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Effect of posteriorly inclined sagittal osteotomy on posterior tibial slope in biplanar medial opening wedge high tibial osteotomy: a case series study

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Abstract

Background Medial opening wedge high tibial osteotomy aims to correct coronal plane deformities and redistribute the load in varus-aligned knees. However, changes in the sagittal plane during medial opening wedge high tibial osteotomy can influence the posterior tibial slope, potentially affecting knee biomechanics. The sagittal inclination angle of the osteotomy, which is the angle between the medial joint line and the osteotomy line on lateral view, is a relatively new parameter that has been discussed in the literature, as a factor influencing the posterior tibial slope. The aim of this study is to investigate success rates in achieving the targeted postoperative slope, which is to avoid increasing the slope, with posteriorly inclined sagittal osteotomy.

Methods This research was designed as a retrospective single-center case-series study. In order to avoid increasing the posterior tibial slope, our modified surgical technique involves adjusting the sagittal inclination angle to be 10° posteriorly inclined. This angle was considered to be posteriorly inclined if the anterior portion of the osteotomy was inclined proximally. Pre- and postoperative posterior tibial slope measurements were recorded. Changes in postoperative tibial slope compared to preoperative tibial slope were statistically evaluated using the paired t-test. Changes were categorized as decreases, no change, or increases, and these three groups were compared using the one-sample binomial test.

Results Ninety-five patients (77 women and 18 men) with a mean age of 52.8 ± 7.0 were included in this study. The preoperative mean posterior tibial slope was measured as 12.5 ± 3.9° and the postoperative mean PTS was 10.6 ± 4.3°. A paired t-test revealed a statistically significant difference of 1.9 ± 3.8° (95% confidence interval: 1.13–2.71; $p < .01$). In four cases (4.2%), the PTS remained the same, while for 67 patients (70.5%) the PTS decreased and for 24 patients (25.3%) the posterior tibial slope increased. Therefore, a decrease or no change in the posterior tibial slope was achieved in 74.7% of all cases ($p < .01$).

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Conclusions Modifying the sagittal inclination angle to achieve a posteriorly inclined osteotomy during medial opening wedge high tibial osteotomy may prevent increasing the posterior tibial slope in the majority of cases.

Keywords Medial opening wedge, High tibial osteotomy, Sagittal inclination angle, Posterior tibial slope

Background

Medial opening wedge high tibial osteotomy (MOWHTO) aims to rectify coronal plane deformities and redistribute the load to the lateral compartment in knees with varus alignment [2]. This mitigates stress on the medial compartment, thereby decelerating the progression of osteoarthritis and alleviating symptoms for the patient [13]. Although various techniques have been described for high tibial osteotomy, MOWHTO is commonly employed and has been associated with successful outcomes [3, 22, 26].

Although the primary goal of MOWHTO is to correct coronal plane deformities, the procedure affects all three planes. Changes in the sagittal plane can particularly influence the posterior tibial slope (PTS), leading to undesirable outcomes in knee biomechanics [9, 25, 27]. While there is no consensus in the literature, it has been suggested that during MOWHTO, the PTS should be maintained or slightly reduced in patients with anterior cruciate ligament (ACL) insufficiency [15]. It has also been reported that factors such as incomplete posterior cuts, improper gap ratios, and inappropriate hinge positions can lead to changes in the PTS [14, 27, 28].

In recent years, the effect on the PTS of the sagittal inclination angle of the osteotomy, which is the angle between the medial joint line and the osteotomy line on lateral view, has also begun to be emphasized. (Fig. 1) Miller et al. emphasized the necessity of conducting parallel osteotomy in the sagittal plane to prevent unintended changes in the PTS [19]. Lee et al. found that despite intentions of performing a parallel osteotomy in the sagittal plane with respect to the medial joint line, an osteotomy that was parallel to the PTS was achieved in only 12.9% of cases and the rest of the osteotomies were found to be anteriorly inclined, resulting in the increase of the PTS [17]. In light of emerging evidence regarding the impact of the sagittal inclination angle on the PTS, modifications have been made to surgical techniques in our clinic over the past 5 years, particularly for patients with ACL insufficiency. To avoid increasing the PTS and prevent significant biomechanical changes, we started performing 10° posteriorly inclined sagittal osteotomies.

