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ORIGINAL ARTICLE

Early gait recovery following medial open-wedge high tibial osteotomy: A prospective gait analysis study

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ABSTRACT

Objectives: This study aims to evaluate the effects of medial open-wedge high tibial osteotomy (OWHTO) on gait analysis outcomes in patients with medial compartment osteoarthritis and varus alignment of the knee.

Patients and methods: This prospective, observational study included a total of 22 patients who underwent biplanar medial OWHTO between February 2023 and March 2024 were included. Gait analysis was performed preoperatively and at the sixth postoperative month using the 4D Diers Formetric system. Early postoperative (6 months) gait parameters, angular parameters (tibial slope and correction angle), and joint kinematics were evaluated. Patient-reported outcomes were obtained using the Oxford Knee Score (OKS) to assess pain and physical function before and after the procedure.

Results: Of a total of 22 patients included in the study, 4 were male and 18 were female with a mean age of 55.41 ± 5.86 (range, 47 to 63) years. Postoperatively, patients' walking speed (0.83 ± 1.12 m/s), step length (0.58 ± 0.73 m), and cadence (82.72 ± 92.05 steps/min) increased significantly ($p < 0.001$). The tibial slope angle showed a mean increase of 1.93° ($p < 0.001$). The mean correction angle was 7.53°. The mean knee flexion increased significantly from 35.05° ± 8.74° preoperatively to 52.96° ± 13.21° postoperatively ($p < 0.001$). Knee extension improved minimally but significantly from –7.55° ± 1.18° to –6.03° ± 0.05° ($p = 0.046$). Ankle dorsiflexion increased significantly ($p < 0.001$), whereas changes in plantar flexion were not statistically significant. The OKS score increased significantly from 18.30 preoperatively to 41.50 at the sixth postoperative month ($p < 0.001$).

Conclusion: Medial OWHTO results in early improvements in walking speed, step length, and cadence, as well as enhanced knee flexion kinematics and patient-reported outcomes. These findings indicate that OWHTO is an effective surgical option contributing to the improvement of gait patterns in the early postoperative period.

Keywords: Gait analysis; high tibial osteotomy, knee osteoarthritis, medial open-wedge osteotomy, Oxford knee score.

The knee joint is a complex structure resistant to mechanical stress occurring during range of motion (ROM) and weight-bearing activities. The biomechanical function of the knee joint depends on the alignment of the lower extremity. Deteriorations in lower extremity alignment may lead to imbalances in intra-articular load distribution, thereby predisposing to medial compartment osteoarthritis, varus deformities, ligament injuries, meniscal and cartilage pathologies.[1]

High tibial osteotomy (HTO) is a joint-preserving surgical method aimed at shifting the load passing

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through the joint region exposed to continuous loading or weight from medial to lateral, and thereby realigning the lower extremity.[2,3] It is frequently preferred as an alternative to joint replacement, particularly in young and active patients with medial compartment osteoarthritis and varus deformity, to halt or slow the possible progression of joint degeneration. When performed in appropriately selected patients with proper surgical technique, successful short- and mid-term clinical outcomes have been reported.[4,5]

Gait analysis is an important tool for evaluating functional changes related to knee pathology in patients. Observational, kinetic, and kinematic data obtained during gait analysis allow objective, reliable, archivable, and repeatable comparisons in the assessment of patients' clinical outcomes and treatment effectiveness.

Review of the literature reveals that outcomes after HTO are mostly evaluated based on clinical scores or limited gait parameters. Studies addressing the biomechanical and functional effects of surgical correction in a holistic manner are limited.

In the present study, we aimed to investigate the effects of medial OWHTO performed using a biplanar technique preserving the proximal position of the tibial tuberosity in patients with medial compartment osteoarthritis and varus alignment on gait parameters in the early postoperative period compared to the preoperative period.

