Medial Meniscal Posterior Horn Tears Are Associated With Increased Posterior Tibial Slope

A Case-Control Study

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Background: While the medial meniscal posterior horn (MMPH) is reported to bear a considerable portion of overall load on the knee joint, including compressive and shear forces, no study has yet investigated the relationship between the MMPH and posterior tibial slope (PTS), which is a geometric factor associated with the shear force component in the presence of a compressive load in the knee joint.

Hypothesis/Purpose: The purpose was to investigate the relationship between the PTS and MMPH tears in patients without ligamentous injury. It was hypothesized that the PTS is greater in patients with MMPH tears as compared with those without.

Study Design: Cohort study; Level of evidence, 3.

Methods: From March 2015 to December 2018, 159 patients with isolated MMPH tears and 60 patients without any pathologic findings on magnetic resonance imaging (control group) were included in this study. The PTS in the affected and contralateral knees was compared between the groups, which were statistically matched according to baseline characteristics (ie, age, sex, body mass index, radiographic osteoarthritis grade according to the Kellgren-Lawrence scale, and hip-knee-ankle angle) via the inverse probability of treatment weighting method. Furthermore, the MMPH tear group was subdivided according to meniscal tear patterns; these subgroups were then compared with the control group.

Results: The mean PTS was significantly greater in the MMPH tear group than in the control group (affected knee: MMPH tear group, 7.0° ± 3.4° [mean ± SD]; control group, 5.2° ± 2.1°, $P < .001$; contralateral knee: MMPH tear group, 6.7° ± 3.3°; control group, 4.7° ± 2.2°, $P < .001$). The mean PTS in each subgroup also tended to be greater than that in the control group. In the receiver operating characteristic curve analysis, the cutoff point of the PTS discriminating between the MMPH tear and control groups was 6.6° for the affected knee (sensitivity, 55.3%; specificity, 75.0%) and 5.5° for the contralateral knee (sensitivity, 61.0%; specificity, 76.7%).

Conclusion: An increased PTS is strongly associated with an increased incidence of MMPH tears and less affected by the meniscal tear patterns.

Keywords: knee; posterior tibial slope; meniscal tear; medial meniscal posterior horn

The geometric structure of the tibial plateau is known to have a direct influence on the biomechanics of the tibiofemoral joint.[14] In particular, the posterior tibial slope (PTS) is considered to be associated with the shear force component in the presence of a compressive load during weightbearing activities.[13,14] The PTS, defined as the posterior inclination of the tibial plateau, is known to be associated with the kinematics of the knee joint.[1,13] It has been reported that as the PTS increases, the magnitude of the shear force associated with the compressive joint force on the tibia also increases.[11] In this perspective, numerous studies have been conducted on the relationship between the PTS and anterior cruciate ligament (ACL) injury; these studies suggest that an increased PTS is a potential risk factor of ACL injury.[28,31] However, there is a paucity of data regarding the relationship between the PTS and meniscal tears.

The meniscus has various biomechanical functions, including shock absorption, load transmission, and passive

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stabilization.[9,12] Shock absorption and load transmission are generally accepted as 2 of its most important functions. The meniscus distributes compressive force across the tibiofemoral joint by converting it to tensile stress along its circumferential collagen fibers. In a recent biomechanical study, Walker et al[27] indicated that the medial meniscus plays an important role in transmitting shear force with compressive force. They reported that the medial meniscal posterior horn (MMPH) carried the highest percentage of overall load, including compressive and shear forces. In actual clinical settings, meniscal tears are observed more frequently in the medial meniscus, and the posterior horn of the medial meniscus is the most commonly involved site.[22]

If we take these findings into consideration, we can expect an increased PTS to influence the shear force applied to the MMPH. Consequently, it is reasonable to assume that if the PTS increases, the risk of MMPH tears would also increase owing to the relatively high shear force applied to the meniscus. Although there have been several studies on the association between the PTS and secondary MMPH tears in patients with ACL-deficient knees, there have been few studies concerning the relationship between the PTS and MMPH tears in patients without ligamentous injury. As MMPH tears are associated with various etiologies rather than with trauma alone,[25] it is important to elucidate the relationship between the PTS and MMPH tears in the absence of ligamentous injury. Therefore, the aim of this study was to investigate the relationship between the PTS and MMPH tears in patients without ligamentous injury. It was hypothesized that the PTS is greater in patients with MMPH tear as compared with those without MMPH tear.