The aim of this study is to investigate success rates in achieving the targeted postoperative slope with posteriorly inclined sagittal osteotomy, which has been demonstrated to impact the slope in 3D modelling studies in the literature. The null hypothesis of this study is that posteriorly inclined sagittal osteotomy will result in an increase of the PTS.

Methods

This research was designed as a retrospective single-centre case-series study. Patients between the ages of 18 and 60 who underwent MOWHTO from January 2020 to December 2023 were included in the study. Indications for MOWHTO included symptomatic medial compartment osteoarthritis, varus knee alignment with a mechanical femoral-tibial angle of more than 5°, and flexion contracture of less than 10° for moderate and high activity levels. Patients with a history of periarticular knee fractures or patellar dislocations, previous patellar tendon surgery, previous open knee surgery, or BMI of >35 were excluded.

Radiological measurements

Preoperative and early postoperative (day 1) anteroposterior and lateral knee X-rays were taken. The relevant lateral radiographs were obtained with the patient in a supine position using a standard technique with the limb not rotated, with the knee flexed from 20° to 30° and the central beam directed to the joint line. The goal was for the posterior condylar lines to overlap with tolerance of 5 mm. Pre- and postoperative PTS measurements were recorded using the method described by Brazier et al., measured in relation to the posterior tibial cortex [4]. Measurements were performed by two orthopaedic surgeons independently who were blinded to patients. The sagittal inclination angle was defined as the angle between the medial joint line and the osteotomy line on lateral view. This angle was considered to be posteriorly inclined if the anterior portion of the osteotomy was inclined proximally. Further analysis was conducted among our cohort to observe the rate of patients with PTS change of more than 5°.

Surgical technique

In the course of preoperative planning, the targeted correction angle and distraction amount were determined based on the Fujisawa point and the Miniaci method [7, 11, 20]. Two Kirschner wires were used to determine the sagittal inclination angle as described in the literature [18]. After placing the Kirschner wires so that they barely passed through the medial cortex, a line connecting the two wires was drawn with a marker (Fig. 2A). The angle between this line and the line parallel to medial tibia plateau is measured using goniometer. To avoid increasing the PTS and prevent significant biomechanical changes, the Kirschner wires were placed 10° posteriorly inclined to the slope. Posteriorly inclined osteotomy

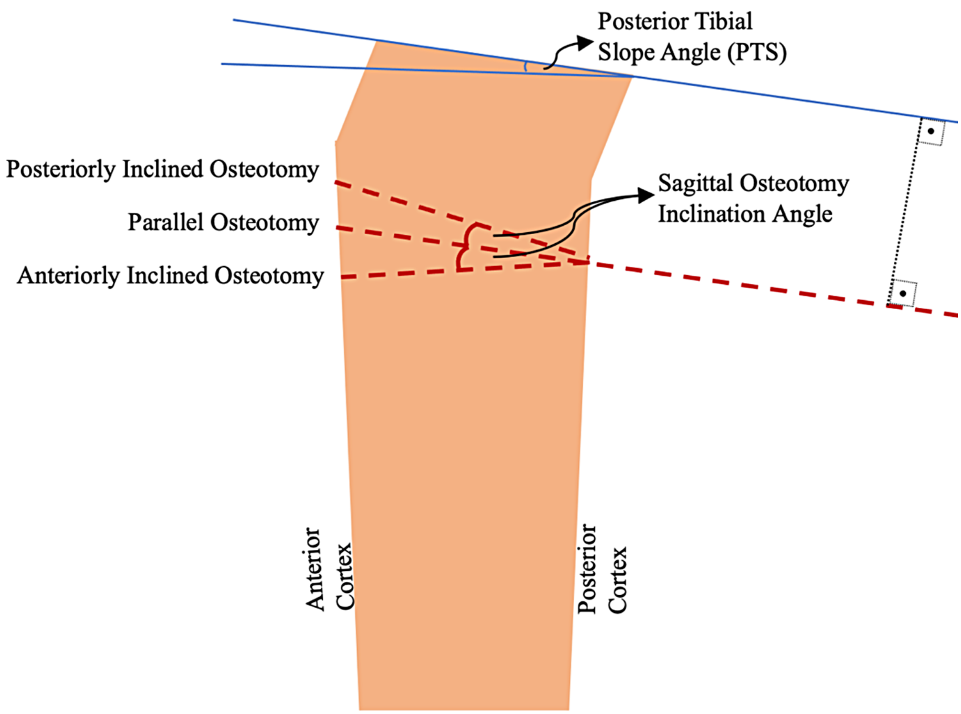

Fig. 1 Illustration of posteriorly and anteriorly inclined osteotomies in sagittal view

