ORIGINAL CLINICAL RESEARCH – KNEE

acta orthopaedica belgica, 2026, 92, online-only

doi.org/10.52628/92.2.15408

# Sagittal Plate Position and Posterior Tibial Slope Changes After Medial Open-Wedge High Tibial Osteotomy

Ö. ESMEZ[1], Ş. DEMIR[2], B. CAN[2], G. DENIZ[3]

[1]*Department of Orthopaedics and Traumatology, Elazığ Fethi Sekin City Hospital, 23100, Elazığ, Türkiye;* [2]*Department of Orthopaedics, Faculty of Medicine, Fırat University, 23100, Elazığ, Türkiye;* [3]*Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Erzurum Technical University, 25055, Erzurum, Türkiye.*

Correspondence at: Ömer Esmez, MD, Department of Orthopaedics and Traumatology, Elazığ Fethi Sekin City Hospital 23100 Elazığ, Türkiye. E-mail: dresmezomer@gmail.com

## ABSTRACT

Medial open-wedge high tibial osteotomy (HTO) is a well-established joint-preserving procedure for medial compartment osteoarthritis with varus malalignment. However, unintended changes in posterior tibial slope (PTS) may occur and affect knee biomechanics and cruciate ligament loading. This retrospective cohort study included 60 patients who underwent medial open-wedge HTO between 2018 and 2024. We investigated whether sagittal plate position on postoperative lateral radiographs (anterior vs posterior) influenced postoperative PTS change and its association with coronal alignment and short-term functional outcomes. Radiographic assessments included PTS, tibiofemoral angle, hip–knee–ankle angle, and mechanical axis deviation. Clinical outcomes were evaluated using the Hospital for Special Surgery (HSS) Knee Score and the Tegner Activity Scale. Multivariable linear regression was used to determine whether plate position independently predicted ΔPTS. The posterior plate group demonstrated a significantly greater increase in PTS than the anterior group (ΔPTS $4.3° \pm 1.6°$ vs $0.9° \pm 1.2°$, $p < 0.001$), and postoperative PTS ≥12° was more frequent in the posterior group (67% vs 10%, $p < 0.001$). Coronal alignment parameters and functional scores were comparable between groups (all $p > 0.05$). Sagittal plate position was independently associated with postoperative PTS change after medial open-wedge HTO. Posterior placement resulted in greater slope increase, whereas anterior positioning better preserved sagittal alignment without compromising coronal correction or short-term clinical outcomes.

**Keywords:** High tibial osteotomy, posterior tibial slope, plate position, sagittal alignment.

## INTRODUCTION

Medial open-wedge high tibial osteotomy (HTO) is a widely used joint-preserving procedure for patients with medial compartment osteoarthritis and varus knee alignment. By shifting the mechanical axis laterally, the load on the medial compartment is reduced, potentially decreasing pain and delaying the need for total knee arthroplasty, particularly in younger, active patients[1,2]. For this reason, achieving accurate coronal correction is considered a key determinant of surgical success.

However, medial open-wedge HTO does not affect only coronal alignment. The procedure can also alter sagittal tibial geometry. Posterior tibial slope (PTS) is a crucial anatomical parameter that affects anterior–posterior tibial translation and overall knee stability. An increased PTS may lead to greater anterior tibial translation and increased stress on the anterior cruciate ligament (ACL). In contrast, a decreased PTS may increase loading on the posterior cruciate ligament (PCL)[2-5]. Therefore, maintaining an appropriate sagittal alignment is important to preserve normal knee biomechanics after HTO.

Several intraoperative factors may contribute to postoperative changes in PTS, including the relative opening of the anterior and posterior osteotomy gaps, the lateral hinge position, the orientation of the osteotomy plane, graft use, and fixation technique. Meta-analyses have shown that PTS frequently increases after medial open-wedge HTO, suggesting that slope alteration is multifactorial[6].

