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Steep posterior slope and shallow concave shape of the medial tibial plateau are risk factors for medial meniscus posterior root tears

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Abstract

Purpose Bone morphological factors are important for menisci. Their association with medial meniscus posterior root tears, however, has not yet been studied. This study aimed to compare sagittal medial tibial slope and medial tibial plateau depth between knees with and without medial meniscus posterior root tears.

Methods Nine healthy volunteers, 24 patients who underwent anterior cruciate ligament reconstruction, and 36 patients who underwent medial meniscus posterior root pullout repair were included. Magnetic resonance imaging examinations were performed in the 10°-knee-flexed position. The medial tibial slope and medial tibial plateau depth were compared among the groups.

Results In healthy volunteers, the anterior cruciate ligament reconstruction group, and the medial meniscus posterior root tear group, the medial tibial slopes were $3.5° \pm 1.4°$, $4.0° \pm 1.9°$, and $7.2° \pm 1.9°$, respectively, and the medial tibial plateau depths were 2.1 ± 0.7 mm, 2.2 ± 0.6 mm, and 1.2 ± 0.5 mm, respectively. Patients with medial meniscus posterior root tears had a significantly steep medial tibial slope and shallow medial tibial plateau concavity compared to those of healthy volunteers ($P < 0.01$) and the anterior cruciate ligament group ($P < 0.01$). In the multivariate logistic regression analysis, body mass index, medial tibial slope, and medial tibial plateau depth were significantly associated with medial meniscus posterior root tears.

Conclusions A steep posterior slope and a shallow concave shape of the medial tibial plateau are risk factors for medial meniscus posterior root tear.

Level of evidence Level III: Case–control study.

Keywords Medial meniscus · Posterior root tear · Magnetic resonance imaging · Medial tibial slope · Medial tibial plateau depth

Abbreviations

ACL	Anterior cruciate ligament
BMI	Body mass index
ICC	Intra-class correlation coefficient
LTS	Lateral tibial slope
MMPRT	Medial meniscus posterior root tear
MRI	Magnetic resonance imaging
MTPD	Medial tibial plateau depth
MTS	Medial tibial slope
PRT	Posterior root tear

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Introduction

The interest in medial meniscus posterior root tears (MMPRT) has been increasing, and they have been widely studied. Knee motions associated with descending stairs and downhill slopes are the most common injury patterns of MMPRTs [9]. MMPRT pullout repair is recommended to prevent subsequent cartilage degeneration or meniscus extrusion [4], and favourable clinical outcomes have been reported after transtibial pullout repair of MMPRT [16, 22]. Severe chondral lesions, varus alignment, and older age have been reported to predict a poor prognosis after MMPRT

fixation, and MMPRT pullout repair is recommended in patients with a femorotibial angle < 180° and mild cartilage lesions [5, 24].

To date, many studies about the association between tibial geometry or biomechanics and the anterior cruciate ligament (ACL) or meniscus have been reported [6, 12, 19, 26, 27, 30]. The geometry of the tibial plateau has a direct influence on the biomechanics of the tibiofemoral joint [3, 7]. An important characteristic of the tibial plateau is its posterior slope (with the anterior elevation being higher than the posterior elevation) [7, 10]. Biomechanical studies have shown that a steep medial tibial slope (MTS) leads to increased anterior tibial translation under load, which may increase the forces acting on the menisci [1, 7, 10, 20, 21, 25]. Furthermore, a biconcave medial tibial plateau is reported to be more frequently associated with a complex medial meniscus tear [2] and a shallower MTS and lateral tibial slope (LTS) may result in impingement of the posterior horn of the medial meniscus and the anterior horn of the lateral meniscus, respectively. However, no significant association was found between medial tibial plateau depth (MTPD) and meniscal tears [15].

These associations in relation to MMPRT, however, have not been studied thus far and were, therefore, the subject of the present study. The purpose of this study was to investigate the unique bone geometry in patients with MMPRT. This study hypothesized that patients with MMPRT would have a steeper MTS and shallower MTPD compared to subjects without MMPRT.

