Decreased Posterior Tibial Slope Is Associated With The Degenerative Tears of Lateral Meniscus Anterior Horn

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A Master's Thesis Submitted
to the Department of Medicine
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Master of Medical Science

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December 2024

This certifies that the Master's Thesis of Min-Hwan Huh is approved

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December 2024

ACKNOWLEDGEMENTS

I would like to express my heartfelt thanks to everyone who supported me during my research. First, I am grateful to my supervisor, Professor Sung-Hwan Kim, for their guidance and encouragement throughout this process. I would also like to extend my appreciation to my committee members, Professors Hoon Park and Sungjun Kim, for their constructive feedback and suggestions that helped refine my work.

This work would not have been possible without all of you.

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ABSTRACT

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Purpose

While lateral meniscus anterior horn (LMAH) tears can result in elevated peak contact pressure in knee joint, limited research has explored the connection between LMAH tears and posterior tibial slope (PTS), closely associated with knee joint kinematics. This study aimed to investigate the association between PTS and LMAH tears. We hypothesized that patients with LMAH tears would exhibit lower PTS values compared to those without such tears.

Methods

Our study included patients with isolated LMAH tears and those with no pathological findings on magnetic resonance imaging between January 2010 and October 2023. PTS was compared between groups. Baseline characteristics of each group were also compared. Multivariable logistic regression analysis was applied to identify risk factors associated with LMAH tears. The inverse probability of treatment weighting (IPTW) approach was employed to align the baseline characteristics between the study and control groups, enabling a fair comparison of PTS. Additionally, the receiver operating characteristic (ROC) curve analysis was conducted to establish the PTS threshold that differentiates patients with LMAH tears from the control group.

Results

Mean PTS was significantly smaller in the LMAH tear group (LMAH tear group, 4.70° ± 2.16°; control group, 6.58° ± 2.95°, *P*<.001). In multivariable logistic regression, the adjusted odds ratio of PTS in the LMAH tear group was 0.762 (95% confidence interval [CI] 0.621-0.934, *P*=0.009). After IPTW matching, mean PTS was significantly smaller in the LMAH tear group (LMAH tear group, 4.83° ± 3.60°; control group, 6.51° ± 3.01°, *P*=0.006). The ROC curve analysis identified a PTS cutoff value of 4.49° for distinguishing between the LMAH tear group and the control group (sensitivity, 48.57%; specificity, 80.72%) and the odds ratio of PTS greater than 4.49° was 0.253 (95% CI 0.107-0.597, *P*=0.002).

Conclusions

Smaller PTS is significantly associated with higher incidence of LMAH tears.

Key words : posterior tibial slope, lateral meniscus, tibial translation

I. INTRODUCTION

Posterior tibial slope (PTS) is described as the backward angle of the tibial plateau[1] and is assessed as the angle between the line indicating the posterior slope of the tibial plateau and a line perpendicular to the center of the tibial diaphysis[2]. The kinematics of the knee joint are closely influenced by PTS[3, 4]. Increased PTS can influence anterior-posterior knee instability by increasing anterior tibial translation[1]. Due to these characteristics, numerous studies have investigated the association between an anterior cruciate ligament (ACL) deficiency and increased PTS[5-7].

The meniscus is an important structure in the knee with primary functions that include joint stabilization, shock absorption, and load transmission[8, 9]. Previous studies reported that degenerative meniscus tear was a risk factor for knee osteoarthritis[10-12]. Tibial translation due to PTS is one of several causes of meniscus tears[13, 14]. Increased PTS is associated with lateral meniscus posterior horn (LMPH) tears and medial meniscus posterior horn (MMPH) tears[15, 16]. Nevertheless, few studies have explored the connection between PTS and anterior horn meniscus tears. Shepard et al reported that the proportion of meniscus anterior horn tears was small compared to other types of meniscus tear, and mainly involved the lateral meniscus[17]. Lateral meniscus anterior horn (LMAH) tears could also lead to increased peak contact pressure in the knee tibiofemoral joint[18, 19]. In previous studies, smaller PTS was found to increase stress on anterior subchondral bone and to be associated with higher remaining posterior tibial translation[3, 20]. Logically combining these factors, we predict that there will be an association between PTS and LMAH tears. However, few studies have evaluated PTS and LMAH tears.

This study aimed to investigate the association between PTS and LMAH tears. We hypothesized that patients with LMAH tears would exhibit lower PTS values compared to those without such tears.