METHODS

Patient Enrollment

This study was approved by the institutional review board (3-2019-0192) of Gangnam Severance Hospital of the Yonsei University College of Medicine, which waived the requirement for informed consent from the patients owing to the retrospective nature of the study. Data from March 2015 to December 2018, were retrospectively reviewed for 591 consecutive patients who underwent arthroscopic management of the knee by a single surgeon (S.-H.K.) in our institution. In the present study, patients with isolated MMPH tears who were treated with arthroscopic meniscectomy and/or meniscal repair were included. Patients who met the following conditions were excluded: (1) concomitant ligamentous injury, (2) combined osteotomy and/or cartilage surgery for moderate to severe osteoarthritis (Kellgren-Lawrence grades 3 and 4),[17] (3) combined meniscal allograft surgery (owing to the extensive meniscal tear affecting at least 2 portions of the meniscus, including the posterior horn), (4) combined debridement surgery for septic arthritis, and (5) surgical history of the affected knee. In addition, patients with concomitant lateral meniscal tears and medial meniscal tears in the anterior horn and/or midbody portion were excluded. Thus, 159 patients with isolated MMPH tears were included in the study and categorized into the MMPH tear group. These patients were further classified into 4 subgroups according to the tear patterns confirmed during surgery: (1) horizontal or horizontal flap tear group (HFT group), (2) posterior horn root tear group (RT group),[18] (3) vertical longitudinal or vertical flap tear group (VLT group), and (4) complex tear group (CXT group) (Figure 1). The control group included 60 patients without any pathologic findings on magnetic resonance imaging (MRI) who visited the outpatient clinic with knee pain during the same period.

Radiographic Assessment

All patients underwent radiographic assessment before surgery, including true lateral knee radiographs with both femoral condyles completely overlapped at approximately 30° of knee flexion. The lateral knee radiographs were usually obtained in both knees since the bilaterality would provide comparison criteria, as well as additional information to distinguish pathologic findings. The PTS was measured on the true lateral knee radiograph and was defined as the angle between a line drawn along the medial tibial plateau and a line vertical to the posterior cortical line (Figure 2). The posterior cortical line was used as a reference line, as it has been reported to show high reliability.[6,15] The PTS was measured on the affected and contralateral knees in all patients. Two orthopaedic surgeons (H.-S.M. and K.-S.E.) who were blinded to patient information assessed all radiographic measurements using a picture archiving and communication system (GE Medical System Information Technologies) at an interval of 6 weeks.

Statistical Analysis

Statistical analyses to compare between the groups were performed with SAS (v 9.3; SAS Institute), and receiver operating characteristic (ROC) curve analyses were

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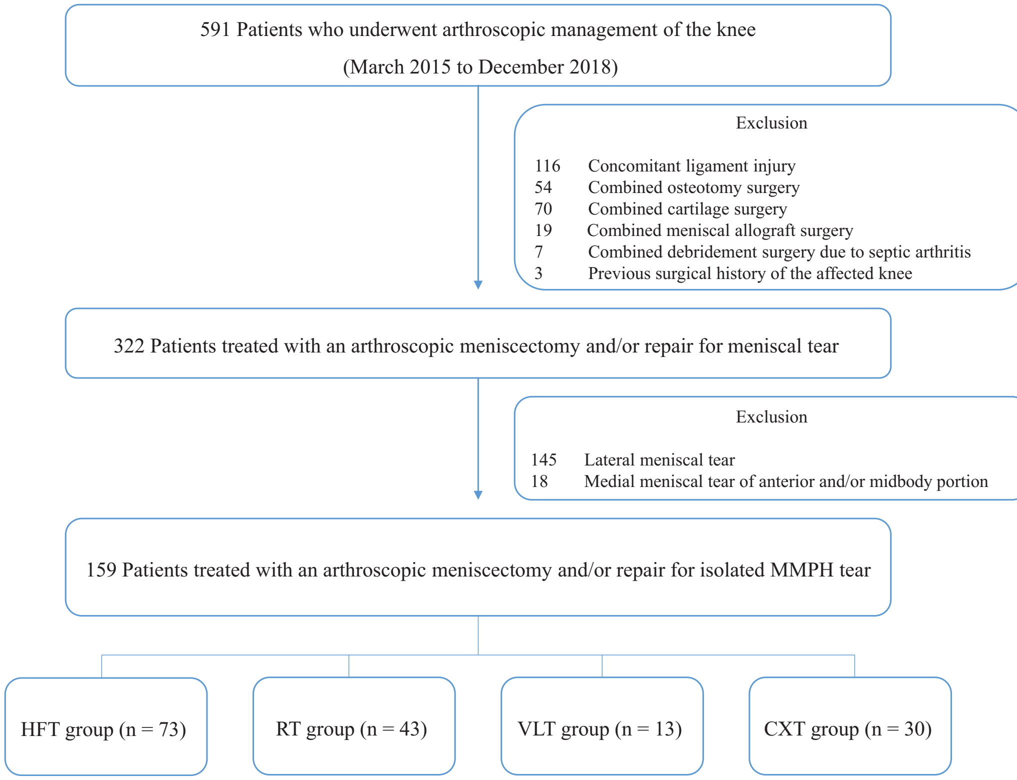