Materials and methods

A retrospective design was used to compare sagittal MTS and MTPD among healthy volunteers (group V), patients who underwent ACL reconstruction (group A), and patients who underwent MMPRT pullout repair (group M). A chart review was conducted using our electronic medical record system to identify healthy volunteers and all patients undergoing ACL reconstruction or MMPRT pullout repair at our institution between January 2013 and November 2018. Exclusion criteria were concomitant injuries such as ACL rupture and MMPRT and a history of previous surgery at the index knee.

A total of 26 healthy volunteers underwent open MRI examinations, 49 patients underwent ACL reconstruction, and 44 patients underwent MMPRT pullout repair. Of those, 9 (35%), 24 (49%), and 36 (82%) were women. For the purpose of this study, only women were included for further analysis because a significant difference has been reported between the within-subject MTS values when male and female subjects were considered as separate groups [11]. Thus, the final sample sizes were 9, 24, and 36 in groups V, A, and M, respectively, which demonstrated adequate power (> 0.95) to detect a significant difference between each pair of groups.

The Kellgren–Lawrence grade was determined using plain radiographs and MMPRT type through careful arthroscopic examination [4]. MMPRT were defined as avulsion injuries of the medial meniscus posterior root or complete radial tears within 1 cm from the posterior bony insertion of the medial meniscus [8]. Patient demographics are shown in Table 1.

MRI measurement

The patients underwent open MRI evaluations using the Oasis 1.2 T MRI system (Hitachi Medical, Chiba, Japan) with a coil in the 10° knee-flexed position in a non-weight-bearing condition and with the following settings: 16-cm field of view with an acquisition matrix size of 320 (phase) × 416 (frequency) and 4-mm slice thickness with

Table 1 Demographic and clinical characteristics

	Healthy volunteer group	ACL group	MMPRT group	P value
Number of patients	9	24	36	
Age (years)	37.8 ± 15.7^a	27.5 ± 13.6^a	60.8 ± 9.8	< 0.01
Height (m)	1.6 ± 0.1	1.6 ± 0.1^a	1.5 ± 0.1	< 0.01
Weight (kg)	51.7 ± 6.4^a	60.7 ± 11.1	62.8 ± 11.7	< 0.05
BMI (kg/m^2)	$21.1 \pm 3.2^{a, b}$	23.8 ± 4.4^a	26.3 ± 4.1	< 0.01
Root tear classification type 1/2/3/4/5	N/A	N/A	2/27/1/6/0	
Kellgren–Lawrence grade I/II	N/A	N/A	16/20	

ACL anterior cruciate ligament, *BMI* body mass index, *MMPRT* medial meniscus posterior root tear, *NA* not applicable (N/A)

Data are presented as mean ± standard deviation. A significant difference (P < 0.05) was analysed using one-way analysis of variance