PATIENTS AND METHODS

This single-center, prospective, observational study was conducted at Ankara Bilkent City Hospital, Department of Orthopedics and Traumatology between February 2023 and March 2024. Out of 29 patients who underwent biplanar medial OWHTO, 22 were included in the study. Inclusion criteria were as follows: age 40 years or older, isolated medial compartment osteoarthritis, varus knee alignment (< 15°), intact lateral compartment, stable knee without instability, active lifestyle, and ability to attend routine follow-ups. Exclusion criteria were as follows: having neurovascular conditions affecting gait, pathology in other lower extremity joints, prior surgery on the same or contralateral limb, body mass index (BMI) > 35 kg/m², smoking, and having rheumatic diseases. Accordingly, five patients declined to participate, one patient did not undergo surgery, and one patient refused to attend scheduled follow-ups. A written informed consent was obtained from each patient. The study protocol was approved by the Ankara City Hospital Clinical Research Ethics Committee (Date: 08.02.2023, No.: E1/3246/2023). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Preoperative evaluation

Patients' pain and complaints were evaluated using the Oxford Knee Score (OKS) prior to surgery. Detailed physical examination and radiological assessments (knee radiographs, tibial slope measurement, and lower extremity mechanical varus angle evaluation) were performed. Correction degrees were calculated based on the Fujisawa point. Preoperative gait analysis was performed in the laboratory using the DIERS Formetric 4D Motion® System (DIERS International GmbH, Wiesbaden, Germany).

Surgical technique

Patients were placed in the supine position under spinal or regional anesthesia. A pneumatic tourniquet was applied proximally on the operated leg. The extremity was sterilized, considering the potential need for iliac crest autograft. Diagnostic arthroscopy was routinely performed through anteromedial and anterolateral portals. The patellofemoral joint, medial and lateral compartments, menisci, cruciate ligaments, presence of plica, and osteochondral lesions were evaluated. Necessary arthroscopic interventions were performed and documented. A C-arm fluoroscopy unit was prepared. Anatomical landmarks were marked on the skin. Skin incision was made from the midpoint between the posteromedial and anterior cortices of the tibia, 1 cm distal to the joint line, in an oblique manner of 6 to 8 cm. The infrapatellar branch of the saphenous nerve was preserved. Sartorial fascia and pes anserinus were elevated to expose the superficial medial collateral ligament (MCL) fibers. The superficial MCL was carefully detached from the tibial insertion to expose the posteromedial cortex of the proximal tibia. A radiolucent Hohmann retractor was placed posterior to the tibia. The medial border of the patellar tendon originating from the tibial tuberosity was exposed at the anterior edge of the incision. The leg was, then, placed in full extension, and fluoroscopy was positioned to obtain a true anteroposterior (AP) view of the knee. The medial and lateral compartments were confirmed to be symmetrically aligned, the patella was positioned anteriorly, and approximately one-third of the fibular head was overlapped by the tibia. Under fluoroscopic guidance, the plate was temporarily positioned on the proximal tibia. The proximal screw holes were confirmed to remain proximal to the osteotomy line, and the guide line was marked. The goal was to ensure that all proximal screw holes remained in the bone block above the osteotomy line. Two 2.3-mm guidewires were inserted parallelly under fluoroscopic guidance, targeting approximately the proximal one-third of the tibiofibular joint. The inter-wire distance was confirmed to be approximately 2 cm, ending at the lateral cortex. The adequacy of the proximal tibial segment for all screws in the longitudinal direction was confirmed. The patellar tendon and tibial tuberosity were used to plan the osteotomy. To protect posterior neurovascular structures, the knee was flexed. Posterior, medial, and anteromedial osteotomy cuts were made with a fine saw, parallel to the tibial slope, starting approximately 1 to 2 cm posterior to the tibial tuberosity and leaving approximately 1 cm to the lateral cortex. In the biplanar osteotomy, a second cut was made from 1 to 2 cm posterior to the tibial tuberosity at approximately 120° to 130° anterosuperiorly. The osteotomy was completed from the proximal side, leaving the distal segment of the tibial tuberosity intact. Irrigation was applied during sawing to prevent osteonecrosis. Controlled widening of the osteotomy was performed using long and broad osteotomes while preserving the lateral cortex, with fluoroscopic control. The posterior cortex was confirmed to be fully cut. After sufficient opening, a lamina spreader was placed as posteriorly as possible to prevent an increase in tibial slope. The pre-calculated correction was gradually achieved and measured using a sterile ruler. Fluoroscopic cable testing was performed to confirm mechanical alignment. The plate was inserted distally through a subcutaneous tunnel. The longitudinal arm of the plate was aligned with the tibial diaphysis to avoid anterior or posterior cortical protrusion. Proximal locking screws were, then, placed subchondrally near the joint line using the cutting guide. Temporary fixation was achieved with Kirschner wires (K-wires). After drilling with a 4.3-mm drill bit, three proximal screws were inserted. One distal screw was placed as a non-locking cortical screw to approximate the plate to the bone. Distal locking screws were inserted through small incisions, and the temporary cortical screw was replaced with a locking screw. Iliac crest autograft was applied to the osteotomy gap, if necessary. Two-plane fluoroscopic images were obtained for documentation. The tourniquet was released, and hemostasis was achieved. Soft tissue and skin were closed anatomically in layers to ensure adequate coverage of the implant.

