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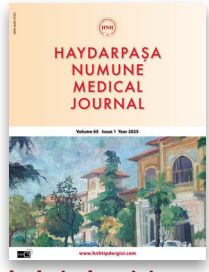

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ORIGINAL ARTICLE

The Effect of Implant Type Used in High Tibial Osteotomy on Tibial Slope Angle

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Abstract

Introduction: Knee osteoarthritis, marked by cartilage degeneration in the medial compartment, disrupts joint load balance and diminishes quality of life. Medial open-wedge high tibial osteotomy (MOWHTO) is a surgical procedure aimed at correcting these deformities. This study evaluates how different implant types used in MOWHTO affect the posterior tibial slope angle (PTSA), patellar height, and functional outcomes.

Methods: Between 2017 and 2023, a retrospective study at Yeditepe University Kosuyolu Hospital analyzed 231 patients who underwent MOWHTO. Patients were categorized based on the implant type used: symmetric blocked plate (n=179), Puddu plate (n=26), and asymmetric blocked plate (n=26). The study evaluated pre- and postoperative parameters, including PTSA, hip-knee-ankle (HKA) angle, complication rates, and patient satisfaction. Statistical analyses involved paired t-tests for continuous variables, one-way ANOVA or Kruskal-Wallis tests for group comparisons, and chi-square tests for complication rates. The normality of data distribution was assessed using the Kolmogorov–Smirnov test for groups with n≥30 and the Shapiro–Wilk test for groups with n<30.

Results: Postoperative changes in PTSA varied by implant type: the symmetric blocked plate group exhibited an average increase of +1.50°±0.85°, the Puddu plate group showed +1.90°±1.10°, and the asymmetric blocked plate group had a minimal change of +0.31°±0.65°. The mean operative time was 90.23±12.5 minutes, and the average hospital stay was 3.02±0.9 days. Patient satisfaction averaged 8.52±1.1 out of 10. Notably, the incidence of tibial plateau fractures was significantly higher in the asymmetric blocked plate group (15.38%, p=0.029).

Discussion and Conclusion: Implant types can significantly affect PTSA and surgical outcomes after MOWHTO. All symmetrical plates showed similar PTSA changes, whereas this change was lower in the asymmetrical blocked plate group. Implant selection and surgical planning are critical for optimization of surgical outcomes.

Keywords: Knee biomechanics; medial open-wedge high tibial osteotomy; posterior tibial slope.

Knee osteoarthritis (OA) is a common orthopedic problem associated with cartilage degeneration in the medial compartment of the knee, leading to varus deformity and disrupting joint load balance.[1] Medial open-wedge high tibial osteotomy (MOWHTO) is an effective surgical method to correct these deformities, reduce the medial compartment load, and relieve pain.[2] However, insufficient attention to sagittal plane factors such as posterior tibial slope (PTSA) and patellar height during surgery may increase the risk of complications and negatively affect biomechanical compliance.[3]

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Previous studies have emphasized the effect of plate types, sagittal tilt angle, and alignment correction methods used during osteotomy on PTSA change and functional outcomes.[4] However, there is no consensus on the long-term clinical impact of these parameters and the optimal surgical approach.[5] With the details of the mechanisms which govern surgical results being understood better, the postoperative recovery period can be enhanced.

The intent of the article is to determine the impact of various types of implants used during MOWHTO on the stability of the PTSA, its height, and various functional outcomes. Simultaneously, we analyze the best way to handle the sagittal plane parameters and how they affect the results in the long run. Thus, we expect this study to highlight the areas where there have been gaps in the literature in order to convey a better perception regarding surgical planning.

High tibial osteotomy (HTO) is often the surgical procedure of choice to correct knee alignment and relieve pain in medial compartment osteoarthritis. However, there are conflicting findings in the literature regarding the effects of open wedge (MOWHTO) and closed wedge (LCWHTO) techniques on posterior tibial slope (PTS) and patellar height (PH). Open-wedge osteotomy has been suggested to increase PTS and cause loss of patellar height, while some studies claim that these changes are minimal.[6]

Furthermore, the contribution of implant designs, osteotomy plane, and surgical techniques used during surgery to these changes is not fully explained. For example, it has been reported that specific implants such as Puddu plates can cause significant changes in PTS depending on the way they are applied.[7] In addition, there is limited information on surgical planning methods to prevent unwanted changes in the sagittal plane.[3] In our study, we investigated the effects of different implant types used during MOWHTO on PTS and other surgical parameters. The principal assumption of the investigation is that PTS variation and the result of the surgical procedure may differ significantly on the basis of the implant types. The influence of the implant configurations on the patient's functional biomechanical compliance as well as pleasing the patient was also assessed.

