Restoration of Native Leg Length After Opening-Wedge High Tibial Osteotomy

An Intraindividual Analysis

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Background: Opening-wedge high tibial osteotomy (OWHTO) has been shown to significantly increase leg length, especially in patients with large varus deformity. Thus, the current literature recommends closing-wedge high tibial osteotomy to correct malalignment in these patients to prevent postoperative leg length discrepancy. However, potential preoperative leg length discrepancy has not been considered yet.

Hypothesis: It was hypothesized that patients have a decreased preoperative length of the involved leg compared with the contralateral side and that OWHTO would subsequently restore native leg length.

Study Design: Case series; Level of evidence, 4.

Methods: Included were 67 patients who underwent OWHTO for unilateral medial compartment knee osteoarthritis and who received full leg length assessment pre- and postoperatively. Patients with varus or valgus deformity ($>3^\circ$) of the contralateral side were excluded. A musculoskeletal radiologist assessed imaging for the mechanical axis, full leg length, and tibial length of the involved and contralateral lower extremity. Statistical analysis determined the pre- and postoperative leg length discrepancy and the influence of the mechanical axis.

Results: Most patients (62.7%) had a decreased length of the involved leg, with a mean preoperative mechanical axis of $5.0^\circ \pm 2.9^\circ$. Length discrepancy averaged -2.2 ± 5.8 mm, indicating a shortened involved extremity ($P = .003$). OWHTO significantly increased the mean lengths of the tibia and lower limb by 3.6 ± 2.9 and 4.4 ± 4.7 mm ($P < .001$), leading to a postoperative tibial and full leg length discrepancy of 2.8 ± 4.3 mm and 2.2 ± 7.3 mm ($P < .001$ and $P = .017$, respectively). Preoperative leg length discrepancy was significantly correlated with the preoperative mechanical axis of the involved limb ($r = 0.292$; $P = .016$), and the amount of correction was significantly associated with leg lengthening after OWHTO ($r = 0.319$; $P = .009$). Patients with a varus deformity of $\geq 6.5^\circ$ (n = 14) had a preoperative length discrepancy of -4.5 ± 1.6 mm ($P < .001$) that was reduced to 1.8 ± 3.5 mm ($P = .08$).

Conclusion: Patients undergoing OWHTO have a preoperative leg length discrepancy that is directly associated with the varus deformity of the involved extremity. As OWHTO significantly increases leg length, restoration of native leg length can be achieved particularly in patients with large varus deformity.

Keywords: osteoarthritis; varus; mechanical axis; high tibial osteotomy; knee

Varus malalignment of the lower extremity has shown to increase joint contact forces across the medial compartment of the knee, leading to the progression of chondral degeneration.[1,10,16,17] Hence, high tibial osteotomy (HTO), as a joint-preserving realignment procedure, is a viable treatment option for patients with symptomatic unicompartmental osteoarthritis (OA), cartilage defects in the medial compartment, meniscal deficiency, and/or ligament instability to restore adequate contact forces.[2,18,20,21]

Among various types of HTO, the 2 most commonly used techniques are opening-wedge HTO (OWHTO) and closing-wedge HTO (CWHTO), yet neither has shown superiority over the other regarding clinical outcome.[4-6,9] However, postoperative leg length discrepancy remains a concern in patients submitted to HTO as several studies have reported lower limb length changes after both OWHTO and CWHTO.[3,12,14,19] In fact, in a prospective randomized controlled trial investigating lower limb length discrepancy after HTO for medial compartment OA, Kim et al[12] reported that OWHTO increased leg length by 7.6 ± 2.1 mm ($P < .001$), while CWHTO decreased leg length by just -0.8 ± 2.5 mm ($P = .073$). In addition, the change in leg length was directly correlated with the degree of correction

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in the studied cohort. Consequently, the authors concluded that CWHTO should be preferred in patients with unilateral medial compartment knee OA to prevent leg length discrepancy, particularly if a large correction is necessary.[12] These results were confirmed by a 2019 meta-analysis comparing the change in leg length after both HTO techniques.[13] However, studies assessing the effect of HTO on postoperative leg length have either excluded patients with preoperative leg length discrepancy or did not consider contralateral leg length in their analysis.[3,12,14,19] Yet, theoretical considerations suggest that patients with unilateral medial compartment knee OA have a decreased length of the involved lower extremity because of the height loss of the medial compartment and subsequent varus deformity. Consequently, these patients would benefit from lower limb lengthening provided by OWHTO rather than CWHTO, as it would restore native leg length compared with the contralateral side.