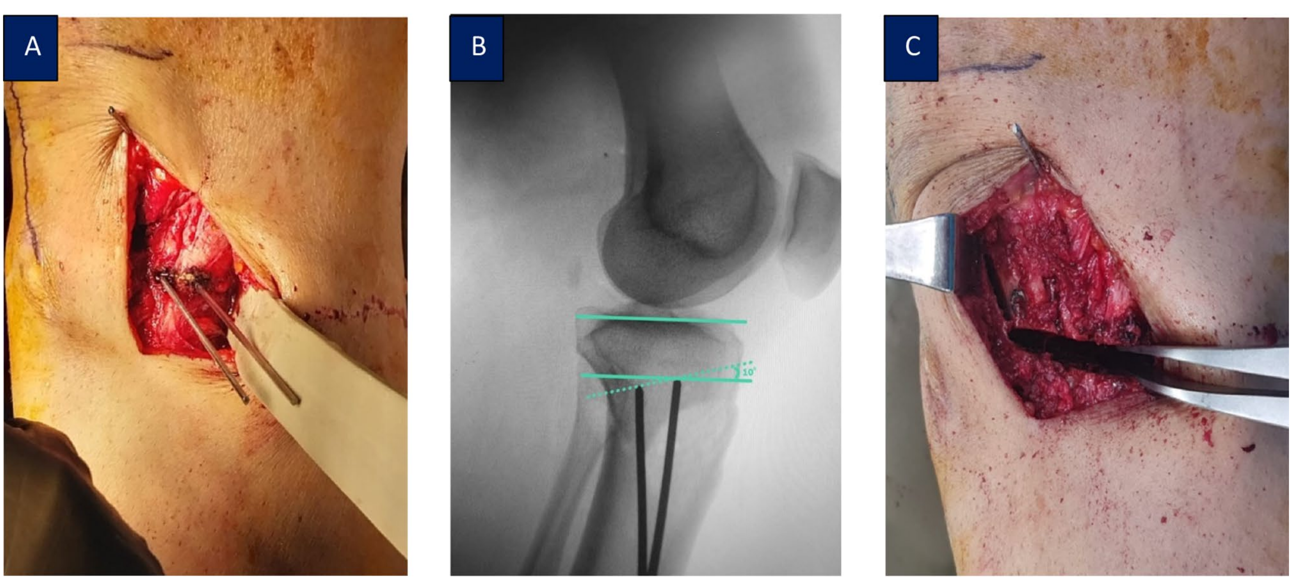

Fig. 2 Steps of the surgical technique. (**A**) Two K wires placed through medial cortex. (**B**) Fluoroscopy image of knee lateral view after K wires were placed and measurement of sagittal inclination angle. (**C**) Medial opening of the osteotomy

was confirmed with intraoperative fluoroscopy images (Fig. 2B). The osteotomy was performed in a biplanar manner. The horizontal osteotomy was performed just below the two Kirschner wires, starting approximately 4 cm below the joint line and progressing obliquely upwards towards the centre of the fibular head while gradually opening the osteotomy to preserve the lateral bone bridge. The horizontal osteotomy was continued up to 1 cm medial to the lateral tibial cortex using depth markings on the saw and fluoroscopic images. Subsequently, an ascending osteotomy was applied, leaving the tibial tuberosity on the distal fragment. The desired correction angle was achieved and the osteotomy gap was maintained with a laminar spreader positioned near posterior tibial cortex (Fig. 2C). The alignment of the mechanical axis was checked using fluoroscopy with a long alignment rod and the cable of an electrocautery device. The medial proximal tibia was fixed using a self-locking plate (Tomofix, Synthes, Solothurn, Switzerland). All surgeries were performed by a single surgeon.