Among these factors, sagittal plate position is a modifiable technical variable. Posterior plate placement may promote greater posterior gap opening, thereby increasing PTS, whereas anterior placement may help preserve the native slope[7]. However, existing evidence remains limited and partially inconsistent. Although some studies report increased slope with posterior plate positioning, the magnitude of this effect and its clinical relevance—particularly regarding coronal alignment and functional outcomes—remain unclear[7-9].

Therefore, this study aimed to determine whether sagittal plate position influences postoperative PTS following medial open-wedge HTO and to evaluate its association with coronal alignment parameters and clinical outcomes.

## METHODS

### Study Design and Patient Selection

This retrospective, non-randomized comparative cohort study included 60 consecutive patients who underwent medial open-wedge high tibial osteotomy (HTO) between 2018 and 2024. All procedures were performed by the same experienced orthopedic surgeon using a standardized medial open-wedge technique. The minimum follow-up was 24 months, with a mean follow-up duration of 28.6 ± 6.4 months. No patients were lost to follow-up.

Inclusion criteria were:

1. Medial compartment knee osteoarthritis (Kellgren–Lawrence grade ≥2),
2. Varus deformity ≤15°,
3. Complete and standardized preoperative and postoperative radiographs,
4. Minimum follow-up of 24 months.

Patients were excluded if they had previous knee surgery, significant ligament insufficiency, combined ligament injuries, or incomplete radiographic data.

The study protocol was approved by the Non-Interventional Research Ethics Committee of Fırat University (2025/05-17) and conducted in accordance with the Declaration of Helsinki.

This study adhered to the STROBE guidelines for observational studies.

### Surgical Technique

A standard medial open-wedge HTO technique was used in all cases. After performing the medial osteotomy and preserving the lateral cortical hinge, the osteotomy gap was gradually opened until the planned coronal correction was achieved. Particular attention was paid to maintaining a balanced anterior and posterior gap opening to minimize unintended changes in posterior tibial slope (PTS). Fixation was performed using the same locking medial HTO plate system in all patients, according to the manufacturer's recommendations.

### Assessment of Sagittal Plate Position

To minimize subjectivity and enhance reproducibility, sagittal plate position was quantified using a normalized Plate Position Ratio (PPR). To reduce rotational bias, only standardized true lateral knee radiographs demonstrating complete superimposition of the posterior femoral condyles were included.

On the true lateral radiograph, the total anteroposterior (AP) length of the proximal tibial plateau (D) was measured along a line drawn parallel to the tibial plateau surface. The anterior tibial cortex at the plateau level was used as the reference point, the sagittal distance from the anterior cortex to the center of the proximal plate head (d) was recorded.

The Plate Position Ratio was calculated as:

$$PPR = d / D$$

Cases with PPR < 0.5 were classified as anterior plate placement (anterior half of the tibial AP dimension), whereas cases with PPR ≥ 0.5 were classified as posterior plate placement (posterior half of the tibial AP dimension) (Figure 1).

Because sagittal plate positioning was not randomized and may reflect intraoperative technical execution, other technical variables known to influence posterior tibial slope—such as the anterior–posterior gap ratio, hinge position, osteotomy plane inclination, wedge size, and grafting strategy—were not quantitatively recorded in the present dataset and therefore could not be included in the regression model.

### Radiographic Evaluation

Radiographic parameters included:

- Posterior tibial slope (PTS),
- Tibiofemoral angle (TFA),
- Hip–knee–ankle angle (HKAA),
- Mechanical axis deviation (MAD).

Posterior tibial slope was measured on standardized true lateral radiographs. The anatomical axis of the tibia was defined by connecting the midpoints of two circles placed within the proximal and distal tibial diaphysis. The angle between a line perpendicular to this axis and the medial tibial plateau was recorded as the PTS.

Change in PTS (ΔPTS) was calculated as the difference between postoperative and preoperative values.