The purpose of the current study was therefore to assess the pre- and postoperative leg length of the involved lower extremity and compare it with the "native" contralateral side in patients submitted to OWHTO for unilateral medial compartmental knee OA. We hypothesized that patients have a decreased preoperative leg length of the involved leg compared with the contralateral side and that OWHTO would subsequently restore native leg length, particularly in patients with large varus deformity.

METHODS

After receiving ethics committee approval, we conducted a retrospective chart review and identified 273 patients who underwent OWHTO for the treatment of medial compartment OA between January 2008 and November 2020. OWHTO was indicated in patients with medial compartment OA and varus deformity without progressed lateral compartment degeneration or lateral meniscal deficiency. OWHTO was contraindicated in patients with an inflammatory joint disease, previous septic arthritis, metabolic or crystalline arthropathies, and flexion contraction of more than 10° or less than 110° of knee flexion. Further exclusion criteria for study participation comprised prior index and/or contralateral leg alignment surgery such as HTO or distal femur osteotomy, prior hip replacement, contralateral tibiofemoral malalignment >3° from the neutral mechanical axis, and unavailability of pre- and/or postoperative full leg alignment assessment. Thus, 67 patients were eligible and included in the current study (Figure 1). Patient's age at the time of surgery, body mass index (BMI), sex, and imaging follow-up were recorded.

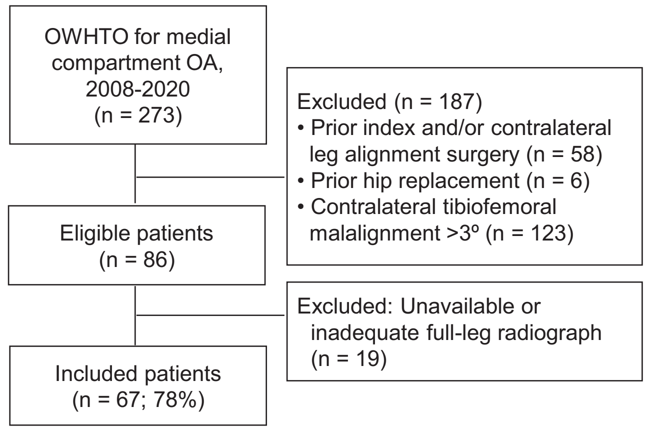

Figure 1. Flow diagram of patient selection. OA, osteoarthritis; OWHTO, opening-wedge high tibial osteotomy.

Radiographic assessment

All imaging was evaluated by a fellowship-trained musculoskeletal radiologist (C.G.). Images were obtained at a mean follow-up of 2.8 ± 2.2 months. The mechanical lower limb axis (hip-knee-ankle angle), leg length, and tibial length were measured for both lower extremities on a full length, standing anteroposterior radiograph pre- and postoperatively. Patients were instructed to stand balanced on both feet with fully extended knees and the patellae facing forward. Pre- and postoperative imaging were assessed for any magnification error. The lower limb mechanical axis was defined as the intersecting angle that was formed by the mechanical axis of the femur and the mechanical axis of the tibia. Lower limb length and tibial length were measured according to the study by Kim et al.[12] Thus, full leg length was defined as the distance from the top of the femoral head to the center of the tibial plafond. Tibial leg length was measured from the center of the tibial plateau (line intersecting the 50% coordinate of the tibial plateau width) to the center of the tibial plafond (Figure 2). Leg length change and discrepancy were determined by subtracting the postoperative leg length of the involved extremity from the preoperative leg length or the leg length of the contralateral side, respectively.

Surgical Technique and Rehabilitation

HTO was performed as previously described.[7,8] Briefly, after the exclusion of any contraindication for HTO, a longitudinal skin incision along the anteromedial proximal tibia was made. The proximal part of the pes anserinus and

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Ethical approval for this study was obtained from the regional ethics committee of the Canton of Zürich (reference No. 2020-01052).