Figure 1. Flowchart illustrating the selection of the patients with MMPH tears for this study. CXT, complex tear; HFT, horizontal or horizontal flap tear; MMPH, medial meniscal posterior horn; RT, posterior horn root tear; VLT, vertical longitudinal or vertical flap tear.

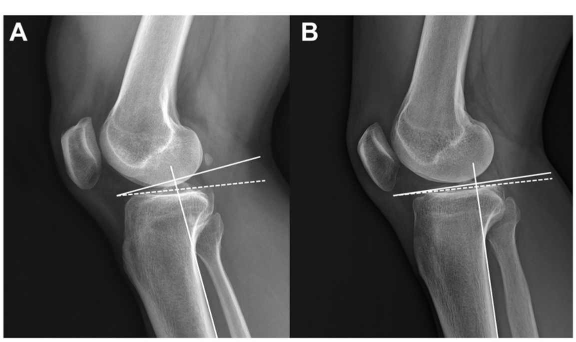

Figure 2. The PTS is defined as the angle between the dotted line drawn along the medial tibial plateau connecting its highest anterior and posterior points and the line vertical to the posterior cortical line drawn along the posterior tibial cortex at the metaphyseal level, which extended proximally. An example of the PTS in (A) the MMPH tear group and (B) the control group. MMPH, medial meniscal posterior horn; PTS, posterior tibial slope.

conducted with the use of MedCalc software (v 19.0.3). Before the PTS was compared, baseline characteristics were compared between the groups, including age, sex, body mass index, hip-knee-ankle angle, and radiographic knee osteoarthritis grade according to the Kellgren-Lawrence scale.[17] However, there were substantial differences in the baseline characteristics between them. Since these factors are known to be possible risk factors for meniscal tear and a potential source of serious bias in the investigation of the difference in the PTS,[8,25] an inverse probability of treatment weighting (IPTW) analysis was performed to minimize the effect of the baseline differences. The IPTW method is a statistical technique used to create a pseudo–data set by weighting individual participants based on the inverse of the probability, which makes the distribution of baseline covariates similar between the groups.[10] By balancing the differences of clinical covariates between the groups by creating the pseudo-population, the IPTW method can reduce selection bias, which would act as an obstacle to draw a solid conclusion. Furthermore, even with the small sample size, it was reported that the IPTW method would yield the correct estimation of treatment effect, with relative bias remaining <10% and without a substantial increase in the type 1 error rate.[23] As this method not only minimizes confounding bias but also maximizes the information obtained from a limited number of patients without missing data, it has been utilized with increasing frequency in the medical literature in recent years.[3] Therefore, IPTW analysis was utilized for all pairwise comparisons in this study when there were differences in the baseline characteristics.

TABLE 1
Comparison of the Posterior Tibial Slope Between the MMPH Tear Group and Control Group[a]

	Overall Cohort			After IPTW Matched[b]		
	MMPH Tear (n = 159)	Control (n = 60)	*P* Value	MMPH tear (n = 167.6)	Control (n = 77.6)	*P* Value
Age, y	53.1 ± 14.1	47.8 ± 12.8	.012	51.3 ± 17.4	51.5 ± 20.7	.936
Sex			.592			.258
Male	70 (44.0)	24 (40.0)		73.6 (43.9)	42.1 (54.3)	
Female	89 (56.0)	36 (60.0)		94.0 (56.1)	35.5 (45.7)	
BMI, kg/m^2	24.9 ± 3.4	23.2 ± 2.9	<.001	24.4 ± 3.8	24.1 ± 3.1	.514
H-K-A angle, deg	3.7 ± 2.7	2.7 ± 2.3	.018	3.4 ± 3.0	3.0 ± 2.8	.317
Kellgren-Lawrence grade			<.001			.966
0	80 (50.3)	47 (78.3)		97.1 (57.9)	46.4 (59.7)	
1	46 (28.9)	12 (20.0)		44.6 (26.6)	21.3 (27.4)	
2	33 (20.8)	1 (1.7)		25.9 (15.5)	10.0 (12.9)	
Posterior tibial slope, deg						
Affected knee	7.0 ± 3.4	5.2 ± 2.1	<.001	6.8 ± 3.6	5.0 ± 2.4	<.001
Contralateral knee	6.7 ± 3.3	4.7 ± 2.2	<.001	6.6 ± 3.5	4.8 ± 4.5	.002