Postoperative follow-up

Postoperative prophylaxis included cefazolin and deep vein thrombosis prevention. Isometric quadriceps exercises were initiated on the first day, and patients were mobilized without weight-bearing using crutches. From the first day, knee flexion exercises were prescribed as tolerated. Partial weight-bearing was allowed at the third week, and full weight-bearing at the fifth week.

Bilateral leg-length radiographs and standard AP knee radiographs were obtained at postoperative 21 and 90 days. Healing times were recorded, and close wound monitoring was performed. Two patients developed early blisters around the incision, which resolved with elevation and cold application. No delayed union or other wound-related complications were observed.

On postoperative Day 180, gait analysis, OKS evaluation of pain and physical function, and radiographs (leg-length and two-plane knee radiographs) were obtained. Gait analysis was performed by a physiotherapy and rehabilitation specialist, and the data were documented.

Gait analysis

Gait analysis was performed preoperatively and postoperatively (at six months) using the DIERS Formetric 4D Motion® System. During the measurements, spinal or muscle activity was not evaluated; only lower extremity kinematic parameters were analyzed. To determine lower extremity segment movements, reflective markers were placed on anatomical reference points detected by the system's optical sensors. The markers were placed sequentially on the anterior superior iliac spine, greater trochanter prominence, midpoint of the gluteal curve, lateral femoral epicondyle, posterior midpoint of the knee joint, midpoint of the tibia, lateral malleolus prominence, Achilles tendon, posterior midpoint of the calcaneus, and the head of the second metatarsal. After marker placement, patients were instructed to walk barefoot on the walking platform at their natural walking speed while maintaining their normal posture.

Before each measurement, the device was calibrated in accordance with the manufacturer's guidelines, and three consecutive gait cycles were recorded from each patient; mean values were used for analysis. Using the specified reference

TABLE I
Descriptive characteristics of the patients included in the study (n = 22)

Variables	n	%
Age (year)		
Under 40	5	22.7
40-60	17	77.3
Sex		
Female	18	81.8
Male	4	18.2
Body mass index		
Under weight	1	4.5
Normal weight	12	54.5
Over weight	9	40.9

points, hip, knee, and ankle joint angles as well as gait parameters (step length, step width, walking speed, and stance and swing phase durations) were calculated. All measurements were performed independently of the surgical team and by the same physiotherapist.

Assessment tools and endpoints

The OKS, which was developed by Dawson et al.,[6] is a short patient-reported outcome measure initially designed to assess pain and physical function in patients undergoing total knee arthroplasty. It is considered one of the most reliable and valid knee-specific patient-reported outcome measures.[7] In addition, it is widely used in patients undergoing viscosupplementation,[8,9] osteotomy,[10] tibial plateau fracture,[11] and osteoarthritis.[12,13] The OKS consists of a 12-item questionnaire completed by the patient. Each item is scored from 0 to 4 (0 = worst knee function, 4 = best knee function). The total score ranges from 0 to 48.[6]

The primary endpoint was the OKS, as it is a patient-reported outcome measure, clinically meaningful, and directly reflects the aim of the study. Secondary endpoints were the gait parameters, joint kinematics, and angular measurements.