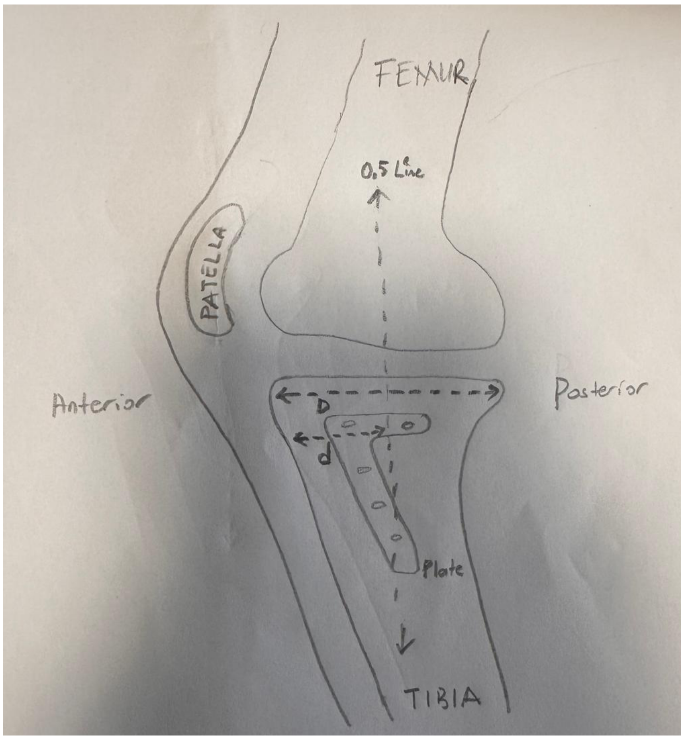



*Fig. 1 — Schematic illustration of the Plate Position Ratio (PPR) measurement on a true lateral radiograph. D represents the total anteroposterior tibial plateau length measured parallel to the plateau surface. d represents the sagittal distance from the anterior tibial cortex to the center of the proximal plate head. The vertical line indicates the midpoint (0.5D), dividing the tibial AP dimension into anterior and posterior halves.*

Posterior tibial slope (PTS) measurements were independently performed by two experienced orthopedic surgeons who were blinded to plate position and clinical outcomes. Each observer repeated all measurements after a 2-week interval to minimize recall bias.

Interobserver and intraobserver reliability were assessed using intraclass correlation coefficients (ICC), based on a two-way random-effects model with absolute agreement definition (ICC[2,1]). An ICC value >0.75 was considered good and >0.90 excellent reliability.

### Clinical Evaluation

Clinical outcomes were assessed at final follow-up using:

- The Hospital for Special Surgery (HSS) Knee Score,
- The Tegner Activity Scale.

### Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Data distribution was evaluated for normality using the Shapiro–Wilk test. Continuous variables were expressed as mean ± standard deviation.

Group comparisons between anterior and posterior plate positions were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Categorical variables were analyzed using the chi-square test.

To determine whether sagittal plate position independently predicted ΔPTS, a multivariable linear regression model was constructed. The model included plate position as the primary independent variable and was adjusted for age, sex, preoperative PTS, and amount of coronal correction. A p-value $< 0.05$ was considered statistically significant.

Multicollinearity was assessed using variance inflation factors (VIF), and model fit was evaluated using adjusted $R^2$. Residual plots were visually inspected to confirm normality and homoscedasticity assumptions of the regression model.

*Evidence level of the study:* Level III, retrospective comparative study.

## RESULTS

### Patient Characteristics

Patients were classified into an anterior plate group (n = 30) and a posterior plate group (n = 30).

There were no significant differences between groups regarding age, sex distribution, body mass index, or follow-up duration (all $p > 0.05$). Baseline demographic characteristics were comparable between groups (Table I).

### Reliability Analysis

Posterior tibial slope (PTS) measurements demonstrated excellent reproducibility. Interobserver reliability was excellent (ICC[2,1] = 0.91; 95% CI 0.85–0.95). Intraobserver reliability was also excellent, with ICC values of 0.93 (95% CI 0.88–0.96) for observer 1 and 0.90 (95% CI 0.83–0.94) for observer 2.

### Posterior Tibial Slope (PTS) Changes

Preoperative PTS did not differ between groups; however, postoperative PTS was significantly higher in the posterior plate group ($p < 0.001$).