[a] A significant difference was observed compared to the MMPRT group

[b] A significant difference was observed compared to the ACL group

a 0-mm gap. Standard sequences of the Oasis included a sagittal proton density-weighted sequence [repetition time (TR)/echo time (TE), 1718/12] using a driven equilibrium pulse. We used a picture archiving and communication system (FUJIFILM Holdings Corporation, Tokyo, Japan) to measure the MTS and MTPD according to the method described by Hudek et al. [13] and Hashemi et al. [11], as described in detail below. Values were rounded to one decimal place. All measurements were performed by two board-certified orthopaedic surgeons on a best agreement basis. To determine the inter-observer reproducibility, additional measurements were performed independently by the two reviewers on 25 randomly selected MRI scans, and interclass correlation coefficients (ICCs) were calculated. The inter-observer/intra-observer reliabilities for the measurements were satisfactory with mean ICC values of 0.91/0.95 for MTS and 0.89/0.90 for MTPD. MTS was measured on sagittal proton density sequences according to the method described by Hudek et al. [13] (Figs. 1, 2). This method has been reported to be the most repeatable method to measure sagittal tibial slopes on MRI and is independent of the proximal tibial length [18]. First, the proximal anatomical axis of the tibia was defined on the central sagittal slice in which the attachment of the posterior cruciate ligament and the intercondylar eminence were visualized, and both the anterior and posterior tibial cortices appeared in a concave shape. Within this slice, two circles were placed into the proximal tibia. The proximal circle was fit within the proximal, anterior, and posterior cortical borders. The distal circle was fit within the anterior and posterior cortices with the centre of the circle positioned on the perimeter of the proximal circle. A line drawn through the centres of both circles defined the proximal anatomical axis. Then, the sagittal slice showing the mediolateral centres of the medial plateau was identified. On this image, a tangent to the medial plateau connecting the uppermost superior anterior and posterior cortex edges excluding articular cartilage was drawn. MTS was defined as the angle from the orthogonal to the proximal anatomical axis and the tangent to the medial plateau. Since no clear definition exists for an abnormal LTS [29], only MTS was measured in the present study. MTPD was measured by drawing a line connecting the superior and inferior crests of the tibial plateau in the same plane in which MTS was measured. A line parallel to this line was then drawn tangential to the lowest point of the concavity, representing the lowest boundary of the subchondral bone. The perpendicular distance between the two lines was then measured and was used to represent MTPD.

The study was approved by the Institutional Review Board at Okayama University (approval no. 1857), and informed consent was provided from all patients and volunteers.
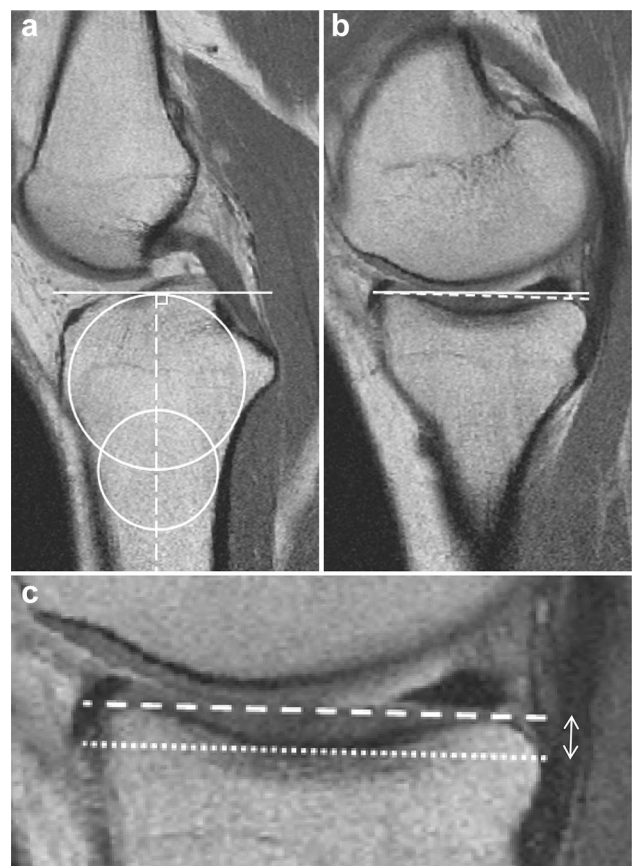

Fig. 1 Magnetic resonance images of a normal left knee. **a** Determination of the tibial axis (long-dashed line) according to the method described by Hudek et al. [13]. The solid line is perpendicular to the tibial axis. **b** Measurement of the medial tibial slope (1.5°). An angle is formed by the solid line perpendicular to the tibial axis and the dashed line connecting the uppermost superior-anterior and posterior cortex edges. **c** Measurement of the medial tibial plateau depth (3.5 mm). The perpendicular distance was measured from the dashed line to the lowest point of the concavity (dotted line)