Statistical analysis

The study was planned as a pilot study; the sample size was determined prospectively, and no *a priori* power analysis was performed. However, in the *post-hoc* power analysis conducted based on the OKS, which was defined as the primary endpoint of the study, the statistical power of the study was calculated as 98%, considering the observed effect size ($r \approx 0.92$), sample size ($n = 22$), and significance level ($\alpha = 0.05$).

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). The normality of data distribution was evaluated using the skewness, kurtosis, and the Shapiro-Wilk test. Since normal distribution was not achieved, non-parametric tests were used. Continuous data were presented in mean ± standard deviation (SD) or median (min-max), while categorical data were presented in number and frequency. Pre- and postoperative measurements were compared using the Wilcoxon signed-rank test. The direction of change was interpreted by comparing pre- and postoperative mean values. A p value of < 0.05 was considered statistically significant.

RESULTS

Of a total of 22 patients included in the study, 4 were male and 18 were female with a mean age of 55.41 ± 5.86 (range, 47 to 63) years. Demographic characteristics of the participants included in the study are presented in Table I.

The angular parameters of patients who underwent HTO, specifically tibial slope angles and correction angles, were analyzed. The results of these analyses in the preoperative and postoperative periods are presented in Table II. The mean tibial slope angle was 4.09° ± 0.43° preoperatively and 6.02° ± 0.79° postoperatively. The mean difference in the slope angle was 1.93° and this finding was statistically significant ($p < 0.001$). The correction

TABLE II
Comparison of mean scores of patients' angular parameters

	Preoperative	Postoperative 6th month		
Variables	Mean ± SD	Mean ± SD	z	*p*
Tibial slope angles (°)	4.09 ± 0.43	6.02 ± 0.79	–4.867	**< 0.001**
Varus angles (°)	8.67 ± 1.23	1.14 ± 0.98	–4.015	**< 0.001**

SD, standard deviation. In the Wilcoxon signed-rank test, the sign of the z value depends on the direction of the differences; therefore, the direction of increase or decrease was interpreted by comparing the preoperative and postoperative mean values.

angles were measured as follows: the mean varus angle was 8.67° ± 1.23° preoperatively and 1.14° ± 0.98° postoperatively, indicating a statistically significant difference ($p < 0.001$). The mean correction angle was 7.53°, which falls within the optimal correction range of 7° to 9° reported in the literature and is considered clinically significant.

In Table III, when joint angles were compared between the preoperative period and the sixth postoperative month, a significant increase in hip flexion was observed (preoperative 22.41° ± 4.52°; postoperative 28.18° ± 4.28°). Hip extension also showed a similarly significant increase in the postoperative period (preoperative 9.41° ± 2.91°; postoperative 11.86° ± 3.14°). Knee flexion increased from 35.05° ± 8.74° preoperatively to 52.96° ± 13.21° postoperatively, and this increase was statistically significant ($p < 0.001$). Knee extension showed minimal, but statistically significant improvement in the postoperative period (preoperative –7.55° ± 1.18°; postoperative –6.03° ± 0.05°; $p = 0.046$). Examination of ankle ROM revealed a marked increase in dorsiflexion postoperatively ($p < 0.001$). In contrast, although plantar flexion decreased postoperatively, this change was not statistically significant ($p > 0.05$).

In the changes of joint ROM (°), there was no statistically significant difference in hip joint ROM scores between the preoperative period and the sixth postoperative month (preoperative 36.55° ± 6.63°; postoperative 37.59° ± 5.85°; $p = 0.462$) (Table IV). In contrast, a marked increase was observed in knee joint ROM in the postoperative period (preoperative 56.50° ± 8.29°; postoperative 74.95° ± 13.21°; $p < 0.001$). This increase was consistent with improved knee function due to corrected load distribution and reduced pain.

In the gait analysis performed preoperatively and at sixth postoperative month, postoperative increases in total step length (0.58 → 0.73 m), cadence (82.72 → 92.05 steps/min), and walking speed (0.83 → 1.12 m/s) were statistically significant (all $p < 0.001$). In contrast, total step time (2047.23 → 1547.77 ms) and walking duration (5.25 → 5.11 s) decreased significantly postoperatively (Table V). Step time was observed to shorten in parallel with the increase in walking speed. Since the patients walked on the same platform over the same distance, the walking path parameter could not be evaluated.