The mean increase in PTS (ΔPTS) was +0.9° ± 1.2° in the anterior group and +4.3° ± 1.6° in the posterior group ($p < 0.001$).

The effect size for the difference in ΔPTS between groups was very large (Cohen's d = 2.4), indicating a strong and clinically meaningful association between posterior plate placement and slope increase.

A significantly higher proportion of patients in the posterior plate group had postoperative PTS ≥12° compared to the anterior group (67% vs 10%, $p < 0.001$). The distribution of ΔPTS according to sagittal plate position is illustrated in Figure 2. Detailed distribution of postoperative slope threshold values is presented in Table II.

### Multivariable Linear Regression Analysis

Posterior plate position remained an independent predictor of ΔPTS, with an estimated increase of 3.2° (95% CI 2.6 to 3.8; $p < 0.001$). Age, sex, preoperative PTS, and coronal correction amount were not significant predictors (all $p > 0.05$). Detailed regression results are presented in Table III.

### Coronal Alignment Parameters

Preoperative tibiofemoral angle (TFA) was comparable between groups.

There were no significant differences between groups in postoperative TFA, postoperative HKAA, or mechanical axis deviation (all $p > 0.05$).

These findings indicate that sagittal plate position did not influence coronal alignment correction.

### Clinical Outcomes

At final follow-up, HSS Knee Score and Tegner Activity Scale were comparable between groups (all $p > 0.05$). Thus, despite significant differences in slope change, sagittal plate position did not affect short-term functional outcomes (Table II).

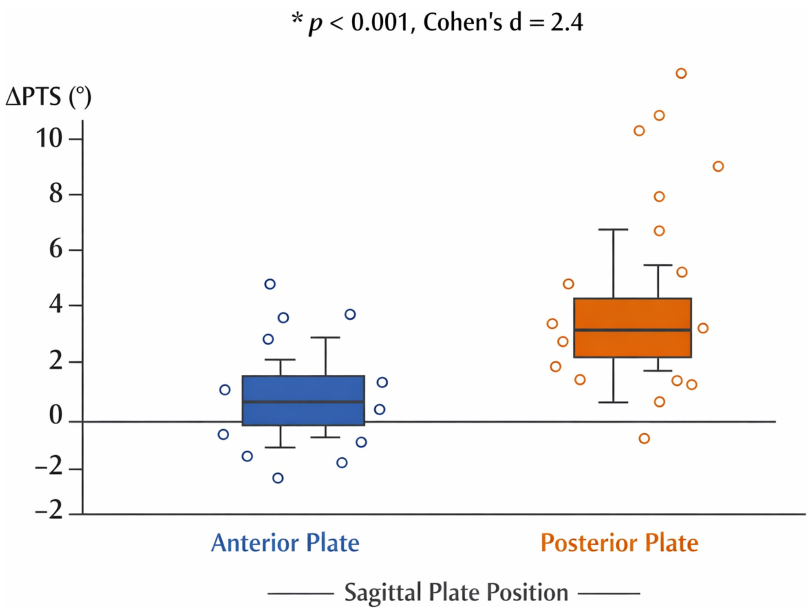
## DISCUSSION

This study evaluated whether sagittal plate position influences posterior tibial slope (PTS) after medial open-wedge high tibial osteotomy. Our findings showed that posterior plate placement was associated with a greater increase in slope, whereas anterior placement resulted in minimal change. In addition, multivariable analysis confirmed that plate position itself was an independent factor affecting postoperative slope. The relatively high adjusted $R^2$ value should be interpreted cautiously, as it may partially reflect the binary group separation combined with a large intergroup effect size. The magnitude of slope increase observed in the posterior group may be clinically relevant, particularly in patients at risk for ligamentous instability.