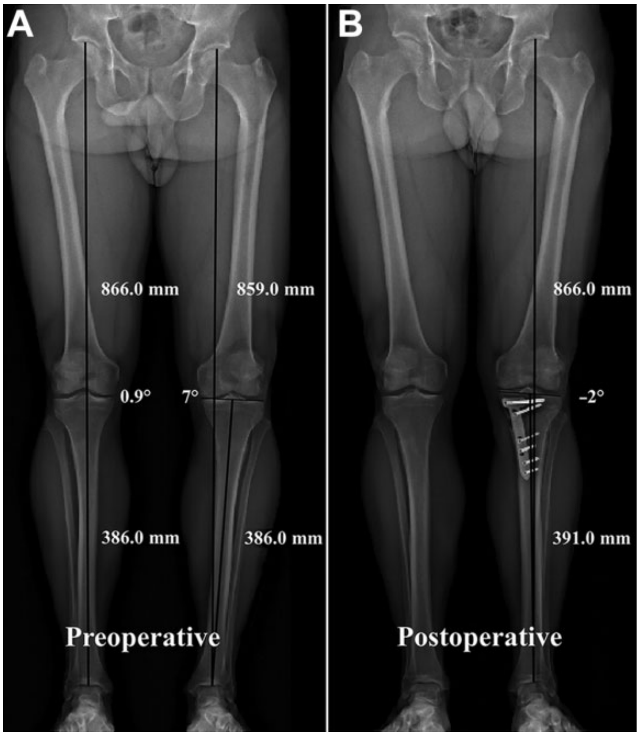

Figure 2. (A) Preoperative and (B) postoperative measurements of the lower limb mechanical axis, full leg, and tibial length standing anteroposterior radiograph. This patient had a preoperative lower limb discrepancy of –7 mm and a preoperative mechanical axis of the involved leg of 7° varus compared with 0.9° of varus on the contralateral side. Postoperatively, the mechanical axis was corrected to 2.2° of valgus, resulting in restored native lower limb length.

the distal part of medial collateral ligament were released to prevent postoperative medial compartment overload. Then, an ascending biplanar OWHTO was performed, leaving the tibial tubercle on the distal fragment. The intended correction was documented and confirmed by fluoroscopy, and the osteotomy was fixed using an angular stable locking system (Surfix [Surfix-Integra] or TomoFix [DePuy Synthes]), followed by standard wound closure.

Patients were kept touchdown weightbearing for 6 weeks without limitation of range of motion, followed by progression to full weightbearing as tolerated.

Statistical Analysis

All data were assessed for normality using the Shapiro-Wilk test. Accordingly, continuous variables were analyzed with the paired *t* test or Wilcoxon signed-rank test, and categorical variables were assessed by the chi-square test. Pearson correlation was used to assess the relationship between lower limb mechanical axis and leg length. All statistical analyses were performed in SPSS for Mac (Version 23.0; SPSS). Significance was set at $P < .05$. A post hoc power analysis showed that with a sample size of 67 patients, the study had a power of 0.92 to detect a lower limb length discrepancy between both extremities at a level of significance of .05. Power calculation was performed with G-power (Version 3.1; Heinrich Heine University).

TABLE 1
Comparison of Radiographic Parameters Between Preoperative and Postoperative State and the Native, Uninvolved Extremity[a]

Parameter	Mean ± SD	Range	*P* Value
Preoperative lower limb length, mm			**.003**
Involved leg	841.7 ± 59.8	713.0 to 998.0	
Uninvolved leg	843.9 ± 59.7	730.0 to 1000.0	
Involved lower limb length, mm			**<.001**
Preoperative	841.7 ± 59.8	713.0 to 998.0	
Postoperative	846.1 ± 60.0	722.0 to 1001.0	
Postoperative lower limb length, mm			**.017**
Involved leg	846.1 ± 60.0	722.0 to 1001.0	
Uninvolved leg	843.9 ± 59.7	730.0 to 1000.0	
Preoperative tibial length, mm			.077
Involved leg	371.0 ± 28.7	304.0 to 448.0	
Uninvolved leg	371.8 ± 28.8	315.0 to 448.0	
Involved tibial length, mm			**<.001**
Preoperative	371.0 ± 28.7	304.0 to 448.0	
Postoperative	374.7 ± 29.1	312.0 to 452.0	
Postoperative tibial length, mm			**<.001**
Involved leg	374.7 ± 29.1	312.0 to 452.0	
Uninvolved leg	371.8 ± 28.8	315.0 to 448.0	
Preoperative mechanical axis alignment,[b] deg			**<.001**
Involved leg	5.0 ± 2.9	0.0 to 21.8	
Uninvolved leg	1.1 ± 1.3	–2.4 to 3.0	
Involved mechanical axis alignment,[b] deg			**<.001**
Preoperative	5.0 ± 2.9	0.0 to 21.8	
Postoperative	–2.4 ± 2.5	–8.2 to 3.1	