The OKS was used to evaluate pain and physical function in our patients. Accordingly, the mean increase in total OKS scores in HTO patients between pre- and postoperative periods was 23.2 points, and this increase was statistically

TABLE III
Comparison of mean scores of changes in patients' joint kinematics

	Preoperative	Postoperative 6th month		
Variables	Mean ± SD	Mean ± SD	z	*p*
Hip flexion angle (°)	22.41 ± 4.52	28.18 ± 4.28	–4.181	**<0.001**
Hip extension angle (°)	9.41 ± 2.91	11.86 ± 3.14	–2.075	0.038
Knee flexion angle (°)	35.05 ± 8.74	52.96 ± 13.21	–4.134	**<0.001**
Knee extension angle (°)	–7.55 ± 1.18	–6.03 ± 0.05	–2.000	0.046
Ankle dorsiflexion angle (°)	10.86 ± 3.93	22.18 ± 13.45	–2.839	**<0.001**
Ankle plantar flexion angle (°)	6.14 ± 5.74	2.73 ± 3.41	–1.202	0.229

SD, standard deviation. In the Wilcoxon signed-rank test, the sign of the negative z value depends on the direction of the differences; therefore, the direction of change was interpreted by comparing the mean values of preoperative and postoperative measurements.

TABLE IV
Comparison of patients' mean joint range of motion scores

	Preoperative	Postoperative 6th month		
Variables	Mean ± SD	Mean ± SD	z	*p*
Hip range of motion (°)	36.55 ± 6.63	37.59 ± 5.85	–0.735	0.462
Knee range of motion (°)	56.50 ± 8.29	74.95 ± 13.21	–4.134	**<0.001**

SD, standard deviation. The Wilcoxon signed-rank test was used. The direction of the change was evaluated by comparing the preoperative and postoperative mean values.

TABLE V

Comparison of patients' gait parameters

Variables	Period	n	Mean ± SD	z	*p*
Total step length (m)	Preoperative	22	0.58 ± 0.09	–10.348	**< 0.001**
	Postoperative 6th month	22	0.73 ± 0.13		
Total step time (ms)	Preoperative	22	2047.23 ± 952.60	4.012	**< 0.001**
	Postoperative 6th month	22	1547.77 ± 484.01		
Cadence (steps/min)	Preoperative	22	82.72 ± 10.36	*	*
	Postoperative 6th month	22	92.05 ± 6.43		
Walking path (m)	Preoperative	22	2.73 ± 0.83		
	Postoperative 6th month	22	2.73 ± 0.83		
Walking speed (m/s)	Preoperative	22	0.83 ± 0.30	–10.000	**< 0.001**
	Postoperative 6th month	22	1.12 ± 0.28		
Walking duration (s)	Preoperative	22	5.25 ± 0.26	2.806	0.011
	Postoperative 6th month	22	5.11 ± 0.21		

SD, standard deviation; * Analysis could not be performed because the preoperative and postoperative 6th month scores were identical. The Wilcoxon signed-rank test was used. The direction of change was evaluated by comparing the preoperative and postoperative mean values.

TABLE VI

Comparison of patients' mean OKS scores in the preoperative and postoperative periods

	Preoperative	Postoperative 6th month		
Variables	Mean ± SD	Mean ± SD	z	*p*
OKS	18.30 ± 2.35	41.50 ± 2.39	–4.308	**< 0.001**

SD, standard deviation; OKS, Oxford Knee Score. The Wilcoxon signed-rank test was used. The direction of change was evaluated by comparing the preoperative and postoperative mean values.

significant in the paired comparison ($p < 0.001$) (Table VI). The effect size was calculated as $r \approx 0.92$, indicating a "very large" effect.