[a]Values are presented as mean ± SD or No. (%). BMI, body mass index; H-K-A, hip-knee-ankle; IPTW, inverse probability of treatment weighting; MMPH, medial meniscal posterior horn.
[b]Adjustment for baseline covariates: age, sex, BMI, H-K-A angle, Kellgren-Lawrence grade.

The Student *t* test was used to compare numerical variables (ie, age, body mass index, hip-knee-ankle angle, and PTS), which were expressed as means and standard deviations. Pearson chi-square test or Fisher exact test was used for categorical variables (ie, sex and radiographic osteoarthritis grade), which were presented as frequencies and rates. The ROC curve was used to obtain the cutoff point of the PTS for discriminating between the MMPH tear group and control group. The area under the curve (AUC) can be interpreted as representing discriminative power, and the optimal cutoff point derived with the ROC curve was determined to optimize sensitivity and specificity. Since the ROC curve could not be obtained after IPTW analysis, it was drawn without an adjustment for baseline characteristics. The intra- and interobserver reliabilities in the measurement of the PTS in both knees were calculated with the intraclass correlation coefficient (ICC) set at a 95% CI. Furthermore, Bland-Altman plots were obtained with SPSS (v 25.0; IBM Corp) to assess the bias (mean difference) and the limits of agreement concerning the measurements of the PTS within the observer as well as between 2 observers. The limits of agreement were expected to include 95% of the differences between the measurements in each comparison. The statistical significance level was set at a *P* value of .05.

RESULTS

Comparison Between the MMPH Tear Group and Control Group

The PTS in the affected and contralateral knees was significantly greater in the MMPH tear group than the control group ($P < .001$ in the affected knee; $P < .001$ in the contralateral knee). Subsequent IPTW analysis was performed owing to the differences in the baseline characteristics of the patients. After IPTW, significant differences were still observed in the PTS in both knees between the groups ($P < .001$ in the affected knee; $P = .002$ in the contralateral knee); conversely, there were no differences in the other baseline patient characteristics (Table 1).

Subgroup Comparisons

The nature of the tear and the treatment strategies differed among subgroups classified according to the meniscal tear patterns (Appendix Table A1, available in the online version of this article). The 4 subgroups of the MMPH tear group were compared with the control group in turn. Additional IPTW analysis was performed, as differences in baseline characteristics were observed among groups in all comparisons. In the comparison between the HFT group and the control group after IPTW, the PTS tended to be greater in the HFT group, but there was no significant difference in the affected knee; conversely, a significant difference was noted in the contralateral knee ($P = .051$ in the affected knee; $P = .03$ in the contralateral knee) (Table 2).

In the comparison between the RT group and the control group after IPTW, the PTS in the affected knee was significantly greater in the RT group, but only a tendency was observed without statistical significance in the contralateral knee ($P = .03$ in the affected knee; $P = .075$ in the contralateral knee) (Table 3).

In the comparison between the VLT group and the control group after IPTW, the PTS in both knees was significantly greater in the VLT group ($P = .007$ in the affected knee; $P = .004$ in the contralateral knee) (Table 4).

Similarly, the PTS in both knees was significantly greater in the CXT group than the control group ($P =$

TABLE 2
Subgroup Comparison of the Posterior Tibial Slope Between the HFT Group and Control Group[a]

	Subgroup Comparison			After IPTW Matched[b]		
	HFT (n = 73)	Control (n = 60)	*P* Value	HFT (n = 83)	Control (n = 71.3)	*P* Value
Age, y	53.8 ± 11.2	47.8 ± 12.8	.004	50.5 ± 17.8	52.2 ± 20.0	.595
Sex			.123			.536
Male	39 (53.4)	24 (40.0)		38.4 (46.3)	37.3 (52.3)	
Female	34 (46.6)	36 (60.0)		44.6 (53.8)	34.0 (47.7)	
BMI, kg/m^2	24.2 ± 2.9	23.2 ± 2.9	.06	23.5 ± 4.6	23.7 ± 2.9	.688
H-K-A angle, deg	3.7 ± 2.6	2.7 ± 2.3	.03	3.1 ± 3.6	3.0 ± 2.5	.904
Kellgren-Lawrence grade			.02			.956
0	43 (58.9)	47 (78.3)		55.8 (67.2)	45.6 (63.9)	
1	21 (28.8)	12 (20.0)		21.0 (25.4)	20.3 (28.4)	
2	9 (12.3)	1 (1.7)		6.1 (7.4)	5.5 (7.7)	
Posterior tibial slope, deg						
Affected knee	6.5 ± 3.2	5.2 ± 2.1	.008	6.0 ± 3.9	5.0 ± 2.7	.051
Contralateral knee	6.2 ± 3.2	4.7 ± 2.2	.002	5.8 ± 3.6	4.6 ± 3.3	.03