Statistical analysis

Data are reported as mean ± standard deviation. Statistical analysis and sample size/power calculation were performed using EZR software (Saitama Medical Center Jichi Medical University, Tochigi, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). Differences in MRI measurements or subjects' demographics among the three groups were evaluated using the Mann–Whitney U test or one-way analysis of variance with the post hoc Tukey HSD test. Statistical significance was set at $P < 0.05$. Two orthopaedic surgeons independently measured MTS and MTPD. Each observer performed each measurement twice, at 2-week intervals. Inter-observer and intra-observer reliabilities were assessed using ICC. ICC values > 0.9 were considered excellent, values between 0.8 and 0.9 were considered good, and
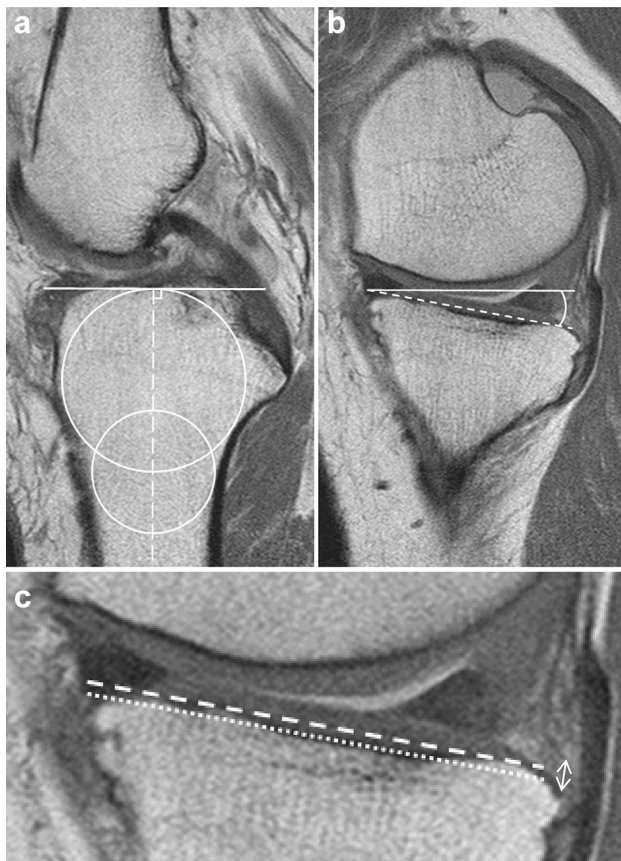
Fig. 2 Magnetic resonance images of a knee with a medial meniscus posterior root tear. **a** Determination of the tibial axis (long-dashed line) according to the method described by Hudek et al. [13] The solid line is perpendicular to the tibial axis. **b** Measurement of the medial tibial slope (10°). An angle is formed by the solid line perpendicular to the tibial axis and the dashed line connecting the uppermost superior-anterior and posterior cortex edges. **c** Measurement of the medial tibial plateau depth (0.9 mm). The perpendicular distance was measured from the dashed line to the lowest point of the concavity (dotted line)

values < 0.8 were considered poor. A multivariate logistic regression analysis was performed to evaluate the odds ratios of the preoperative prognostic factors using the stepwise method by computation via analysis for MMPRT. To determine the number of test samples, sample size calculation was performed under a significance level of 0.05 and a power of 0.80, and the resulting sample sizes were 6, 8, and 24 in groups V, A, and M, respectively.

Results

The mean age and body mass index (BMI) of the healthy volunteer group (group V) were 37.8 ± 15.7 years and 21.1 ± 3.2 kg/m^2. respectively, and those of the ACL reconstruction group (group A) were 27.5 ± 13.6 years and
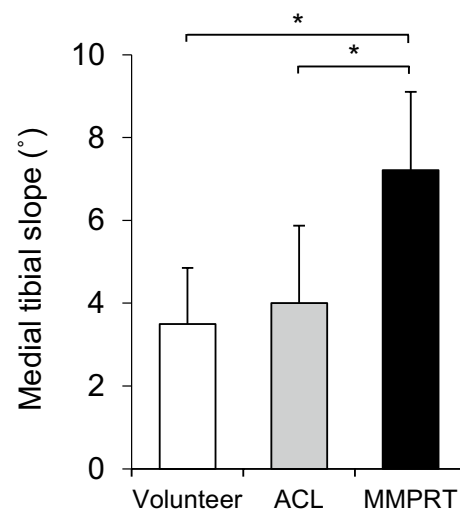

Fig. 3 Magnetic resonance image-based medial tibial slope. The medial tibial slope in the medial meniscus posterior root tear (MMPRT) group was significantly steeper than that in the volunteer group and the anterior cruciate ligament (ACL) group. *$P < 0.01$

23.8 ± 4.4 kg/m^2, respectively. A significantly higher age and BMI were observed in the MMPRT repair group (group M) than in groups V and A (60.8 ± 9.8 years and 26.3 ± 4.1 kg/m^2, respectively).