The observed slope increase with posterior plate positioning is consistent with previous biomechanical and clinical studies[6,12,13]. When the plate is located

**Table I.** — Demographic and Radiographic Parameters According to Sagittal Plate Position.

| Variable | Anterior Plate (n=30) | Posterior Plate (n=30) | p-value |
|---|---|---|---|
| Age (years) | 52.1 ± 4.8 | 52.8 ± 5.6 | 0.48 |
| BMI (kg/m²) | 27.8 ± 3.3 | 28.1 ± 3.5 | 0.31 |
| Preoperative PTS (°) | 9.6 ± 1.7 | 8.7 ± 1.8 | 0.06 |
| Postoperative PTS (°) | 10.5 ± 2.0 | 13.1 ± 2.7 | <0.001 |
| ΔPTS (°) | 0.9 ± 1.2 | 4.3 ± 1.6 | <0.001 |
| Postoperative TFA (°) | -4.7 ± 1.3 | -4.5 ± 1.5 | 0.77 |
| Postoperative HKAA (°) | -2.9 ± 1.4 | -2.8 ± 1.5 | 0.68 |
| MAD (mm) | 36.5 ± 7.0 | 35.2 ± 6.8 | 0.35 |




*Box plot illustrating the distribution of change in posterior tibial slope (ΔPTS) according to sagittal plate position. Posterior plate placement was associated with a significantly greater increase in ΔPTS compared with anterior placement ($p < 0.001$; Cohen's $d = 2.4$).*

**Table II.** — Clinical Outcomes According to Sagittal Plate Position.

| Parameter | Anterior Plate (n=30) | Posterior Plate (n=30) | p-value |
|---|---|---|---|
| HSS Knee Score | 85.4 ± 5.9 | 84.9 ± 6.2 | 0.62 |
| Tegner Activity Scale | 3.9 ± 0.7 | 4.0 ± 0.8 | 0.49 |
| Postoperative PTS ≥12° | 3 (10%) | 20 (67%) | <0.001 |

Values are presented as mean ± standard deviation or number (%).

**Table III.** — Multivariable Linear Regression Analysis for ΔPTS.
Dependent variable: Change in posterior tibial slope (ΔPTS).

| Variable | β Coefficient | 95% Confidence Interval | p-value |
|---|---|---|---|
| Posterior plate position | 3.2 | 2.6 – 3.8 | <0.001 |
| Age | 0.04 | −0.02 – 0.10 | 0.18 |
| Sex | 0.12 | −0.45 – 0.69 | 0.67 |
| Preoperative PTS | 0.09 | −0.05 – 0.21 | 0.22 |
| Coronal correction | 0.07 | −0.04 – 0.15 | 0.19 |

Posterior plate position was coded as posterior vs anterior.
*Model statistics:* The overall regression model was statistically significant ($p < 0.001$), with an adjusted $R^2$ of 0.58. Variance inflation factors (VIF) ranged from 1.05 to 1.32, indicating no evidence of multicollinearity.

more posteriorly, the posterior part of the osteotomy gap may open relatively more during distraction, leading to slope elevation. In contrast, anterior placement may help maintain a more balanced gap and preserve the native tibial slope[14]. These findings support the idea that even small changes in plate positioning can influence sagittal alignment.

In our cohort, the magnitude of slope increase in the posterior group was notable. A considerably higher proportion of patients in this group had postoperative PTS values ≥12°, a threshold that has been associated with increased risk of anterior cruciate ligament (ACL) injury and graft failure in previous reports[17,18]. Although we did not observe early instability, such slope elevations may become clinically relevant over time, especially in active individuals.

Interestingly, sagittal plate position did not affect coronal alignment. Tibiofemoral angle (TFA), hip–knee–ankle angle (HKAA), and mechanical axis deviation (MAD) were similar between groups. This suggests that coronal correction depends mainly on osteotomy planning and hinge stability rather than on plate position in the sagittal plane[15,16]. In other words, adequate coronal correction can be achieved even when sagittal alignment is altered.

Short- to mid-term functional outcomes were comparable between groups. However, the absence of early clinical differences does not necessarily mean that slope elevation is harmless. Given the relatively small sample size and the use of general functional scores such as HSS and Tegner, a type II error cannot be excluded regarding subtle functional differences associated with slope change. Increased PTS has been linked to greater anterior tibial translation and higher ACL loading[17,18]. It has also been associated with changes in posterior cruciate ligament (PCL) biomechanics[19]. These biomechanical considerations may be particularly important in younger patients or in those with previous or potential future ligament surgery.