DISCUSSION

In the present study, we investigated the effects of medial OWHTO performed using a biplanar technique preserving the proximal position of the tibial tuberosity in patients with medial compartment osteoarthritis and varus alignment on gait parameters in the early postoperative period compared to the preoperative period. The innovative aspect of this study is the combined evaluation of joint kinematics, tibial slope change, and patient-reported outcomes using multidimensional gait analysis in the early period (at six months) after biplanar medial OWHTO. The main findings of this study were that medial OWHTO significantly improved walking speed, step length, and cadence, enhanced knee flexion and ankle dorsiflexion during gait, and markedly improved OKS outcomes. Furthermore, the procedure achieved the intended correction angle while maintaining only a minimal increase in posterior tibial slope (PTS), indicating that early functional recovery can be achieved without clinically meaningful alterations in sagittal tibial alignment. These findings suggest that biplanar medial OWHTO is an effective surgical option for improving early gait function and patient-reported outcomes while achieving satisfactory coronal correction with minimal changes in PTS.

In our study, we observed a significant increase postoperatively in walking speed, total step length, and cadence values. A decrease in total step time was also detected. The increase in walking speed and step length indicates an improvement in the propulsive force generated per step, while the rise in cadence reflects an enhancement in cyclical gait rhythm. This pattern is consistent with the redistribution of load from the medial to the lateral compartment and the reduction of the knee adduction moment following HTO and is in parallel with the biomechanical outcomes reported in the literature.[2,4,6-8,14]

Changes in the tibial slope angle are among the key parameters affecting knee biomechanics, particularly after HTO. The literature reports that tibial slope increases after HTO usually range between 1° and 3°, and excessive increases may adversely affect anterior knee stability.[8,9] In our study, a postoperative tibial slope increase of 1.93° was observed, which is clinically tolerable. However, the potential increase in PTS should not be overlooked, as it may elevate anterior tibial translation and strain on the anterior cruciate ligament (ACL). Posterior tibial slope is considered an important biomechanical parameter influencing knee stability in the sagittal plane. As the PTS increases, the tibia tends to translate anteriorly relative to the femur. The primary structure preventing this anterior translation is the ACL. Experimental and biomechanical studies have shown that increases in PTS lead to greater anterior tibial translation and increased strain on the ACL.[9,15,16] Even small increases in PTS under axial loading can facilitate anterior tibial displacement and alter knee kinematics. Therefore, an increased PTS is recognized as a potential risk factor contributing to ACL insufficiency and knee instability.

Undesired increases in PTS after medial OWHTO have long been recognized as a significant risk. Technical factors such as the osteotomy line orientation, wedge opening amount, and fixation method can influence sagittal plane changes.[17] Accordingly, PTS increases after OWHTO remain a well-documented concern that should be considered in surgical planning. However, the clinical impact of increased PTS is particularly debated within the typical OWHTO patient population. Of note, OWHTO is primarily performed in patients with medial compartment osteoarthritis who are middle-aged, elderly, or have relatively low activity levels. Clinical studies have shown that even when PTS increases postoperatively, this does not necessarily result in clinically significant ACL insufficiency or symptomatic instability. Therefore, the anterior translation observed biomechanically does not always translate into functional instability in this population, and clinical effects may vary according to patient characteristics.

Recent studies have suggested that increased PTS after OWHTO may not only have mechanical implications, but may also be associated with degenerative changes in the ACL.[18] However, these findings cannot be generalized to all patient groups, and their clinical relevance is considered limited in osteoarthritic patients with low activity levels. In the light of these discussions, surgical techniques have undergone significant evolution. Contemporary technique-focused studies indicate that careful planning of the osteotomy angle in the sagittal plane and modification of the osteotomy line can reduce or stabilize PTS increases.[16,19] This reflects practical shifts in surgical approaches reported in the literature. Consequently, the surgical objectives now include not only correcting deformity, but also preserving the sagittal plane slope.