2. METHODS

2.1.Patient Selection

Approval for this study was obtained from the institutional review board (IRB) of Gangnam Severance Hospital, Yonsei University College of Medicine (approval number: 3-2024-0252). Due to the retrospective design of the research, the IRB waived the requirement for informed consent. Data were retrospectively gathered from patients who underwent arthroscopic knee surgery performed by a single surgeon (S.-H.K.) at Severance and Gangnam Severance Hospitals between January 2010 and October 2023. Patients with isolated LMAH tears who underwent treatment through arthroscopic meniscectomy and/or repair were included in the study. Patients who fulfilled the following criteria were excluded: (1) discoid lateral meniscus, (2) combined osteotomy, ligament, or cartilage surgery, (3) lateral meniscus tear with medial meniscus tear, (4) previous surgical history of the affected knee, (5) combined meniscal allograft surgery, and (6) septic arthritis or inflammatory arthritis. In addition, patients with LMPH tears, body tears, or entire degenerative tears were excluded (**Fig 1**). The control group originally consisted of patients diagnosed in the outpatient clinic with "internal derangement of knee, unspecified, unspecified meniscus or ligament" (the international classification of diseases 10th revision code: M23.99) and presenting acute knee pain during the same period. However, only those with no pathological findings on magnetic resonance imaging (MRI) were ultimately selected (**Fig 2**).

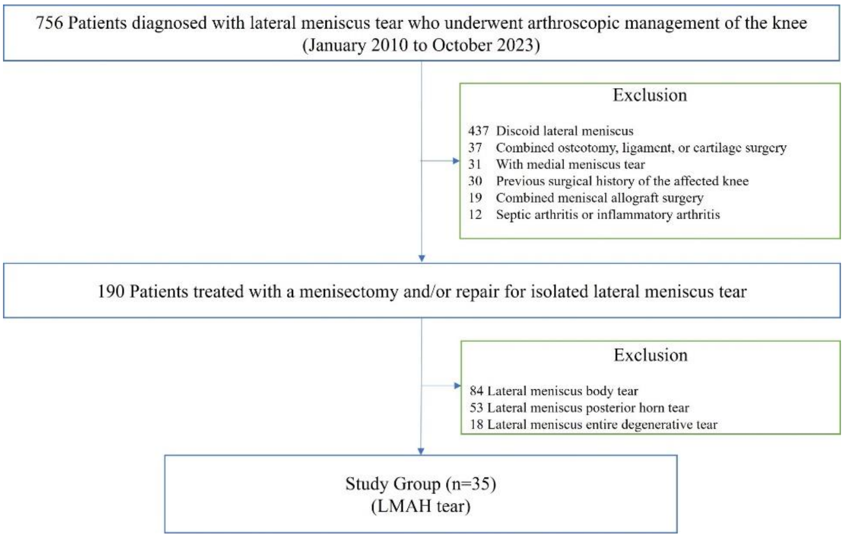

Figure 1. Flowchart of selection of patients with LMAH tears. LMAH, lateral meniscus anterior horn.

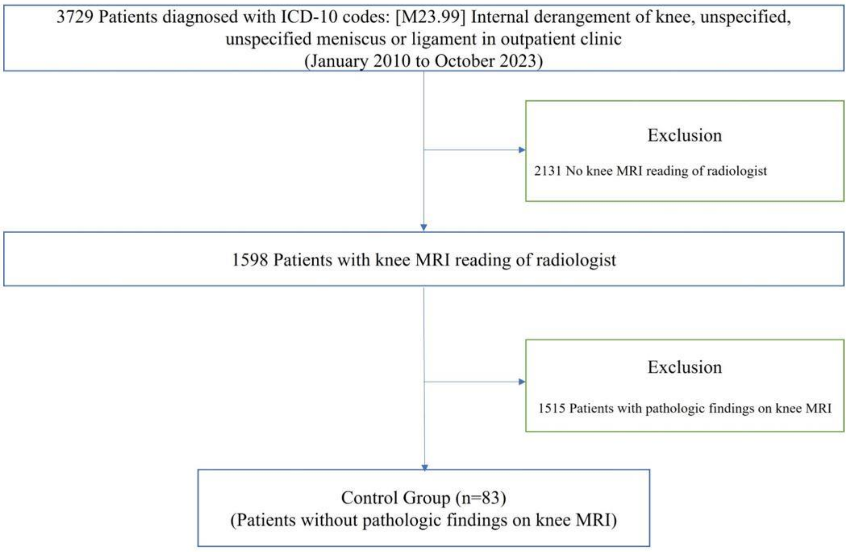

Figure 2. Flowchart of selection of patients without pathologic findings on knee MRI. ICD, international statistical classification of diseases and related health problems; MRI, magnetic resonance imaging.