The clinical relevance of posterior tibial slope has been emphasized in previous studies, including reports published in this journal. For example, Sayıt et al. demonstrated the biomechanical importance of increased PTS in the context of noncontact ACL injuries, highlighting its role in anterior tibial translation and ligament loading[20]. Our findings extend this perspective to the setting of medial open-wedge high tibial osteotomy, suggesting that intraoperative technical factors influencing sagittal alignment may have potential biomechanical implications.

In addition, the short-term functional outcomes observed in our cohort are consistent with previously reported clinical results after medial open-wedge HTO in this journal[21]. While our study did not demonstrate early functional deterioration despite slope changes, careful control of sagittal alignment may still be relevant, particularly in active or ligament-sensitive patients.

From a practical standpoint, sagittal plate position is one of the few technical variables that can be adjusted intraoperatively without altering planned coronal correction. For this reason, being attentive to plate placement may help avoid unintended slope increase.

Although medial HTO plates are commonly positioned in a posteromedial location for mechanical stability and anatomical conformity, our findings suggest that relative sagittal positioning within this region may influence posterior tibial slope. Therefore, attention to sagittal alignment during fixation may be important, even when standard posteromedial plate placement is used.

The most important limitation of this study is that sagittal plate position was not a randomized variable but rather reflected intraoperative surgical preference and technical execution. As such, plate positioning may have been associated with other technical factors known to influence posterior tibial slope (PTS), including anterior–posterior gap ratio, osteotomy plane inclination, hinge position, wedge size, and grafting strategy. Because these variables were not quantitatively recorded in the present dataset, residual confounding cannot be excluded.

Therefore, the observed differences in PTS should be interpreted as an association with plate position rather than definitive evidence of direct causality. In this context, sagittal plate position may represent a surrogate marker of the overall surgical technique rather than an isolated biomechanical determinant.

Future prospective studies with larger cohorts and systematic recording of technical variables—such as hinge position classification and anterior–posterior gap ratio—incorporated into multivariable regression models are warranted to further clarify these relationships.

Overall, our findings demonstrate a strong association between sagittal plate position and postoperative posterior tibial slope changes following medial open-wedge high tibial osteotomy. Posterior plate placement was consistently associated with greater slope increase. However, given the non-randomized nature of plate positioning and potential technical confounding, these results should be interpreted as associative rather than strictly causal. Careful attention to sagittal plate positioning may nevertheless contribute to improved control of postoperative slope.

## CONCLUSION

Sagittal plate position was associated with changes in posterior tibial slope after medial open-wedge high tibial osteotomy. Posterior plate placement was associated with a greater increase in slope, while anterior placement resulted in smaller changes.

Although coronal alignment and short-term functional outcomes were similar between groups, increased slope may have biomechanical implications, particularly in active patients or those with ligament concerns. For this reason, attention to sagittal plate positioning during surgery may help preserve native tibial slope.

Further long-term studies are needed to clarify the clinical impact of postoperative slope changes.

*Conflict of interest:*The authors declare that they have no conflict of interest.

*Funding:* No funding was received for this study.

*Ethics approval:* The study was approved by the Non-Interventional Research Ethics Committee of Fırat University (2025/05-17) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