The mean MTS in group V was $3.5° \pm 1.4°$ and that in group A was $4.0° \pm 1.9°$. A significantly higher MTS was observed in group M than in groups V and A ($7.2° \pm 1.9°$). The mean MTPD in group V was 2.1 ± 0.7 mm and that in group A was 2.2 ± 0.6 mm. A significantly lower MTPD was observed in group M than in groups V and A (1.2 ± 0.5 mm). In summary, group M showed a significantly steeper MTS and a shallower MTP concavity than did groups V and A. Group comparisons of MRI measurements are shown in Figs. 3 and 4. In the multivariate logistic regression analysis, BMI, MTS, and MTPD were significant factors associated with MMPRT (Table 2).

Discussion

The most important finding of this study was that a steeper MTS and a shallower MTPD were observed in patients with MMPRT than in healthy volunteers and patients with ACL injuries. To date, many studies about bone morphological factors influencing cartilage, menisci, and ACL have been reported [28]. The geometry of the tibial plateau has a direct influence on the biomechanics of the tibiofemoral joint in terms of translation, location of instantaneous centre of rotation, screw-home mechanism, and strain biomechanics of the knee ligament [3, 7]. An important characteristic of the tibial plateau is its posterior slope
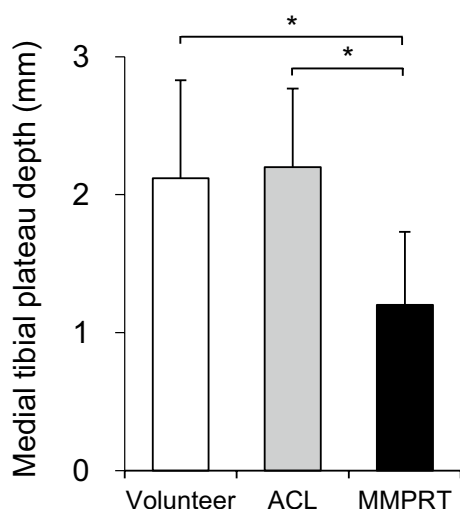
Fig. 4 Magnetic resonance image-based medial tibial plateau depth. The medial tibial plateau depth in the medial meniscus posterior root tear (MMPRT) group was significantly shallower than that in the volunteer group and the anterior cruciate ligament (ACL) group. *$P<0.01$

(with the anterior elevation being higher than the posterior elevation); when this characteristic is considered in association with a large compressive joint-reaction force such as that produced during weight-bearing activities, the force may have an anteriorly directed shear force component that acts to produce a corresponding anteriorly directed translation of the tibia [7, 10]. Biomechanical studies have shown that a steep tibial slope leads to increased anterior tibial translation under load, which may increase the forces acting on the menisci [1, 7, 10, 20, 21, 25]. Furthermore, a biconcave medial tibial plateau was reported to be more frequently associated with a complex medial meniscus tear [2] and shallower MTS and LTS may result in impingement of the posterior horn of the medial meniscus and anterior horn of the lateral meniscus, respectively, although no significant association was observed between MTPD and meniscal tears [15]. However, only one study has analysed the association between tibial geometry and MMPRT. This study demonstrated that MMPRT and a higher posterior tibial slope were more closely associated

with the development of spontaneous osteonecrosis of the knee than with that of osteoarthritis [31].