[a]Values are presented as mean ± SD or No. (%). BMI, body mass index; HFT, horizontal or horizontal flap tear; H-K-A, hip-knee-ankle; IPTW, inverse probability of treatment weighting.
[b]Adjustment for baseline covariates: age, sex, BMI, H-K-A angle, Kellgren-Lawrence grade.

TABLE 3
Subgroup Comparison of the Posterior Tibial Slope Between the RT Group and Control Group[a]

	Subgroup Comparison			After IPTW Matched[b]		
	RT (n = 43)	Control (n = 60)	*P* Value	RT (n = 61.3)	Control (n = 78.4)	*P* Value
Age, y	59.0 ± 7.1	47.8 ± 12.8	<.001	55.2 ± 16.3	52.1 ± 20.6	.325
Sex			.041			.82
Male	9 (20.9)	24 (40.0)		24.4 (39.8)	34.0 (43.4)	
Female	34 (79.1)	36 (60.0)		36.9 (60.2)	44.4 (56.6)	
BMI, kg/m^2	26.1 ± 3.4	23.2 ± 2.9	<.001	25.4 ± 3.3	24.2 ± 4.6	.077
H-K-A angle, deg	3.8 ± 2.8	2.7 ± 2.3	.03	2.5 ± 11.0	2.9 ± 2.8	.787
Kellgren-Lawrence grade			<.001			.508
0	17 (39.5)	47 (78.3)		28.1 (45.8)	50.1 (63.8)	
1	15 (34.9)	12 (20.0)		24.3 (39.6)	18.4 (23.4)	
2	11 (25.6)	1 (1.7)		8.9 (14.5)	10 (12.9)	
Posterior tibial slope, deg						
Affected knee	7.2 ± 3.5	5.2 ± 2.1	.002	7.3 ± 7.3	5.2 ± 2.7	.03
Contralateral knee	7.2 ± 3.3	4.7 ± 2.2	<.001	6.9 ± 7.5	5.0 ± 4.5	.075

[a]Values are presented as mean ± SD or No. (%). BMI, body mass index; H-K-A, hip-knee-ankle; IPTW, inverse probability of treatment weighting; RT, posterior horn root tear.
[b]Adjustment for baseline covariates: age, sex, BMI, H-K-A angle, Kellgren-Lawrence grade.

.018 in the affected knee; P = .046 in the contralateral knee) (Table 5).

Moreover, additional comparisons were made among subgroups. As in the comparison between each subgroup and the control group, the IPTW method was used because the baseline characteristics were different among the subgroups. As a result, the PTS tended to be greater in the VLT group as compared with the HFT group and CXT group, whereas there were no significant differences in other between-subgroup comparisons (Appendix Tables A2-A7, available online).

ROC Curve Analysis

To obtain the optimal cutoff point of the PTS for discriminating between the MMPH tear and control groups, the ROC curve was drawn for both knees. The AUC was 0.654 and 0.688 for the affected knee and contralateral knee, respectively; the cutoff point of the PTS discriminating between the groups was 6.6° for the affected knee (sensitivity, 55.3%; specificity, 75.0%) and 5.5° for the contralateral knee (sensitivity, 61.0%; specificity, 76.7%) (Figure 3).