## REFERENCES

1. Brouwer RW, Huizinga MR, Duivenvoorden T, van Raaij TM, Verhagen AP, Bierma-Zeinstra SM. Osteotomy for treating knee osteoarthritis. Cochrane Database Syst Rev. 2014;(12):CD004019.
2. Murray R, Winkler PW, Shaikh HS, Musahl V. High tibial osteotomy for varus deformity of the knee. JAAOS Glob Res Rev. 2021;5(7):e21.
3. Yoon KH, Park SY, Park JY, et al. Influence of posterior tibial slope on clinical outcomes and survivorship after anterior cruciate ligament reconstruction using hamstring autografts: minimum 10-year follow-up. Arthroscopy. 2020;36(10):2718-2727.
4. Salmon LJ, Heath E, Akrawi H, et al. 20-year outcomes of anterior cruciate ligament reconstruction with hamstring tendon autograft: the catastrophic effect of age and posterior tibial slope. Am J Sports Med. 2018;46(3):531-543.
5. Tischer T, Paul J, Pape D, et al. The impact of osseous malalignment and realignment procedures in knee ligament surgery: a systematic review. Orthop J Sports Med. 2017;5(3):2325967117697287.
6. Nha KW, Kim HJ, Ahn HS, Lee DH. Change in posterior tibial slope after open-wedge and closed-wedge high tibial osteotomy: a meta-analysis. Am J Sports Med. 2016;44(11):3006-3013.
7. Nibe Y, Takahashi T, Kubo T, et al. Effect of plate position on tibial displacement and posterior tibial slope after cyclic loading in medial open-wedge high tibial osteotomy: a biomechanical study using porcine tibia. Clin Biomech (Bristol, Avon). 2023;109:106076.
8. Moon DK, Seo MS, Kim CW, et al. The influence of different hinge position on posterior tibial slope during high tibial osteotomy: comparison between open-wedge and closed-wedge techniques. Eur J Orthop Surg Traumatol. 2023;33(4):1341-1347.
9. Mabrouk A, An JS, Fernandes LR, et al. Maintaining posterior tibial slope and patellar height during medial opening-wedge high tibial osteotomy. Orthop J Sports Med. 2023;11(12):23259671231213595.
10. Narin S, Unver B, Bakirhan S, Bozan O, Karatosun V. Cultural adaptation, reliability, and validity of the Turkish version of the Hospital for Special Surgery knee score. Acta Orthop Traumatol Turc. 2014;48(3):241-248.
11. Briggs KK, Steadman JR, Hay CJ, Hines SL. Lysholm score and Tegner activity level in individuals with normal knees. Am J Sports Med. 2009;37(5):898-901.
12. Song JH, Bin SI, Kim JM, et al. Risk factors for increase in posterior slope after medial open-wedge high tibial osteotomy. Orthop J Sports Med. 2022;10(11):23259671221137042.
13. Wang JH, Bae JH, Lim HC, et al. Medial open-wedge high tibial osteotomy: the effect of the cortical hinge on posterior tibial slope. Am J Sports Med. 2009;37(12):2411-2418.
14. Erquicia JI, Gil-Gonzalez S, Ibañez M, et al. A lower starting point for the medial cut increases posterior slope in opening-wedge high tibial osteotomy: a cadaveric study. J Exp Orthop. 2022;9(1):124.
15. Dragosloveanu S, Cristea S, Dragosloveanu C. The effect of high tibial osteotomy on posterior tibial slope. Maedica (Bucur). 2014;9(2):173-176.
16. Kim MK, Ko BS, Park JH. The proper correction of the mechanical axis in high tibial osteotomy with concomitant cartilage procedures: a retrospective comparative study. J Orthop Surg Res. 2019;14(1):281.
17. Fares A, Horteur C, Abou Al Ezz M, et al. Posterior tibial slope ≥10° is a risk factor for further anterior cruciate ligament injury; BMI is not. Eur J Orthop Surg Traumatol. 2023;33(5):2091-2099.
18. Liu Z, Jiang J, Yi Q, et al. Increased posterior tibial slope is associated with higher risk of graft failure following ACL reconstruction: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2022;30(7):2377-2387.
19. Bernhardson AS, DePhillipo NN, Daney BT, et al. Posterior tibial slope and risk of posterior cruciate ligament injury. Am J Sports Med. 2019;47(2):312-317.
20. Sayit E, Sayit AT, Terzi Y. Evaluation of the posterior tibial slope in noncontact ACL injuries using magnetic resonance imaging. Acta Orthop Belg. 2017;83(2):245-250.
21. De Neve F, Braems B, Holvoet M, De Scheerder MA, Arnout N, Victor J. Return to sport and work after medial open wedge high tibial osteotomy: a case series. Acta Orthop Belg. 2021;87(1):117-124.