2.2 Radiographic Assessment

PTS was assessed using true lateral knee radiographs. It was obtained with medial and lateral femoral condyles perfectly superimposed at 30° of knee flexion. The line of posterior cortex was chosen as the reference due to its demonstrated high reliability and minimized error in manual measurement procedures[21]. The PTS was determined by measuring the angle between a line perpendicular to the posterior tibial cortex and a line representing the medial tibial plateau (**Fig 3**). The medial tibial plateau was used for measurements in true lateral knee radiographs because its relatively flat, slightly concave shape provides landmarks for measurement[1, 22]. The hip-knee-ankle angle (HKAA), lateral distal femoral angle (LDFA), and medial proximal tibial angle (MPTA) were also measured on the whole leg radiographs and joint line congruency angle (JCA) was measured on knee anteroposterior radiographs. HKAA values were positive for varus alignment and negative for valgus alignment. Likewise, positive values of JCA indicated that the medial gap of the knee joint was tighter than the lateral gap, while negative values of JCA indicated that the lateral gap of the knee joint was tighter than the medial gap. All radiographs were measured in a blinded manner at four-week intervals using a picture archiving and communication system. To assess interobserver reliability, a second surgeon independently measured the radiographs, also in a blinded state.

Figure 3. PTS is measured by the angle (*) between the line drawn along the tibial plateau connecting its highest anterior and posterior bony ridge and the line perpendicular to the posterior

tibial cortex line at the metaphyseal level, which is extended proximally. PTS, posterior tibial slope.

2.3. Statistical Analysis

Statistical analyses were conducted using version 9.4 of SAS software (SAS Institute, Cary, NC, USA). PTS was compared including known risk factors of meniscus tears[13, 14]. Student's *t* test was applied to analyze numerical variables (i.e., body mass index [BMI], age, HKAA, MPTA, LDFA, JCA, and PTS), which were presented as standard deviations and means. For categorical variables (i.e., radiographic osteoarthritis severity classified by the Kellgren-Lawrence grade [KL grade] system and sex), Fisher's exact test or Pearson's chi-square test was used. Multivariable logistic regression was utilized to assess the impact of each factor, with the results expressed as odds ratios[23].

Baseline characteristics included were probable risk factors of meniscus tears, so that these factors could be accounted for in comparisons of PTS[13]. However, selection bias could not be fully avoided in this case-control study. Therefore, to address potential biases, an inverse probability of treatment weighting (IPTW) analysis was also conducted. This method generates pseudo-datasets by weighting participants according to the inverse of their treatment probability, ensuring balanced baseline characteristics across groups[24]. By making clinical covariates similar, the IPTW matching method could effectively minimize selection bias.

The receiver operating characteristic (ROC) curve analysis was conducted to establish the PTS threshold that differentiates patients with LMAH tears from the control group. The area under the curve (AUC) reflects the discriminative ability, and the optimal cutoff point was identified to balance sensitivity and specificity effectively.

Finally, the intraobserver and interobserver reliabilities of PTS measurements were assessed using the intraclass correlation coefficient (ICC), calculated with a 95% confidence interval (CI) based on mixed two-way models and absolute agreement. Statistical significance was defined as *P*-values less than 0.05.

3. RESULTS

3.1. Comparison between LMAH Tear and Control Groups

We included 35 patients in the LMAH tear group and 83 patients in the control group. PTS was significantly smaller in the LMAH tear group (LMAH tear group, 4.70° ± 2.16° [mean ± standard deviation]; control group, 6.58° ± 2.95°, *P*<.001). Furthermore, HKAA in the LMAH tear group had significantly more valgus alignment than in the control group (LMAH tear group, -0.42° ± 2.98°; control group, 1.64° ± 2.68°, *P*<.001). MPTA (LMAH tear group, 87.27° ± 2.20°; control group, 85.92° ± 2.41°, *P*=0.005) and the ratio of KL grade 1 osteoarthritis (LMAH tear group, 51.43%; control group, 27.71%, *P*=0.029) was significantly greater in the LMAH tear group. However, there were no significant differences in other factors (**Table 1**). For the measurement of PTS, the ICC of the intraobserver reliabilities was 0.949 (95% CI 0.927-0.965) and the interobserver reliability was 0.94 (95% CI 0.880-0.971).