Considering these aspects will be useful in appreciating the impact of the implant choice on the functional outcomes, biomechanical compliance, and also how many complications there are. This study aims to bring the surgical techniques closer to perfection and remedy the deficits in the literature.

Materials and Methods

Our retrospective study was conducted on patients who underwent high tibial osteotomy (HTO) with a diagnosis of medial compartment osteoarthritis (MCOA) at the Orthopedics and Traumatology Clinic of Yeditepe University Kosuyolu Hospital between 2017 and 2023. The patients included in the study were divided into three groups according to the type of implant used: symmetric block plate (block plate and symmetric wedge plate combined) (n=179, 77.5%) (Group 1), Puddu plate (n=26, 11.3%) (Group 2), and asymmetric block plate (n=26, 11.3%) (Group 3). Surgical and radiologic parameters and functional outcomes were compared between the groups. Only patients who underwent medial open-wedge osteotomy, had a follow-up period of at least 4 months, and used one of the specified implant types were included in the study.

Exclusion criteria were lateral closed-wedge osteotomy, concomitant ligament surgery, revision surgery due to deep infection or nonunion, implant failure, and a follow-up period of less than 4 months. Demographic and clinical data were recorded in detail. These data included age, gender, body mass index (BMI), surgical side (right/left), type of implant used, and follow-up time. In addition, surgical complications and patient satisfaction were also assessed.

Radiologic evaluations were performed on preoperative and postoperative lateral knee radiographs. The posterior tibial slope angle (PTSA) was calculated by measuring the angle between the reference line drawn on the tibial cortex and the tibial plateau. The measurements were performed using the same method and by the same investigators. In addition to PTSA, other radiologic parameters such as hip-knee-ankle angle (HKA) were also analyzed.

Surgical procedures were performed under general or spinal anesthesia according to a standard protocol. The proximal tibia was exposed through an anteromedial longitudinal incision. The osteotomy line was planned under fluoroscopic guidance and applied gradually between the cortices. When the targeted correction angle was reached, the appropriate implant was placed. Differences between the groups were evaluated depending on the type of implant used.

Statistical Analysis

Statistical analyses were performed with paired t-test to compare preoperative and postoperative PTSA and PCA values, and one-way ANOVA or Kruskal–Wallis test

to analyze the differences between groups according to implant types. Chi-square test, as appropriate, was used to analyze the relationship between complication rates and implant types. The normality distribution of the data was checked with the Kolmogorov–Smirnov test for groups with n≥30 and Shapiro–Wilk test for groups with n<30, and it was confirmed that the continuous variables were normally distributed. Statistical significance level was accepted as $p<0.05$.

In our study, the adequacy of statistical power for each group was assessed and the methodological accuracy of the results was analyzed. In the power analysis according to Cohen's d=0.5 effect size, it was determined that the statistical power was below the targeted 80% level in two groups with the current number of patients. This was reported as a lack of power due to low sample sizes, especially in the Puddu plate and asymmetric block plate groups with only 26 patients each. To compensate for the power deficiencies, the analysis methods were carefully selected and the normality of the data was carefully checked. Accordingly, the impact of power deficiencies on the interpretation of results was taken into account (Fig. 1).

Our study was approved by the Haydarpaşa Numune Training and Research Hospital Clinical Research Ethics Committee on 03.09.2024 with the approval number HNEAH-GOAEK 2024/110. The study was conducted in accordance with the Declaration of Helsinki and informed consent was obtained from all patients.

Results

In our study, 231 patients were evaluated and the mean age was 54.1 years (range 37–74). The majority of the study group was female (83.5%) and the mean BMI was 26.2 kg/m^2. In surgical side preference, the right side was represented by 46.8% and the left side by 53.2%. The mean follow-up period was 25.2 months (range 6–48). The most commonly used implant type was the symmetric blocked plate (blocked plate and symmetric wedge plate combined) with a rate of 77.5%. The graft choice was a combination of tibial autograft and allograft with a rate of 93.1%. The mean operative time was 90.23 minutes and the mean hospital stay was 3.02 days. Patient satisfaction was found to be high with a mean score of 8.52 on a scale of 1 to 10 (Table 1).