Failure to control the sagittal plane during HTO can lead to increased PTS, thereby elevating anterior shear forces during gait. This, in turn, may increase load and strain on the ACL, raising the risk of instability.[15,16] Although short-term correction of the mechanical axis improves gait parameters, increased PTS may increase long-term ACL loading and further elevate instability risk. Therefore, long-term follow-up to assess knee stability is crucial. In our study, the mean correction angle was 7.53°. This angular change aligns with the 7° to 9° correction range reported in the literature to be associated with successful outcomes, supporting the accuracy of the surgical technique applied in our study. Postoperative studies with similar designs have shown that adequate correction of joint alignment results in clinically beneficial outcomes.[2,20,21] This level of mechanical axis shift from the medial to lateral compartment is sufficient to prevent complications associated with over- or under-correction. Therefore, our findings are consistent with the literature in terms of both technical efficacy and preservation of biomechanical balance, and are clinically meaningful.

In the present study, medial OWHTO was associated with favorable changes in lower-extremity joint kinematics during gait. Although increases in hip flexion and extension did not reach statistical significance, these trends may reflect adaptations to increased walking speed and compensatory mechanisms during the terminal swing phase. Previous studies have shown that proximal tibial osteotomies can alter hip kinetics and kinematics by modifying lower-limb alignment, resulting in bidirectional kinematic changes depending on the degree of correction.[11] In contrast, knee kinematics improved significantly, with increased knee flexion and a modest improvement in knee extension. These improvements are likely attributable to pain relief, redistribution of the mechanical load across the knee joint, and enhanced quadriceps function following realignment, thereby contributing to improved gait performance. At the ankle, dorsiflexion increased significantly after surgery, suggesting more physiological load transfer during gait, whereas the reduction in plantar flexion was not statistically significant, indicating that distal adaptations may vary among individuals.[4] Moreover, the extent of angular correction achieved during HTO has been reported to influence lower-extremity joint kinematics, and postoperative knee and ankle motion has been shown to approach values observed in healthy individuals.[14,22] Our findings are consistent with these previous reports and support the beneficial effects of medial OWHTO on restoring more physiological gait mechanics during the early postoperative period.

Furthermore, we observed a significant improvement in OKS following HTO. This result is consistent with reduced medial compartment loading and mechanical correction. Our findings align with previous studies reporting marked improvements in patient-reported outcomes following HTO.[23-25] Large series and multi-center studies have reported that the mean OKS often reaches 40 to 43 points at one year postoperatively or in the early to mid-term period; this range corresponds closely to the mean postoperative value in our study (41.50 points).[26] Several studies have also indicated that pain scores decrease progressively over time after HTO, starting in the early postoperative period (six months and beyond) which, in turn, improves patients' adaptation to daily life activities.[20,23,26,27]

The main strengths of our study include its prospective design, preoperative-to-postoperative comparison within the same cohort, implementation of a standardized surgical protocol, and evaluation of gait analysis data by a physiotherapist independent of the surgical team. Nevertheless, there are several limitations that should be acknowledged. The absence of a healthy control group or comparison with the contralateral limb limits the interpretation of postoperative gait normalization. The relatively small sample size (n = 22) may have limited the statistical power to detect subtle differences in some variables. In addition, the follow-up period was restricted to six months, precluding assessment of the long-term effects of medial OWHTO on gait mechanics and functional outcomes. Finally, gait analysis was performed under standardized laboratory conditions, which may not fully reflect patients' gait patterns during daily activities.

In conclusion, medial OWHTO resulted in early improvements in gait speed, step length, and cadence, together with enhanced knee flexion kinematics. These findings, combined with reduced pain and improved patient-reported functional outcomes, suggest that the procedure contributes to improved gait patterns and quality of life. Achieving optimal mechanical axis alignment remains a key determinant of successful HTO, as appropriate patient selection and accurate correction can reduce medial compartment loading, alleviate pain, and facilitate the restoration of more physiological gait mechanics. Further large-scale studies with longer follow-up are warranted to determine the durability of these improvements and to establish whether optimal alignment targets should be individualized according to patient characteristics.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: M.M.E.: Concept/idea, design, supervision/control, data collection and processing, analysis and interpretation, critical review, literature search, manuscript writing; Ö.S.U.: Manuscript review and editing; J.H., G.J.: Literature search; U.Ö.: Manuscript writing; E.A.: Analysis, processing, and interpretation of gait analysis data; O.T., D.A.Ö.: Concept/idea, design, critical review.

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