<Table 1> Comparisons of PTS between the LMAH tear and control groups

	LMAH Tear (n=35)	Control (n=83)	*P* value
Age, y	42.17 ± 15.33	38.24 ± 13.07	.159
Sex			.292
Male	21 (60.00)	41 (49.40)	
Female	14 (40.00)	42 (50.60)	
BMI, kg/m^2	24.56 ± 3.83	23.18 ± 3.39	.055
HKA angle, degree	-0.42 ± 2.98	1.64 ± 2.68	<.001
MPTA, degree	87.27 ± 2.20	85.92 ± 2.41	.005
LDFA, degree	85.74 ± 2.13	86.18 ± 1.98	.289
JCA, degree	0.89 ± 1.83	1.28 ± 1.50	.221
KL grade			.029
0	18 (51.43)	60 (72.29)	
1	17 (48.57)	23 (27.71)	
PTS, degree	4.70 ± 2.16	6.58 ± 2.95	<.001

Values are presented as mean ± standard deviation or no. (%).
PTS, posterior tibial slope; LMAH, lateral meniscus anterior horn; BMI, body mass index; HKA, hip-knee-ankle; MPTA, medial proximal tibial angle; LDFA, lateral distal femoral angle; JCA, joint line convergence angle; KL, Kellgren-Lawrence.

In univariable logistic regression, the odds ratios of HKAA (0.767; 95% CI 0.656-0.897, *P*=0.001), MPTA (1.276; 95% CI 1.967-1.525, *P*=0.008), osteoarthritis (KL grade 1) (2.464; 95% CI 1.086-5.587, *P*=0.031), and PTS (0.739; 95% CI 0.611-0.893, *P*=0.002) demonstrated a statistically significant correlation with LMAH tear. After multivariable logistic regression of those factors, the adjusted odds ratio of PTS was 0.762 (95% CI 0.621-0.934, *P*=0.009) (**Table 2**).

<Table 2> Univariable and multivariable logistic regressions between the LMAH tear and control groups

	Univariable		Multivariable	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Age, y	1.02 (0.99 - 1.05)	.160		
Sex				
Male	Ref			
Female	0.65 (0.29 - 1.45)	.294		
BMI, kg/m^2	1.11 (1.00 - 1.25)	.059		
HKA angle, degree	0.77 (0.66 - 0.90)	.001	0.82 (0.67 - 1.00)	.055
MPTA, degree	1.28 (1.07 - 1.53)	.008	1.12 (0.89 - 1.41)	.321
LDFA, degree	0.90 (0.74 - 1.10)	.288		
JCA, degree	0.86 (0.67 - 1.10)	.222		
KL grade				
0	Ref		Ref	
1	2.46 (1.09 - 5.59)	.031	2.53 (0.99 - 6.51)	.053
PTS, degree	0.74 (0.61 - 0.89)	.002	0.76 (0.62 - 0.93)	.009

PTS, posterior tibial slope; LMAH, lateral meniscus anterior horn; BMI, body mass index; HKA, hip-knee-ankle; MPTA, medial proximal tibial angle; LDFA, lateral distal femoral angle; JCA, joint line convergence angle; KL, Kellgren-Lawrence; OR, odds ratio; CI, confidence interval.

In a comparison after IPTW matching analysis, the mean PTS was significantly smaller in the LMAH tear group (LMAH tear group, 4.83° ± 3.60°; control group, 6.51° ± 3.01°, *P*=0.006) (**Table 3**).

<Table 3> Comparison of PTS between the LMAH tear and control groups after IPTW matching· 5

	LMAH Tear (n=54.55)	Control (n=92.71)	*P* value
Age, y	38.89 ± 22.00	39.07 ± 14.77	.960
Sex			.757
Male	29.00 (56.89)	47.72 (53.15)	
Female	21.97 (43.11)	42.05 (46.85)	
BMI, kg/m^2	23.81 ± 3.79	23.58 ± 4.36	.742
HKA angle, degree	0.64 ± 3.14	1.19 ± 3.03	.312
MPTA, degree	86.91 ± 2.49	86.26 ± 2.87	.163
LDFA, degree	86.37 ± 3.53	86.19 ± 2.06	.737
JCA, degree	1.03 ± 1.58	1.20 ± 1.60	.548
KL grade			.568
0	30.56 (59.95)	59.72 (66.53)	
1	20.41 (40.05)	30.05 (33.47)	
PTS, degree	4.83 ± 3.60	6.51 ± 3.01	.006