In our study, surgical and mobilization parameters were compared according to different implant types. Preoperative PTSA values were 9.52° in the symmetrical blocked plate group, 9.93° in the Puddu plate group, and 13.98° in the asymmetrical blocked plate group, with a statistically significant difference between groups ($p<0.001$). Similar changes were observed in the postoperative PTSA values, with a change of 1.50° in the symmetric blocked plate group, 1.90° in the Puddu plate

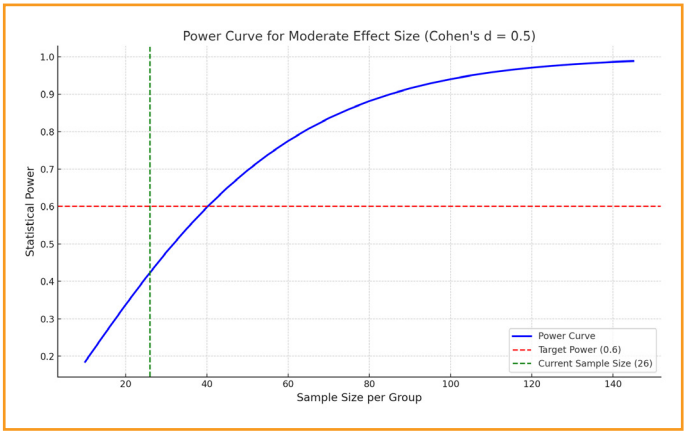

Figure 1. Power Curve for Moderate Effect Size (Cohen's d = 0.5).

Table 1. Demographic Data, Baseline Characteristics, and Surgical Parameters

Parameter	Value
Number of Patients (n)	231
Age (years)	54.1±7.3 (37–74)
Gender, n (%)	
Female	193 (83.5)
Male	38 (16.5)
Body Mass Index (BMI) (kg/m^2)	26.2±2.0 (21–31)
Side, n (%)	
Right	108 (46.8)
Left	123 (53.2)
Follow-up Duration (months)	25.2±9.9 (6–48)
Implant Type and Brand, n (%)	
Symmetric Block Plate (Blocked + Symmetric Wedge)	179 (77.5)
Puddu Plate	26 (11.3)
Asymmetric Block Plate	26 (11.3)
Graft Type, n (%)	
Tibia Auto + Allograft	215 (93.1)
Tibia Autograft	16 (6.9)
Operation Duration (minutes)	90.23±14.87
Hospital Stay (days)	3.02±1.02
Patient Satisfaction Score (1–10)	8.52±1.03

Continuous variables are presented as mean±standard deviation and (minimum–maximum). BMI: Body Mass Index. Patient satisfaction score was measured on a scale from 1 to 10.

group, and 0.31° in the asymmetric blocked plate group. The difference in PTSA change between groups was statistically significant (p=0.023). While the HKA values decreased in all groups from preoperative to postoperative assessment, this change was significantly different between groups (p=0.018), with the smallest change in the asymmetric block plate group (-1.21°) compared to the symmetric block plate (-2.33°) and Puddu plate (-2.30°) groups.

Table 2. Comparison of Implant Types, Pre-Post Values and Changes by Group

Parameter	Symmetric Block Plate (n=179)	Puddu Plate (n=26)	Asymmetric Block Plate (n=26)	p*
PTSA Measurements				
PTSA Preoperative (°)	9.52±3.33	9.93±2.64	13.98±2.47	<0.001
PTSA Postoperative (°)	11.02±3.54	11.83±3.10	14.29±2.74	<0.001
PTSA Change (°)	1.50±2.21	1.90±2.68	0.31±2.01	0.023
HKA Measurements				
HKA Preoperative (°)	10.91±1.82	11.37±2.97	10.92±0.95	0.561
HKA Postoperative (°)	8.58±1.84	9.07±2.84	9.71±0.74	0.007
HKA Change (°)	-2.33±0.98	-2.30±1.13	-1.21±0.69	0.018
Functional Scores Change				
VAS Change	-2.89±0.78	-3.15±0.82	-3.25±0.86	0.087
WOMAC Total Score Change	-19.21±7.56	-20.12±8.33	-21.45±8.91	0.354
KSS Change	19.85±8.73	20.42±9.15	20.96±8.47	0.765
Other Parameters				
Osteotomy Angle (°)	17.42±5.12	17.07±2.22	21.26±1.37	<0.001