[a]Bolded *P* values indicate statistically significant differences ($P < .05$). Deg, degree.
[b]Negative values indicate valgus alignment.

RESULTS

The reviewed cohort of 67 patients was predominantly male (77.6%) with a mean age of 41.9 ± 9.5 years and a BMI averaging 28.0 ± 4.3 kg/m^2. Of the included patients, 42 patients (62.7%) had a decreased leg length on the involved side (–5.6 ± 4.0 mm), 5 patients (7.5%) had a symmetrical leg length, and 20 patients (29.8%) had a longer involved lower limb compared with the contralateral side (4.5 ± 2.9 mm). Among all patients, mean preoperative mechanical axis of the involved leg was 5.0° ± 2.9° with a leg length discrepancy averaging –2.2 ± 5.8 mm, indicating a shortened involved lower extremity ($P = .003$).

Table 1 shows all pre- and postoperative radiographic measurements and their comparison with the native, contralateral lower limb. OWHTO significantly increased the mean lengths of the tibia and the lower limb by 3.6 ± 2.9 mm and 4.4 ± 4.7 mm ($P < .001$), leading to a significant postoperative tibial and full leg length discrepancy of 2.8 ± 4.3 ($P < .001$) and 2.2 ± 7.3 mm ($P = .017$), respectively. The mechanical axis of the involved leg was corrected from a varus malignment to a slight valgus by a mean of 7.5° ± 3.0° ($P < .001$).

When assessing the relationship of leg length and mechanical axis, preoperative leg length discrepancy was significantly correlated with the preoperative mechanical axis of the involved limb ($r = 0.292$; $P = .016$), and the amount of correction was significantly associated with leg lengthening after OWHTO ($r = 0.319$; $P = .009$). Twenty-nine of 42 patients (69%) with a shortened involved leg had a reduction of leg length discrepancy after OWHTO, while only 1 of 25 patients (4%) with a preoperative symmetrical or longer leg length experienced a reduction of lower limb length discrepancy ($P < .001$). This patient had a preoperative limb length discrepancy of 6 mm that was reduced to 4 mm after OWHTO, as the mechanical axis was corrected from 2.1° to –4.4°. Patients with a varus deformity of ≥6.5° (n = 14; 20.9%) had a preoperative length discrepancy of –4.5 ± 1.6 mm ($P < .001$) that was reduced to 1.8 ± 3.5 mm ($P = .08$).

DISCUSSION

The key finding of the current study is that patients submitted to opening-wedge high tibial osteotomy (OWHTO) for the treatment of unilateral medial compartment knee OA regularly have a lower limb length discrepancy that is directly correlated with the amount of varus deformity of the involved leg. Patients with a large varus malalignment of ≥6.5° degrees particularly seem to benefit from leg-lengthening OWHTO, as it ultimately restores native leg length.

The change of lower limb length after HTO has been the focus of previous research, primarily investigating the effect of OWHTO and closing-wedge HTO (CWHTO) on postoperative radiographic lower limb parameters.[3,11,12,14,15,19] In a mathematical model for the preoperative planning of lower extremity osteotomies, Mihalko and Krackow[15] calculated that lower limb length increases after OWHTO, whereas it decreases after CWHTO, both depending on the initial deformity and subsequent osteotomy correction angle.

This was first clinically proven by Magnussen et al,[14] who sought to quantify and compare the leg length change after OWHTO and CWHTO in 64 patients. They reported that patients who underwent OWHTO had a significant leg length increase of 5.5 ± 4.4 mm compared with a decrease of 2.7 ± 4.0 mm in patients after CWHTO. However, both clinically measured changes in leg length were smaller than predicted by the previously published mathematical models.[11,15] These clinical results were later confirmed by Bae et al[3] and Nerhus et al,[19] who both also reported significant leg length increases after OWHTO.