TABLE 4
Subgroup Comparison of the Posterior Tibial Slope Between the VLT Group and Control Group[a]

	Subgroup Comparison			After IPTW Matched[b]		
	VLT (n = 13)	Control (n = 60)	*P* Value	VLT (n = 31.8)	Control (n = 61.5)	*P* Value
Age, y	31.9 ± 15.0	47.8 ± 12.8	<.001	44.2 ± 55.0	46.4 ± 14.8	.779
Sex			<.001			.407
Male	12 (92.3)	24 (40.0)		21.8 (68.5)	27.9 (45.3)	
Female	1 (7.7)	36 (60.0)		10 (31.5)	33.6 (54.7)	
BMI, kg/m^2	24.8 ± 3.5	23.2 ± 2.9	.098	23.6 ± 2.5	23.3 ± 3.1	.654
H-K-A angle, deg	2.0 ± 3.4	2.7 ± 2.3	.353	3.3 ± 6.3	2.8 ± 2.5	.683
Kellgren-Lawrence grade			.203			.524
0	8 (61.5)	47 (78.3)		27.9 (87.7)	48.3 (78.5)	
1	4 (30.8)	12 (20.0)		3.1 (9.8)	11.9 (19.4)	
2	1 (7.7)	1 (1.7)		0.8 (2.6)	1.3 (2.1)	
Posterior tibial slope, deg						
Affected knee	8.9 ± 3.8	5.2 ± 2.1	.004	9.7 ± 9.3	5.2 ± 2.1	.007
Contralateral knee	8.8 ± 3.5	4.7 ± 2.2	.001	9.5 ± 9.3	4.6 ± 2.2	.004

[a]Values are presented as mean ± SD or No. (%). BMI, body mass index; H-K-A, hip-knee-ankle; IPTW, inverse probability of treatment weighting; VLT, vertical longitudinal or vertical flap tear.
[b]Adjustment for baseline covariates: age, sex, BMI, H-K-A angle, Kellgren-Lawrence grade.

TABLE 5
Subgroup Comparison of the Posterior Tibial Slope Between the CXT Group and Control Group[a]

	Subgroup Comparison			After IPTW Matched[b]		
	CXT (n = 30)	Control (n = 60)	*P* Value	CXT (n = 51.7)	Control (n = 63.1)	*P* Value
Age, y	52.2 ± 18.8	47.8 ± 12.8	.257	47.1 ± 30.2	48.5 ± 14.4	.751
Sex			.539			.906
Male	10 (33.3)	24 (40.0)		22.8 (44.1)	26.8 (42.5)	
Female	20 (66.7)	36 (60.0)		28.9 (55.9)	36.3 (57.5)	
BMI, kg/m^2	25.2 ± 4.2	23.2 ± 2.9	.022	23.8 ± 4.2	23.4 ± 3.0	.595
H-K-A angle, deg	4.1 ± 2.6	2.7 ± 2.3	.01	2.9 ± 4.2	2.9 ± 2.4	.934
Kellgren-Lawrence grade			<.001			.613
0	12 (40.0)	47 (78.3)		37.3 (72.0)	46 (72.9)	
1	6 (20.0)	12 (20.0)		7.6 (14.6)	13.1 (20.8)	
2	12 (40.0)	1 (1.7)		6.9 (13.4)	4.0 (6.3)	
Posterior tibial slope, deg						
Affected knee	6.9 ± 3.2	5.2 ± 2.1	.011	7.4 ± 6.1	5.3 ± 2.1	.018
Contralateral knee	6.3 ± 2.9	4.7 ± 2.2	.004	6.3 ± 4.5	4.8 ± 2.7	.046

[a]Values are presented as mean ± SD or No. (%). BMI, body mass index; CXT, complex tear; H-K-A, hip-knee-ankle; IPTW, inverse probability of treatment weighting.
[b]Adjustment for baseline covariates: age, sex, BMI, H-K-A angle, Kellgren-Lawrence grade.

In the measurement of the PTS in both knees, the 95% CIs for the ICCs were 0.953 to 0.979 (observer 1) and 0.910 to 0.978 (observer 2) for the intraobserver reliabilities and 0.927 to 0.951 for the interobserver reliabilities. Bland-Altman analyses showed that the variability in the difference between the pairs of measurements was overall consistent throughout the range of measurements. The biases representing the mean difference of measurements ranged from 0.127 to 0.146 within observer 1, −0.177 to 0.085 within observer 2, and −0.196 to −0.274 in the interobserver comparisons, which were considered clinically acceptable. The limits of agreement in each comparison are presented in Appendix Figure A1 (available online).

DISCUSSION

The principal finding of this study was that the PTS was significantly greater in patients with MMPH tears than in those without. The additional subgroup analysis further emphasized that the PTS was indeed greater in patients with MMPH tears, though less affected by the tear patterns.