Data are presented as mean±standard deviation. PTSA: Posterior Tibial Slope Angle; HKA: Hip-Knee-Ankle Angle; VAS: Visual Analog Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KSS: Knee Society Score; *p-values for group comparisons were calculated using one-way ANOVA or Kruskal-Wallis test as appropriate.

Table 3. Complications

Complication	Symmetric Block Plate (n=179)	Puddu Plate (n=26)	Asymmetric Block Plate (n=26)	p*
Deep Infection (n, %)	0 (0.00)	0 (0.00)	1 (3.85)	0.343
Fracture Extending to the Tibial Plateau (n, %)	10 (5.59)	1 (3.85)	4 (15.38)	0.029
Hyposensitivity in the Saphenous Nerve (n, %)	7 (3.91)	0 (0.00)	1 (3.85)	0.666
Delayed Union (n, %)	4 (2.23)	0 (0.00)	0 (0.00)	0.145
Lateral Cortex Fracture (n, %)	7 (3.91)	1 (3.85)	1 (3.85)	0.392

Data are presented as counts (n) and percentages (%). *Statistical significance was assessed using Chi-square as appropriate. †Post-hoc pairwise comparisons for fracture extending to the tibial plateau showed significant difference between Asymmetric Block Plate and Symmetric Block Plate groups (p=0.034) and between Asymmetric Block Plate and Puddu Plate groups (p=0.041), while no significant difference was found between Symmetric Block Plate and Puddu Plate groups (p=0.713).

Table 4. Comparison of Preoperative and Postoperative Values and Functional Scores

Parameter	Preoperative Mean±SD	Postoperative Mean±SD	t	df	p	Mean Change	95% Confidence Interval
PTSA (°)	10.32±3.41	11.53±3.53	6.21	230	<0.001	1.20	0.82 – 1.59
HKA (°)	10.94±1.97	8.69±1.91	28.53	230	<0.001	-2.25	-2.40 – -2.10
VAS	7.53±0.99	4.56±0.80	30.15	230	<0.001	-2.97	-3.17 – -2.77
WOMAC Total Score	55.32±9.82	35.47±4.93	22.81	230	<0.001	-19.85	-21.57 – -18.13
KSS	60.18±10.03	80.24±5.03	22.45	230	<0.001	20.06	18.30 – 21.82

Data are presented as mean±standard deviation. PTSA: Posterior Tibial Slope Angle; HKA: Hip-Knee-Ankle Angle; VAS: Visual Analog Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KSS: Knee Society Score; Statistical analysis was performed using paired t-test. df: degrees of freedom.

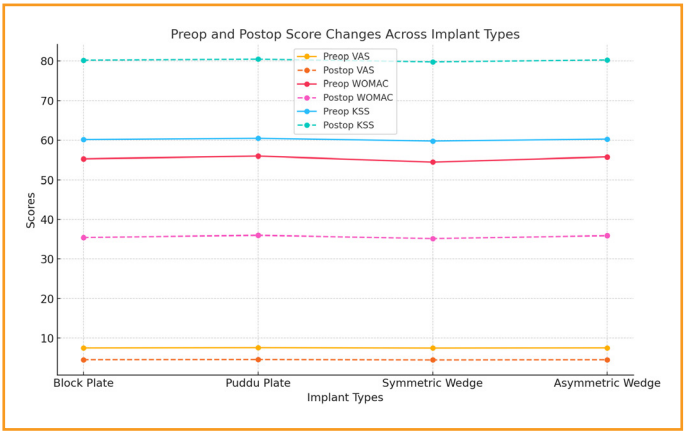

Figure 2. Preop and Postop Score Changes Across Implant Types.

