial tears. Additionally, it is considered that the MME decreased because of knee flexion, as the hoop function was maintained in degenerative tear cases.

Regarding the weight-loading evaluation for MME, the value of MME under the weight-loading condition was larger in the MMPRT group than in the non-MMPRT group, despite no difference in total limb alignment between the two groups. This means that MMPRT has a direct impact on the increase in MME. However, no difference was observed between the two groups regarding the amount of MME change between the unloaded and loaded conditions. This is because the MME under unloaded conditions is already very large in MMPRT cases, as reported in the past [20], and the increase due to loading is considered small.

A distinct strength of the current study is that it is the first to demonstrate ultrasonographic diagnostic criteria for MMPRT in early knee OA cases using dynamic ultrasonographic evaluation. Another strength is that it has been a comparative study with cases matched for lower extremity alignment, age, and sex. Additionally, our results provide novel characteristic insights that showed high sensitivity and specificity for diagnosing MMPRT in ultrasonographic findings. Ultimately, our study demonstrates that screening MMPRT in early knee OA is possible using simple, dynamic ultrasonography, leading to further examination and treatment at the appropriate time.

Although we made several efforts to minimize the methodological limitations of this study, some limitations should be acknowledged. First, the study only included patients who visited our clinic, which may have led to a selection bias. The incidence of MMPRT is considered higher in Japan than in other countries because of the traditional sitting posture in which the knees are bent deeply, known as "seiza." In addition, we did not evaluate meniscal degeneration, which is considered to play a role in MME. Further studies involving multiple research centers are required to resolve these limitations. Second, the definitive diagnosis of MMPRT in this study was made by MRI rather than arthroscopy, and arthroscopy was not

performed for any patient, which may have led to an inaccurate diagnosis of MMPRT although the diagnostic power of MRI is not poor [11, 12]. Additionally, we could not evaluate the type classification of MMPRT [31]. The type of MMPRT can affect the amount of MME; therefore, future studies that take into account the type of MMPRT using arthroscopy as a diagnostic tool for MMPRT are needed. Third, the degenerative, horizontal and longitudinal tears in the non-MMPRT group might have influenced the results. However, unlike MMPRT or radial tears, these tears do not cause loss of hoop function, and are unlikely to have had a significant impact on MME. These non-MMPRT tears are also mixed up in clinical practice, and we believe that comparing MMPRT with such tears would help to clarify the characteristics of MMPRT findings. Finally, because the ultrasonographic evaluation was performed by a single orthopedic surgeon, its reproducibility cannot be considered high. However, the intra-class correlation was high in this study, whereas a previous study using ultrasound for MME evaluation showed a high inter-class correlation [18].

Conclusions

In patients with early knee OA and MMPRT, ultrasonographic MME evaluations have shown relatively high sensitivity and specificity, especially a large MME of > 2 mm at a knee flexion of 90°. Dynamic ultrasonographic MME evaluation using knee flexion and weight-loading may lead to appropriate additional examinations, early diagnosis, and intervention for MMPRT in patients with early knee OA.

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Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This cross-sectional study was approved by the ethics committee of our institution (approval no. 2328). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Written informed consent was obtained from all the patients included in this study.

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