The PTS has been reported as a geometrical factor that influences the biomechanics of the knee joint. Previous studies have shown a direct relationship between a change in the PTS and a change in the anterior tibial translation of the knee.[13,14,24] In this perspective, many studies have

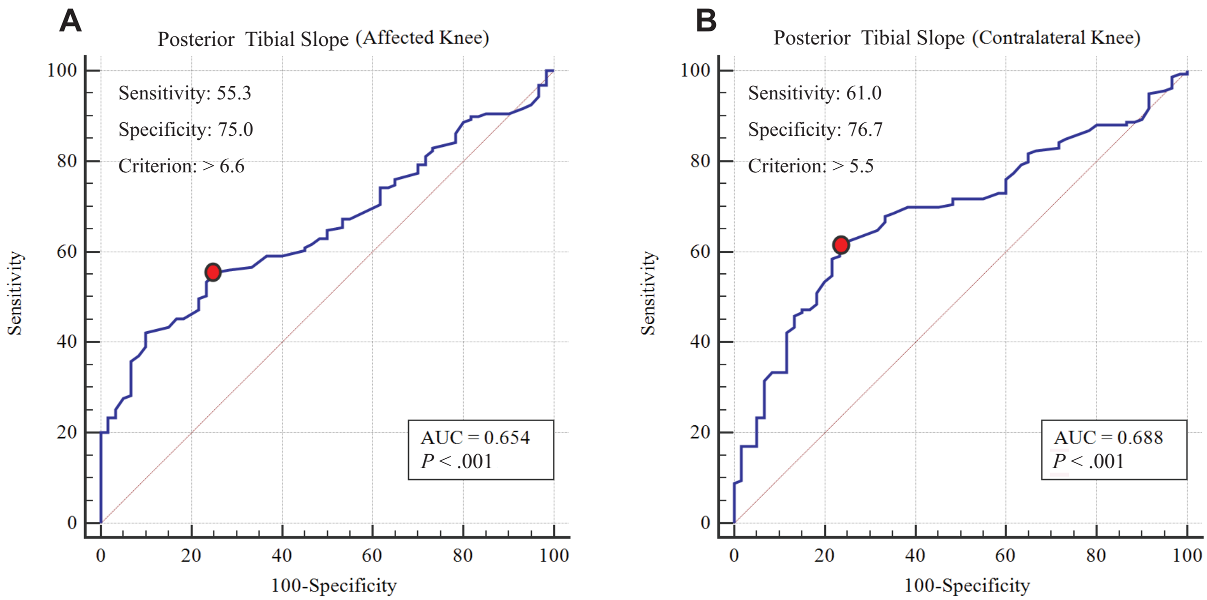

Figure 3. Receiver operating characteristic curve of the posterior tibial slope in (A) the affected knee and (B) the contralateral knee. AUC, area under the curve.

investigated the relationship between the PTS and ligamentous injury, especially ACL injury.[5,19,29] Although there have been marked discrepancies in the suggested values of the PTS in association with ACL injury, owing to the diversity of the measurement methods,[31] it has been consistently reported that an increased PTS results in an anterior translation of the tibia during physiologic loading, which subsequently increases the risk of ACL injury.[28]

Furthermore, several studies have evaluated the association between the PTS and risk of meniscal tears in ACL-deficient knees.[20,21,26] As the MMPH acts as a wedge limiting anterior translation of the tibia in ACL-deficient knees, the stress applied to the MMPH would increase in these knees.[16,26] In this regard, 2 preceding studies reported that an increased sagittal slope of the geometry in the medial tibial plateau was an anatomic risk factor for secondary medial meniscal tears in ACL-deficient knees.[20,26] However, evaluation in ACL-deficient knees could not purely reflect the association between the PTS and MMPH tears. As meniscal injuries are associated with various etiologies, from traumatic tears to degenerative tears, an assessment limited by the conditions associated with trauma should be avoided. To the best of our knowledge, there is a paucity of studies on the relationship between the PTS and MMPH tear among patients with an intact ACL. Alici et al[2] described that the PTS of the lateral tibial plateau is associated with the risk of lateral meniscal tears, while there was no significant difference in the mean value of the PTS between patients with and without medial meniscal tears. Although they assessed the relationship between the PTS and meniscal tears according to the medial and lateral menisci, the patterns and locations of the meniscal tears were not evaluated, which could subsequently decrease the clinical significance. There were also 2 studies that investigated the association between the PTS and meniscal tear patterns but did not compare with those without meniscal tear.[4,32]

This study was performed in a more controlled condition, only for MMPH tears in knees without ligamentous injury, given that the MMPH is the most common site of meniscal tears and is the area where the highest tension is applied.[22,27] Furthermore, the contralateral knee was included in the assessment to validate the comparability. This study revealed that the PTS was significantly increased in the patients with MMPH tears as compared with those without. Similar patterns were observed in the contralateral knee and in each subgroup analysis. These findings may help predict the development of MMPH tears among patients with knee pain. In reference to the cutoff point suggested in this study, the PTS could be used as a radiographic parameter to predict the likelihood of MMPH tears in patients with knee pain.