The osteotomy angle reached the highest level in the asymmetric block plate group (21.26°) and this difference was statistically significant (p<0.001). When functional scores were compared between groups, the changes in VAS, WOMAC Total Score, and KSS were not statistically significant across implant types (p=0.087, p=0.354, and p=0.765, respectively) (Table 2).

When the complication rates of the different implant types were analyzed, deep infection was seen only in the asymmetric block plate group (3.85%) and not in the other groups. The rate of fracture extending to the tibial plateau was higher in the asymmetric blocked plate group (15.38%) and this difference was statistically significant (p=0.029). Loss of sensation in the saphenous nerve was observed at a rate of 3.91% in the symmetric blocked plate group, but this difference was not statistically significant (p=0.666). Delay in slipping was detected only in the symmetric blocked plate group (2.23%), whereas lateral cortex fracture was observed at similar rates in all groups (p>0.05). Overall, there were some differences in complication rates, but in most cases there was no statistically significant difference between the groups (Table 3).

When the preoperative and postoperative parameters and functional scores were compared, a significant increase in PTSA (1.20°, t=6.21, df=230, p<0.001) and a significant decrease in HKA (-2.25°, t=28.53, df=230, p<0.001) were observed postoperatively. Pain level was assessed by VAS and decreased significantly postoperatively (-2.97, t=30.15, df=230, p<0.001). There was a significant postoperative improvement in the WOMAC total score (p<0.001) and a significant increase in the KSS score (p<0.001). All of these findings were statistically significant with strong t values (Table 4) (Fig. 2).

Discussion

High tibial osteotomy (HTO) is one of the most successful surgical interventions employed in the management of medial compartment osteoarthritis. In this study, the effects of different implant types on posterior tibial slope angle (PTSA), hip-knee-ankle (HKA) angle, and functional outcomes were evaluated. The prominent features of this implant type were that symmetrical blocked plates (blocked plate combined with symmetrical wedge plate) were the most preferred implant (77.5%), the increase in postoperative PTSA (+1.50°), and the high overall patient satisfaction (8.52/10). The findings offer useful hints on the correlation between implant types and knee biomechanics after surgery, as well as on patient outcomes. This study has significance in highlighting the current literature's various limitations regarding implant types. Therefore, it is necessary to understand the effect of implant choice on surgical outcomes and to analyze these findings to guide future clinical practice.

In our study, similar PTSA changes were observed in all symmetrical implants: +1.50° in the symmetrical blocked plate group and +1.90° in the Puddu plate group. A lower change (+0.31°) was observed in the asymmetric block plate group. Changes in the posterior tibial slope angle are an important clinical issue in medial opening wedge high tibial osteotomy (MOWHTO). Song et al.[8] showed that the increase in posterior tibial slope was higher in patients with unstable lateral hinge fractures (DPS 28.1% in Type I fracture vs DPS 44.4% in unstable fracture) and that the correction angle was also effective in this increase. The study by Mabrouk et al.[9] demonstrated that the posterior tibial slope could be preserved with careful surgical technique and preoperative planning, and showed that there was no significant change in postoperative PPTA values, especially with the biplanar osteotomy technique (80.4° vs 80.6°, p=0.2). Comparing the EOS system and CT, Yoo et al.[10] showed that both imaging modalities yielded similar results in posterior tibial slope measurements (EOS: -2.96°±9.24° vs CT: 0.17°±2.73°, p=0.142). Zheng et al.[11] compared uniplane and biplane osteotomy techniques and showed that the postoperative PTS increase was more pronounced in the biplane group (16.6° vs 13.4°, p<0.001) and may affect patellofemoral joint function. The study by Chen et al.[12] showed that the use of wedge-shaped cancellous allograft yielded good results in terms of both bone healing and stability, PTSA was preserved in postoperative radiographic evaluation, and clinical scores were significantly improved (KSS-Knee score: increased from 55.4±3.7 to 86.4±2.8, p<0.001).