In 2016, Kim et al[12] published a prospective randomized controlled trial comparing lower limb length discrepancy after OWHTO and CWHTO. In this study, 60 patients with medial compartment OA were assigned to undergo OWHTO or CWHTO as a knee-preserving realignment procedure. Patients were assessed pre- and postoperatively for tibial length, lower limb length, lower limb length discrepancy, and clinical scores. It was reported that the mean lengths of the tibia and lower limb increased significantly after OWHTO by 5.2 ± 3.7 mm and 7.6 ± 2.1 mm, respectively, while tibial length significantly decreased after CWHTO (–6.0 ± 2.1 mm). Interestingly, however, mean lower limb length was not significantly decreased after CWHTO, with a mean of –0.8 ± 2.5 mm ($P = .073$). Thus, the mean postoperative lower limb length discrepancy was significantly increased after OWHTO but not after CWHTO (7.2 vs –1.0 mm). This was mirrored in the clinical results, as 37% of patients who underwent OWHTO were uncomfortable as a result of the postoperative leg length discrepancy compared with only 7% of patients after CWHTO. As the length of the medial opening in OWHTO was the strongest predictor of lower limb length change, those authors concluded that patients who require large correction should receive CWHTO to prevent postoperative leg length discrepancy.[12]

While this may certainly be true in patients with preoperative symmetrical lower limb lengths, theoretical considerations suggest that the height loss of the medial compartment with subsequent varus deformity in patients with unilateral medial compartment knee OA eventually leads to a decreased length of the involved lower extremity. In fact, 62.7% of patients in the current study had a shortened leg preoperatively compared with the native, contralateral side. Interestingly, almost 80% of these patients would have been excluded in the study by Kim et al,[12] as their study included only patients with a preoperative leg length discrepancy of ≤2 mm. Our inclusion of these patients resulted in a mean leg length discrepancy averaging –2.2 ± 5.8 mm in the current study compared with –0.5 ± 0.7 mm reported by Kim et al. This difference in lower limb length discrepancy may also stem from the fact that patients with contralateral tibiofemoral malalignment >3° were strictly excluded in the current study, thus evaluating only patients with true unilateral medial compartment OA with a "native" contralateral lower limb.

To our knowledge, this is the first study to consider the contralateral leg length when assessing the lower limb length change in patients after OWHTO. Despite similar results regarding the effect of leg lengthening after OWHTO, we fundamentally disagree with previously published conclusions that OWHTO should be avoided in patients with medial compartment OA who require large mechanical axis correction to prevent significant postoperative leg length discrepancy.[12,13] As preoperative varus deformity was directly correlated with preoperative lower limb length discrepancy, the results of the current study suggest that particularly patients with large, unilateral varus deformities may benefit from OWHTO, as it frequently decreases leg length discrepancy in patients with a preoperatively shortened leg length, as seen in almost 70% of patients with a limb length discrepancy of ≥–1 mm and in more than 80% with a discrepancy of ≥–3 mm.

We acknowledge the following limitations of the study. First, this study did not assess clinical scores or the subjective sensation/discomfort of the pre- and postoperative leg length discrepancy. Hence, the results of this study may be statistically significant, yet the effect on patient outcome has to be evaluated in future studies. Second, the relatively small coefficient of determination (r^2) of the association between mechanical axis and change in lower limb length discrepancy suggests that other factors play significant roles in affecting leg length. However, these were not assessed in the current study, as this study solely sought to determine pre- and postoperative leg length discrepancy in patients submitted to OWHTO. In particular, the progression of OA on the index and/or contralateral knee may contribute to lower limb length changes, yet the period between the pre- and postoperative radiographs was only 5.6 ± 4.1 months, and thus no progression was seen. The strength and novelty of the herein presented study is that preoperative native, contralateral leg length is considered in the analysis of lower limb length changes after HTO. Thus far, previous studies either assumed preoperative symmetrical leg length or did not assess preoperative contralateral leg length in patients submitted to HTO, hence overrating the negative effect of leg lengthening by OWHTO.

CONCLUSION

Patients undergoing OWHTO have a preoperative leg length discrepancy that is directly associated with the varus deformity of the involved extremity. As OWHTO significantly increases leg length, restoration of native leg length can be achieved particularly in patients with large varus deformity.

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