In addition, the subgroup analysis according to the meniscal tear patterns showed that the PTS of the patients with MMPH tears was greater than that of those without and less affected by the tear patterns. Meniscal tears are generally classified according to the tear patterns (either traumatic or degenerative); in this study, the VLT group can be considered to have traumatic tears and the remaining groups, degenerative tears. Classification of meniscal tears according to their patterns is important, as it not only makes it possible to predict their etiology but also influences the treatment strategy.[7] The finding that the PTS was greater in the patients with MMPH tear versus those without it and less affected by the nature of the tear indicates that it may be applicable to patients in all cases, without being limited to those with trauma.

Furthermore, between-subgroup comparisons in the present study revealed that the PTS was similar among the groups except in the VLT group. The VLT group, mainly associated with a trauma history (Appendix Table A1, available online), showed greater PTS as compared with the HFT group and CXT group. The PTS in the VLT group appeared to be higher than that in the RT group, but this was not statistically significant even after covariate adjustment per the IPTW. This might be influenced by incomplete matching owing to the considerable heterogeneity of baseline characteristics between the groups, which could not be overcome by the use of stabilized weights.[33] Nevertheless, given the overall result of the between-group comparison including the VLT group, it could be suggested that the patients with greater PTS would be relatively vulnerable to a knee injury and more likely to have a trauma-related lesion, as in the relationship between the PTS and ACL injury.[28,31] Other between-subgroup comparisons did not show a significant difference in the PTS, consistent with the study by Wu et al[32] comparing the radial tear and horizontal tear in the MMPH and the study by Barber et al[4] comparing complex medial meniscal tears and other types of medial meniscal tear. The results of the present study are significant in that we compared not only among types of degenerative tear but also included patients without meniscal tear in a strictly controlled state.

This study has the following limitations. First, it had a retrospective design, which could be associated with a risk of bias in evaluation. Moreover, given the retrospective nature of this study, it was practically impossible to analyze with a true control group (ie, without knee pain), which subsequently led us to evaluate patients with knee pain but without pathologic findings on MRI as a control group. Second, the sample size of the subgroups (eg, VLT group) might not be large enough for comparisons among them. However, as all pairwise comparisons in this study were conducted after IPTW, which allowed the creation of a pseudo-population, the statistical power of the outcome comparisons was dependent on the inverse probability of treatment weights rather than the sample size. Furthermore, IPTW can yield correct estimations of treatment effects even in cases of small study samples.[23] Third, despite the statistical advantage of IPTW, there could still be unidentified baseline covariates responsible for the confounding bias. Fourth, there are some limitations in the measurement method of the PTS in this study. MRI, which could more accurately reflect the outline of the medial tibial plateau, was not used in the assessment of the PTS. In addition, the posterior cortical line was used as a reference line in the current study, while the tibial anatomic axis was used in several previous studies.[28] However, there is no standardized method that has been consistently used to measure the PTS; furthermore, the ICCs for the intra- and interrater reliabilities of all measurements indicated that the reliability of the measurement in this study was excellent according to the criteria of Winer.[30] Furthermore, Wang et al,[28] in their meta-analysis of the association between the PTS and risk of ACL injury, also reported that the overall standardized mean difference for the medial PTS did not vary substantially according to the reference line. Fifth, the subgroup classification of the patients with MMPH tears was not based on the most commonly described meniscal tear patterns.[22] However, we attempted to classify the subgroups according to the nature of the meniscal tears while maintaining the minimum number of the patients in each group for the comparison. In addition, the cutoff point of the PTS described in this study could not be generalized because the ROC curve was obtained without an adjustment for baseline covariates. As the ROC curve could not be drawn after IPTW, the suggested cutoff point could not accurately represent the major finding of this study. Moreover, the sensitivity and specificity of the cutoff point presented by the ROC curve were relatively low. Further investigations are needed to obtain a more optimal cutoff point with larger cohorts, controlling for potential covariates or using other statistical methods, such as the propensity score matching method.

CONCLUSION

An increased PTS is strongly associated with an increased incidence of MMPH tears and less associated with meniscal tear patterns. The PTS can be used as a potential radiographic parameter to assess the possibility of MMPH tears among patients with knee pain.

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