In our academic study, we observed an average postoperative decrease of -2.25° in the hip-knee-ankle angle (HKA) values and an average osteotomy angle of 21.26° in the asymmetric block plate group. The osteotomy angles measured as 17.42° in the symmetrical blocked plate group and 17.07° in the Puddu plate group showed similar values in the symmetrical implants. This significant reduction in the AUC indicates that the load on the medial compartment was effectively reduced and overloading of the lateral compartment was avoided.[13] Osteotomy angle values reflect the mechanical correction capacities of the implant types, and similar results were obtained especially with symmetrical implants (symmetrical blocked plate and Puddu plate). According to the findings from the literature, medially angulated wedged high tibial osteotomy (OWHTO) is an effective method to correct the mechanical axis in the knee. For example, a meta-analysis reported that OWHTO increased the posterior tibial slope, but successfully optimized the femoro-tibial angle and ROM.[13] It is also emphasized that proper surgical planning and implant selection reduce complication rates and improve functional outcomes.[14]

Postoperatively, the WOMAC total score improved significantly, decreasing by -19.85 points. Similarly, the pain score (VAS: -2.97) and CSR (+20.06) also improved significantly postoperatively. These findings suggest that functional outcomes generally change favorably after high tibial osteotomy (HTO). In the literature, a similar improvement in WOMAC score was observed after medial open-wedge osteotomies, and it was reported that this procedure decreased pain and increased functional capacity.[15] Patient satisfaction was quite high in the blocked plate group (8.52/10). In the literature, it has been reported that early postoperative mobilization may reduce complication rates at the osteotomy site and increase patient satisfaction.[16]

The high rate of tibial plateau fracture in the asymmetric wedge plate group (15.38%) indicates that the biomechanical effects of these implants on the tibial plateau should be considered. In the literature, it has been reported that such implants may affect the biomechanical load distribution on tibial plateau fractures.[17] Especially this group has been emphasized to increase the risk of complications such as lateral hinge fractures. In addition, the higher incidence of saphenous nerve sensory loss in the symmetrical wedge plate group (8.77%) may be related to the effects of these implants on local nerve tissue. In the literature, the prevalence of complications such as nerve effects after tibial plateau surgery has been discussed, and these results are consistent with similar findings in the literature.[18] The rate of deep infection was observed in only one case (asymmetric wedge plate group, 3.85%), indicating that the risk of infection is generally low. It has been reported in the literature that infection rates in tibial plateau surgery are generally low, but the implants and surgical techniques used may affect this risk.[19]

The methodological approaches and analysis methods used in our article aimed to increase the accuracy of the research results. However, statistical power adequacy could not be achieved due to the low sample size, especially in the symmetric and asymmetric wedge plate groups. The power analysis results showed that the number of participants was not sufficient for Cohen's d=0.5. However, the data were rather consistent, and the research was conducted following all methodological guidelines, which also contributed to the enhancement of the trustworthiness of the results.

Nevertheless, the methodologically homogeneous conduct of the study and careful planning of statistical analyses increased the reliability of the results obtained. In particular, the assessment of postoperative radiologic and clinical parameters in great detail helped to better understand the effects of implant types on tibial slope and function. Therefore, the study also employed modern methods during data analysis to increase the scientific strength of the study.

It is therefore suggested that in future research studies, more participants should be involved and the research should be conducted across different centers. This will enhance the transferability of the findings and help to establish the results in a wider context. Although the results of different implant types can be compared for their long-term effects, future studies should be based on randomized controlled trials. An approach like this may enable a systematic assessment of other variables such as the rate of complications and patients' satisfaction. Also, the application of sophisticated imaging studies may enhance the efficacy of both preoperative and postoperative assessments.

Conclusion

Our study clearly demonstrated the effects of different implant types used in high tibial osteotomy on clinical outcomes. Our findings showed that especially symmetrical implants (symmetrical blocked plate and Puddu plate) were characterized by high patient satisfaction (8.52/10) and similar complication rates. Posterior tibial slope changes were similar and acceptable in both symmetrical implant groups (symmetrical blocked plate: +1.50°, Puddu plate: +1.90°). The results of our study showed that symmetrical implants were successful in maintaining the

posterior tibial slope angle. The high rate of tibial plateau fracture in the asymmetric blocked plate group (15.38%, p=0.029) emphasizes the importance of patient selection and surgical technique in the use of this implant type. The significant improvement in functional scores observed in all groups supports high tibial osteotomy as a successful treatment option in appropriate indications.

Ethics Committee Approval: The study was approved by Haydarpaşa Numune Training and Research Hospital Clinical Research Ethics Committee (No: 2024/110, Date: 03.09.2024).

Conflict of Interest: The authors declare that there is no conflict of interest.

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