Values are presented as mean ± standard deviation or no. (%). Adjustment for baseline characteristics: age, sex, BMI, HKA angle, MPTA, LDFA, JCA, KL grade

PTS, posterior tibial slope; LMAH, lateral meniscus anterior horn; IPTW, inverse probability of treatment weighting; BMI, body mass index; HKA, hip-knee-ankle; MPTA, medial proximal tibial angle; LDFA, lateral distal femoral angle; JCA, joint line convergence angle; KL, Kellgren-Lawrence.

3.2. ROC curve analysis

ROC curves were drawn to obtain optimal cutoff points for PTS to discriminate between the LMAH tear and control groups. The cutoff point for PTS was 4.49° (sensitivity, 48.57%; specificity, 80.72%) and of the AUC was 0.677 (**Fig 4**). The odds ratio of PTS greater than 4.49° was 0.253 (95% CI 0.107-0.597, *P*=0.002).

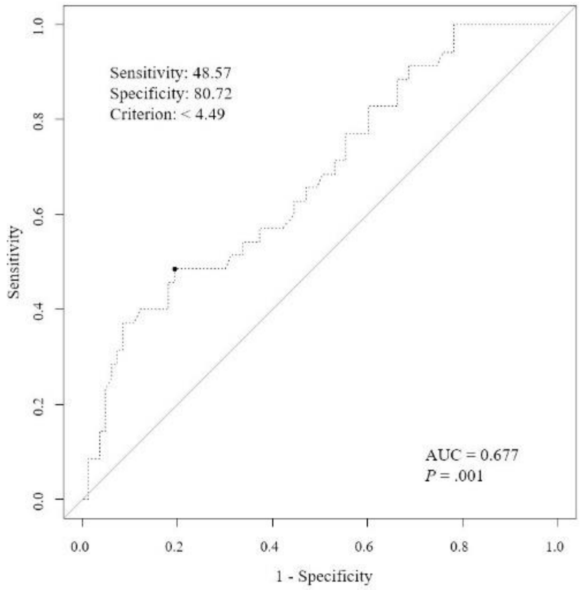

Figure 4. Receiver operating characteristic curve of PTS. PTS, posterior tibial slope; AUC, area under the curve.

4. DISCUSSION

The main outcome of this study revealed that the PTS was significantly smaller in the LMAH tear group compared to the control group. Using ROC curve analysis, the PTS threshold for differentiating the study group from the control group was identified as 4.49°.

PTS is an important factor affecting the kinematics of the knee joint[3, 25]. Previous studies reported that increased PTS is associated with increased anterior tibial translation[4, 6, 26]. Increased anterior tibial translation may lead to greater posterior sliding of the femoral condyle and enhanced internal tibial rotation because of the pivot shift mechanism during knee flexion, potentially causing excessive strain on the LMPH[15, 27, 28]. As a result, large PTS is considered a risk factor of ACL deficiency because increased anterior tibial translation could cause greater strain on the ACL[5-7, 29].

Likewise, higher incidence of lateral meniscus posterior horn and posterior root tears was also associated with increased PTS[15, 30, 31]. For these reasons, the measurement of PTS was important because it has effects on knee structures.

Meniscus tears are considered an important cause of osteoarthritis of the knee[9, 10]. Several previous studies focused on meniscus posterior horn tears because the most frequent location of lesions in the meniscus is the posterior horn[16, 32-34]. However, few studies have examined the causes of LMAH tears. LMAH tears can lead to increased peak contact pressure and impair stability of the knee joint, which might have negative effects on the knee joint in the future[18, 35]. Therefore, treatment of LMAH tears is important, and repair of LMAH tears can improve outcomes[18, 36]. Two previous studies about the characteristics of LMAH tears found that LMAH tears were almost always found in soccer players[37, 38]. The repetitive kicking engaged in by soccer players could lead to hyperextension of the knee joint, so that recurrent impingement of the LMAH between the lateral femoral condyle and the lateral tibial plateau could result in degeneration of the LMAH[37].