In the present study, only women were selected for standardization because women have a higher MTS than men, and MMPRT is more common in women. Subsequently, we evaluated MTS and MTPD using the same method by Hudek et al. and Hashemi et al. [11, 13] because the reproducibility is good [18]. Although our results of MTS and MTPD in groups V and A as the control groups were somewhat different from those of previous studies that used different measurement methods or modalities, such as radiographs or CT [32] [23], they were consistent with the results of previous studies that used the same measurement method [17]. Significantly steeper MTS and shallower MTP concavity were observed in group M than in group V ($P<0.01$) and group A ($P<0.01$). Moreover, in the multivariate logistic regression analysis, BMI, MTS, and MTPD were significant factors leading to MMPRT. This was consistent with previous studies showing that MMPRT is more common in middle-aged women with a high BMI [14].

The present findings suggest that biomechanical alteration to the posterior rollback of the femur has been likely caused by a steep MTS and a shallow MTPD, resulting in impingement of the posterior horn of the medial meniscus and predisposing it to MMPRT. This association can be well explained by biomechanical and clinical data: from a biomechanical view, the tibial slope produces an anteriorly directed shear force when a compressive load is applied to the knee joint, resulting in an anterior translation of the tibia relative to the femur [1, 7, 10, 20, 21, 25]. However, the biomechanical effect of the tibial slope might be even more complex, as characterization of the tibial plateau surface geometry with a single slope represents an insufficient approximation of its three dimensionality [11]. If knees with similar articular cartilage thickness profiles and meniscal geometries were compared, a deeper MTPD will constrain the femoral condyle to a greater extent and may result in increased resistance to the displacement of the tibia relative to the femur [11]. Conversely, the combination of a steep MTS and a shallow MTPD may be associated with a decreased resistance to the displacement of the tibia relative to the femur, placing the knee at an increased

Table 2 Multivariate logistic regression analysis

Dependent variables	Significant variables	Odds ratio	P value	95% CI
Subjects with or without MMPRT, $n=69$	BMI (kg/m^2)	1.24	0.03	1.02–1.51
	MTS (°)	2.76	< 0.01	1.33–5.73
	MTPD (increase of 0.1 mm)	0.63	< 0.01	0.45–0.87

Significant variables ($P<0.05$) were calculated using the forward stepwise method to evaluate risk factors leading to MMPRT

CI confidence interval, *BMI* body mass index, *MMPRT* medial meniscus posterior root tear, *MTS* medial tibial slope, *MTPD* medial tibial plateau depth

risk for MMPRT. Therefore, we believe that a steep MTS and a shallow MTPD may be anatomic risk factors for MMPRT.

The findings of the present study may have several clinical implications. First, the preoperative diagnosis of MMPRT is difficult, and some of these injuries are missed even on preoperative MRI. The results of the present study suggest that a high index of suspicion is especially necessary in patients with a steep MTS and a shallow MTPD detected by plain radiographs, CT, or MRI. Ultimately, better knowledge of the risk factors for MMPRT may increase the diagnostic accuracy because of an increased awareness about this injury.

This study has several limitations, which must be considered when interpreting our results. First, the study design was retrospective, and the number of patients was relatively small; therefore, the validity of our findings is limited. However, the sample size had acceptable statistical power for the endpoint. Second, age was not integrated, and only female Asian patients with MMPRT and ACL injuries were evaluated; therefore, the results may not allow generalization to all patients presenting with MMPRT. However, age may not greatly affect the results because each parameter was measured using cortex edges excluding articular cartilage. Third, biomechanical studies were not performed in patients with various MTS or MTPD. Finally, other factors that increase the risk for MMPRT, such as coronal slope or lateral tibial slope, may exist and were not examined in this study.

In daily clinical work, a more conservative rehabilitation protocol may be beneficial to avoid excessive load on the repaired structure after MMPRT pullout repair.

Conclusions

A steep MTS and a shallow MTPD are considered anatomic risk factors for MMPRT. In MMPRT pullout repair, a more conservative rehabilitation protocol may be beneficial to avoid excessive load on the repaired structure.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval This study was approved by the International Review Board (IRB) of Okayama University (Ethical approval No. 1857).

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