Statistical analysis

For inter-rater reliability, two-way mixed-consistency intraclass correlation analysis was conducted by comparing the values of the preoperative and postoperative PTS. Due to the high correlation values (0.817 and 0.924, respectively), the results were reported using the mean scores provided by the two researchers.

Changes in postoperative PTS compared to preoperative PTS were statistically evaluated using the paired t-test. Changes were categorized as decreases, no change, or increases, and these three groups were compared using the one-sample binomial test. Demographic parameters and radiological measurements were compared between groups using one-way analysis of variance (ANOVA) for normally distributed data and the Kruskal-Wallis test for non-normal distributions. IBM SPSS Statistics 23 (IBM Corp., Armonk, NY, USA) was used for statistical analysis and values of $p<.05$ were considered statistically significant.

Results

Ninety-five patients (77 women and 18 men) with a mean age of 52.8 ± 7.0 were included in this study. Table 1 presents the patient demographics and preoperative and postoperative radiographic measurements. There were no significant differences between the groups in terms of mean age, BMI, correction angle, or patellar height indices. The preoperative mean PTS was measured as 12.5 ± 3.9° and the postoperative mean PTS was 10.6 ± 4.3°. A paired t-test revealed a statistically significant difference of 1.9 ± 3.8° (95% confidence interval: 1.13–2.71; $p<.01$). Figure 3 presents the changes in PTS values among our cohort.

In four cases (4.2%), the PTS remained the same, while for 67 patients (70.5%) the PTS decreased and for 24 patients (25.3%) the PTS increased ($p<.01$). Further analysis showed that only 22 patients (23.2%) experienced PTS change of more than 5° ($p<.01$). Only 5 patients (%5.2) showed PTS increase more than 5° ($p<.01$). Figure 4 shows the distribution of PTS change in our cohort.

Discussion

One of the most important findings of this study is that performing the osteotomy with a posterior inclination in the sagittal plane in patients undergoing MOWHTO resulted in a biomechanically significant increase in PTS in only 5.2% of cases. While the primary aim is to correct coronal plane deformities, alterations in the sagittal plane, particularly those increasing the PTS, can lead to significant biomechanical imbalances [9]. One parameter that has gained popularity in recent years and may contribute to sagittal plane changes is the sagittal osteotomy inclination angle.

The number of clinical studies investigating the effect of the sagittal inclination angle on the PTS in the literature is limited. Generally, it is recommended to perform osteotomy parallel to the PTS to maintain slope stability [2]. However, it may not always be feasible to achieve this intraoperatively. Lee et al. implemented a surgical technique involving the placement of two Kirschner wires parallel to the PTS from the tibial medial cortex for 136 patients and aimed to perform the osteotomy parallel to the PTS, just distal to the wires. They concluded that only 12.9% of the planned parallel osteotomies were successfully performed, with 87.1% of the patients undergoing anteriorly inclined osteotomies [17]. Furthermore, they found a positive correlation between anteriorly inclined sagittal inclination angles and PTS values. The authors noted potential issues such as the attachment site of the pes anserine affecting pin placement, the misleading anterior inclination of the anterior tibial cortex directly visible in the surgical field, and the superficial medial collateral ligament not allowing free positioning of the saw during osteotomy. Moreover, one of the reasons why parallel osteotomy cannot be performed in every patient may be the variation in tibial plateau morphometry. In recent years, numerous studies have reported that the size and geometry of tibial morphometry vary across populations [1, 12, 16]. In the surgical technique, the