In our study, smaller PTS was a risk factor for LMAH tears. The main reason why PTS was smaller in the LMAH tear group was thought to be increased posterior tibial translation due to smaller PTS[39]. Previous studies of the posterior cruciate ligament reported that smaller PTS might result in increased posterior tibial slope[20, 40]. Furthermore, smaller PTS could cause decreased internal rotation of the tibia during flexion of the knee[39]. These factors might result in increased impingement of the LMAH and lateral femoral condyle so that the chances of LMAH tear are increased.

In direct comparisons and univariable logistic regression, patients in the LMAH tear group had more valgus alignment than those in the control group, although there were no significant differences in multivariable logistic regression and comparisons after IPTW matching. The lateral meniscus is partially detached from the joint capsule and is linked to the popliteal hiatus through the popliteomeniscal fascicle[41, 42]. Therefore, the lateral meniscus has greater tendencies toward hypermobility than the medial meniscus[43, 44]. However, in valgus alignment, the natural movement of the lateral meniscus is limited, which could cause increased strain on the lateral meniscus[45]. This might clarify why patients with LMAH tears exhibited a greater degree of valgus alignment compared to the control group.

This study has several limitations. First, the retrospective design of this study inherently makes it susceptible to bias. Second, the sample size was relatively small for comparisons. However, this limitation is partially overcome because of the application of IPTW analysis, which allowed us to create a pseudo-population. Third, even though we evaluated several risk factors for meniscal tears, other factors that were not included could affect risk of LMAH tears. Fourth, we used the medial tibial plateau instead of lateral tibial plateau as a landmark for measurement of PTS. The medial tibial plateau is the major load-bearing compartment of the knee and has advantages of providing landmarks for measurement in radiographs[22]. Furthermore, previous studies suggested that the difference between the medial and lateral tibial slope is not significant[46, 47].

5. CONCLUSIONS

Smaller PTS is significantly associated with higher incidence of LMAH tears.

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Abstract in Korean

감소된 경골 후방 경사각과 외측 반월판연골 전각 퇴행성 파열과의 관계

외측 반월판연골 전각 파열은 슬관절의 접촉압력을 증가 시킬 수 있음에도 불구하고, 외측 반월판연골 전각 파열과 슬관절의 역학과 관련된 경골 후방 경사각과의 관련된 연구는 매우 적은 상황이다. 본 연구의 목적은 인대손상이 동반되지 않은 외측 반월판연골 전각 파열과 경골 후방 경사각과의 관계를 알아보는 연구이다. 연구 가설은 외측 반월판연골 전각 파열 환자군의 경골 후방 경사각의 크기가 대조군에 비해 작다고 설정하였다.

2010년 1월 부터 2023년 10월 까지 단일 정형외과 전문의에게 수술 받은 단독 외측 반월판연골 전각 파열 진단 받은 환자들로 환자군을, 동일기간 단일 정형외과 전문의에게 외래진료 받은 환자 중 슬관절 MRI상 특이병변이 없는 환자들로 대조군을 구성하였다. 각 군의 경골 후방 경사각을 다른 기타 요소들과 함께 비교를 시행하였다. 다중 로지스틱 회귀분석 및 역확률가중치 매칭 방법을 이용하여 환자군과 대조군의 비교도 같이 시행하였다. 마지막으로 환자군과 대조군을 나누는 경골 후방 경사각의 기준값을 구하기 위해 수신자 조작 특성 분석을 시행하였다.

외측 반월판 연골 파열 환자군의 평균 경골 후방 경사각은 대조군에 비해 유의하게 작았다 (환자군, 4.70° ± 2.16°; 대조군, 6.58° ± 2.95°, *P*<.001). 다중 로지스틱 회귀분석의 경우, 환자군의 경골 후방 경사각의 승산비는 0.762 이다 (95% 신뢰구간 0.621−0.934, *P*=0.009). 역확률가중치 매칭시, 환자군의 평균 경골 후방 경사각은 대조군에 비해 유의하게 작았다 (환자군, 4.83° ± 3.60°; 대조군, 6.51° ± 3.01°, *P*=0.006). 수신자 조작 특성 분석의 경우, 환자군과 대조군을 나누는 경골 후방 경사각의 기준값은 4.49° 이며, 4.49° 보다 큰 경골 후방 경사각의 승산비는 0.253 이다 (95% 신뢰구간 0.107−0.597, *P*=0.002).

경골 후방 경사각이 작을수록 외측 반월판연골 전각 파열 발생률이 유의하게 증가된다.

핵심되는 말: 경골 후방 경사각, 외측 반월판연골