Table 1 Patient demographics and measurements

	Patients with increased PTS	Patients with decreased PTS	Patients with unchanged PTS	*p*
Mean BMI	29.8 ± 2.9	29.6 ± 3.0	28 ± 1.0	0.699
Age, years	53.5 ± 6.3	52.2 ± 7.3	57.2 ± 4.6	0.862
Mean correction angle	9.9 ± 1.4	9.5 ± 1.5	8.5 ± 1.2	0.122
Preoperative PTS	10.6 ± 4.1	13.2 ± 3.7	13.6 ± 2.7	0.020
Postoperative PTS	14.0 ± 3.4	9.2 ± 3.9	13.6 ± 2.7	< 0.001
Preoperative Insall-Salvati Index	1.13 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.676
Postoperative Insall-Salvati Index	1.17 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.279
Preoperative Caton-Deschamps Index	0.8 ± 0.1	0.8 ± 0.1	0.9 ± 0.2	0.478
Postoperative Caton-Deschamps Index	0.7 ± 0.1	0.8 ± 0.1	0.8 ± 0.2	0.420

PTS: Posterior tibial slope; BMI: body mass index

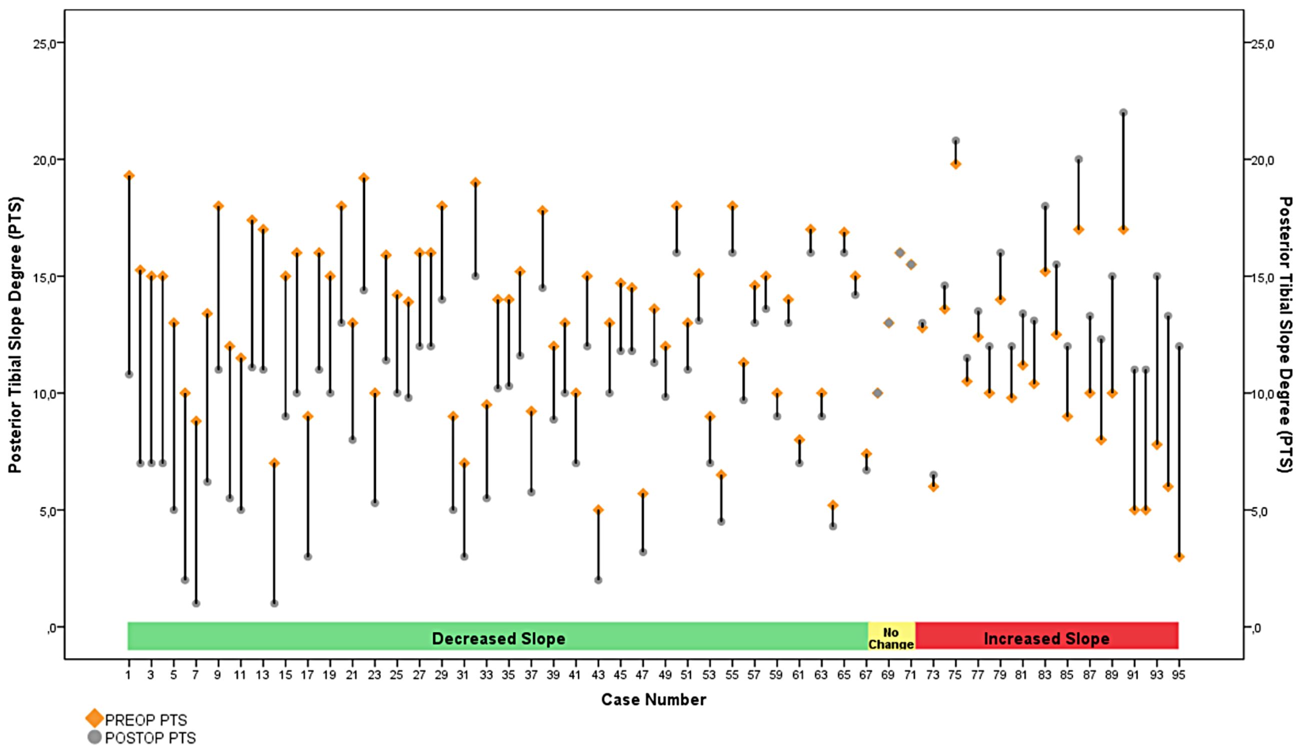

Fig. 3 Posterior tibial slope changes of the patients

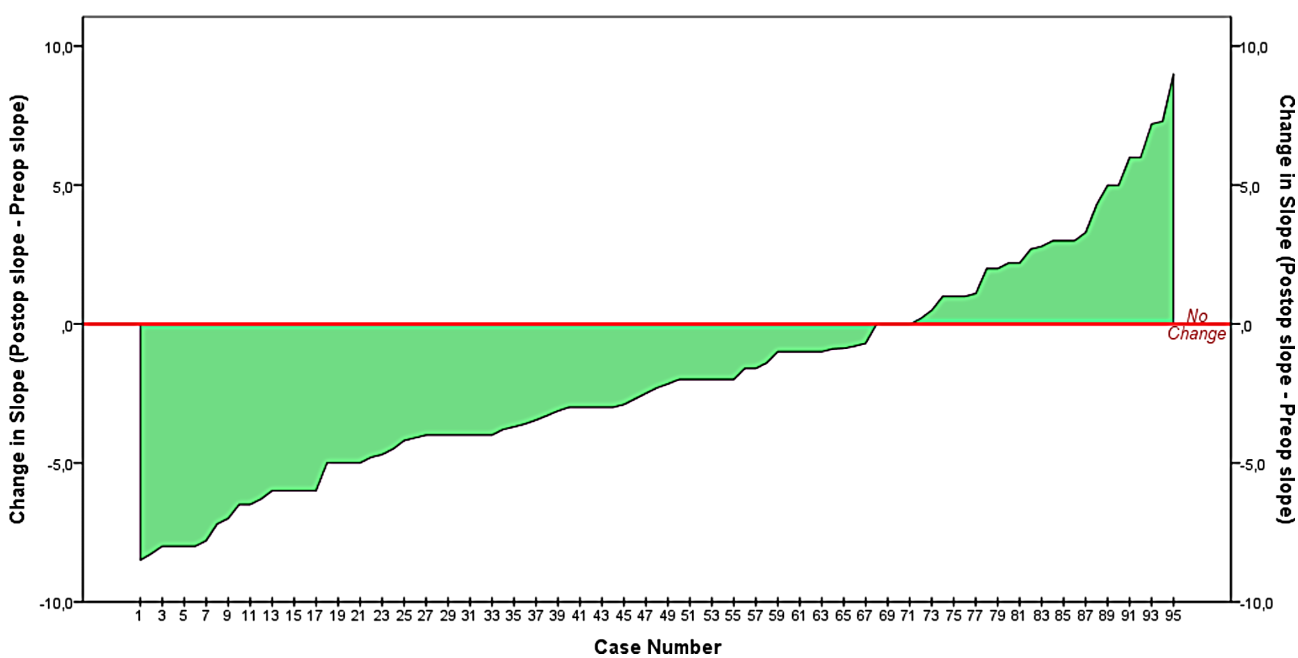

Fig. 4 Tendency of PTS change among the patients

medial tibial plateau is used as a reference when determining the sagittal inclination angle. However, a more concave medial plateau may lead to inaccuracies in fluoroscopic measurements compared to a flatter plateau. Taking into account the results of these studies, we aimed not to increase the tension on the ACL by targeting the sagittal inclination angle in a posteriorly inclined manner in our surgical technique. The current study has shown that by doing so, we achieved a reduction or maintenance of the slope in three-quarters of our cases.

Studies utilizing 3D modelling have investigated the impact of the sagittal inclination angle on the PTS.

Chung et al. performed virtual osteotomies on 3D tibial CT images [5]. They found that for each 1° increase in the absolute value of an anteriorly inclined sagittal osteotomy, the PTS increased by 0.079°, while for each 1° increase in the absolute value of a posteriorly inclined osteotomy, the PTS decreased by 0.067°. It was demonstrated that there was no significant effect on the PTS for values in the range of + 5° to -5° for the sagittal inclination angle. This study showed a mean of 1.9° reduction in the PTS with posteriorly inclined sagittal osteotomies.

In another 3D modelling study, Moon et al. conducted square column modelling, employing 3D modelling software to perform virtual osteotomies at various angles [21]. Additionally, these models were printed using a 3D printer and osteotomies were conducted experimentally. Ultimately, posteriorly inclined osteotomies were found to increase the PTS, while anteriorly inclined osteotomies decreased the PTS. Osteotomies parallel to the PTS did not alter the slope. Furthermore, an increase in the absolute value of the inclination angle corresponded to a greater change in the PTS. As the amount of correction in the coronal plane increased, the magnitude of change in the PTS also increased. The most notable difference between the two aforementioned studies is that while Chung et al. [5] found that anteriorly inclined osteotomies increased the PTS and posteriorly inclined osteotomies decreased the PTS, the study conducted by Moon et al. [21]. yielded the opposite results. The primary reason for this difference could be the hinge position. In the model by Chung et al., the osteotomy extends up to 1 cm medial to the lateral cortex, and the lever arm is placed at the midpoint. In contrast, in the model by Moon et al., a complete osteotomy is performed, and the osteotomy line is opened using a true lateral hinge. In the current study, it was found that posteriorly inclined osteotomies led to a decrease in the PTS for the majority of patients. However, in a small group of patients, an increase in the PTS was observed. This suggests that there are multiple factors influencing changes in the PTS.

The literature describes various factors that may lead to an increase in the PTS during MOWHTO [27]. For example, it has been reported that an imbalance in post-osteotomy gaps and improper placement of wedges can result in changes in the PTS [15, 24]. In osteotomies opened more anteriorly, an increase in the PTS is expected, whereas in those opened more posteriorly, a decrease in the PTS is anticipated [6]. The hinge position is another influential factor for the PTS. Jo et al. demonstrated a significant increase in PTS values in a group of patients with lower hinge placement compared to a group with standard hinge placement [14]. Although a standard surgical technique was applied by a single surgeon for our patient cohort, factors such as these may have led to an increase in the PTS, contrary to the intended outcome, in a quarter of the patients. Further studies are needed to determine the significance of the sagittal inclination angle while considering the factors affecting the PTS.

The impact of the PTS on cruciate ligament tension is well recognized [8, 10, 23]. Particularly for patients with ACL insufficiency, interventions aimed at reducing the slope are recommended during MOWHTO [10, 24]. Conversely, in patients without ACL insufficiency, maintaining a stable slope is advised. However, the number of studies investigating the effect of slope changes resulting from MOWHTO on the ACL is limited. Giffin et al. indicated in their biomechanical cadaver study that changes in slope of up to 5° after MOWHTO did not result in significant biomechanical alterations [9]. In our study, the sagittal inclination angle was adjusted posteriorly to prevent an increase in slope, with only 5 (5.2%) patients experiencing a slope increase of more than 5°. This finding suggests that a posteriorly inclined sagittal inclination angle may be beneficial, particularly for patients with slope sensitivity such as that seen in cases of ACL insufficiency. However, confirming this hypothesis requires more detailed biomechanical investigations.

This study had some limitations. First, clinical outcomes, including patient reported outcomes and complication rates, were not included in this study. Comparing the clinical outcomes and complications associated with changes in the slope will provide highly valuable insights. Second, posteriorly inclined sagittal osteotomies were performed for all patients, but the degree of the sagittal inclination angle for each patient was not recorded in this study. PTS changes were assessed based on 2D radiographs, which may not fully capture the 3D complexity of the knee joint. Third, factors such as hinge position and gap ratio, which could also influence changes in the PTS, were not included among the measurement parameters. Further studies examining sagittal inclination angles together with these confounding factors are needed.

Conclusion

Modifying the sagittal inclination angle to achieve a posteriorly inclined osteotomy during medial opening wedge high tibial osteotomy may prevent increasing the posterior tibial slope in the majority of cases.

Abbreviations

MOWHTO	Medial opening wedge high tibial osteotomy
PTS	Posterior tibial slope
ACL	Anterior cruciate ligament
ANOVA	One-way analysis of variance

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Not applicable.

Author contributions

U.O.: data collection, measurements and writing methods section, E.S.D.: writing discussions regarding surgical protocol and preparing figures and tables; Ib.B.: interpretation and writing of the radiologic results; S.K.: critical revisions and interpretation of the results. Iz.B. and D.A.O.: drafting the manuscript and coordinating the overall research project. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and the relevant institutional review board granted its approval (No. 1-234-209). Informed and written consent was obtained from all patients.

Consent for publication
Not applicable.

Clinical trial number
Not applicable.

Competing interests
The authors declare no competing interests.

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