The effect of osteotomy depth and hinge axis orientation on biplanar surgical accuracy in medial opening-wedge high tibial osteotomy—a deeper understanding by 3D simulations

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Background: Not all surgical osteotomy steps have been properly investigated for their potential impact on surgical accuracy. The main study objective was to investigate the osteotomy parameters that have respectively major and minor impact on coronal and sagittal bony accuracy in medial opening-wedge high tibial osteotomy (MOWHTO).

Methods: Three tibias from an existing 3D MOWHTO osteotomy database were chronologically selected based on segmentation quality, tibial plateau size and the presence of tibial varus. The study consisted of three parts: (I) translating the hinge axis in the coronal plane and switching the osteotomy starting point (30–40 mm) and depth, (II) the hinge axis was rotated stepwise by 10° to perform five simulations, (III) the hinge axis was rotated in the axial plane stepwise by 10° towards anterolateral to perform four simulations (0°, +10°, +20°, +30°). The medial proximal tibial angle (MPTA) and lateral tibial slope were the primary outcomes. Simulations were performed with 5, 10 and 15 mm gap distraction.

Results: In the coronal plane, maximum difference in osteotomy depth was 10 mm which represented an MPTA difference of 0.8°–1.1° in 10 mm gap distraction and 1.2°–2.0° in 15 mm gap distraction. Tibial slope remained unchanged. Rotating the hinge axis in the sagittal plane delivered minor changes on both MPTA (<0.5°) and tibial slope (<1.5°) at 10 mm gap distraction. Per 10° of axial rotation of the hinge axis towards anterolateral, the tibial slope increased by 1.0°–1.3° in 10 mm gap distraction while the MPTA remains nearly unchanged.

Conclusions: The study showed that the medio-lateral osteotomy length is the main parameter for obtaining bony accuracy in the coronal plane and maintaining a strict perpendicular axial hinge axis position is crucial in preserving the native tibial slope. Correct axial alignment of the hinge axis can be obtained by creating an equal osteotomy depth of the anterior and posterior tibial cortices in the lateral metaphyseal area.

Keywords: High tibial osteotomy; 3D simulation; accuracy; hinge axis; posterior tibial slope

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Introduction

Medial opening-wedge high tibial osteotomy (MOWHTO) is considered to be a technically demanding procedure with excellent long-term outcomes when performed accurately (1). Despite good survival rates, conventional MOWHTO techniques (and planning methods) appear to have a surprisingly low accuracy in the coronal plane (2). This can be attributed to imprecise planning methods, difficult translation of the planned correction into surgery, and unpredicted soft-tissue correction after postoperative weight-bearing (3,4). Regarding the intraoperative bony correction, the '1° planned correction =1 mm wedge opening' rule has been outperformed by the Hernigou table and is nowadays commonly used if not applying 3D technology (5-8). The Hernigou table is based on the osteotomy length in order to reliably determine the required wedge opening (mm) at the medial cortex (5). Besides inaccuracy in the coronal plane, unintended tibial slope increase in the sagittal plane is often described after MOWHTO, ranging from 2° to 5° (9,10). The amount of tibial slope increase that can be accepted with regards to anterior cruciate ligament (ACL) strain and knee biomechanics is still debated, however, excessive increase should be strictly avoided (11). Presumed technical reasons for slope increase are the 45° anteromedial approach to the tibia, difficulties in controlling unequal anteroposterior gap distraction and an anterolateral shift of the hinge axis (12).

Despite progressive research and the validation of preoperative 3D osteotomy simulations, not all surgical steps of a MOWHTO and consequent gap distraction are fully understood in a 3-planar fashion (7,8,13). A deeper understanding seems therefore necessary when performing MOWHTO in daily practice to comprehend the key steps of an osteotomy in order to obtain accurate biplanar outcomes. The main study objective was to illustrate the 3-planar impact of several osteotomy parameter on respectively coronal and sagittal bony accuracy in MOWHTO. These factors include the 3D osteotomy plane orientation, the anteroposterior osteotomy length differences, the hinge axis location, the proximal tibial plateau size and the amount of correction.

Highlight box

Key findings

- The medio-lateral osteotomy length is the main parameter for obtaining bony accuracy in the coronal plane in medial opening-wedge high tibial osteotomy.
- Maintaining a perpendicular axial hinge axis position is crucial in preserving the native tibial slope.
- Small tibial plateau size and large corrections bear the highest risk for biplanar inaccuracy.

What is known and what is new?

- Not all surgical osteotomy steps have been properly investigated for their potential impact on surgical accuracy.
- The novelty of the study lies in the identification of the most relevant and irrelevant parameters during osteotomy performance and subsequent distraction.

What is the implication, and what should change now?

- Correct axial alignment of the hinge axis can be obtained by creating an equal osteotomy depth of the anterior and posterior tibial cortices in the lateral metaphyseal area.
- Inaccuracy should be anticipated in small tibial plateaus and large osteotomy corrections by using 3D planning or the use of patient-specific instrumentation.

Methods

From an existing 3D HTO osteotomy database, three full leg CT scans were chronologically selected based on segmentation quality, tibial plateau size and the presence of tibial varus [medial proximal tibial angle (MPTA) <86°]. The CT-scan protocol for the knee joint was a 0.5 mm thickness and spacing, captured in 150 mm centered range. DICOM-files were loaded in medical image software Mimics 23.0 (Materialise®, Leuven, Belgium) with segmentation threshold set at 130–200 HU. The final 3D reconstruction was exported as STL-files and opened in medical 3D planning software 3-matic 14.0 (Materialise®, Leuven, Belgium) in which all measurements, simulations, axes and plane definitions were conducted. Case details of the three selected 3D models are outlined in *Table 1*. Tibial plateaus were intentionally selected to assess relevant difference regarding proximal tibia size [70 mm (small), 77.5 mm (moderate) and 85 mm (large)]. The 3D osteotomy database was searched for tibial plateau width. Given the average tibial plateau width for males and females described earlier (14), it was found that the smallest and largest tibial plateau was respectively 70 and 85 mm. A third model was positioned in the middle of these sizes (77.5 mm) to determine the gradual increase in width during simulations.

Axes and plane definition (Figure 1)

Anatomical tibial axis (ATA)

The center of the tibial plateau was determined by bisecting

Table 1 Patient demographics and bony parameters of the three selected tibias

Patient demographics	Case 1	Case 2	Case 3
Age, years	48	39	60
Sex	Female	Male	Male
Tibial plateau width, mm	70	77.5	85
MPTA, °	85.8	84.0	85.5
Lateral tibial slope, °	92.5	98.9	95.4

MPTA, medial proximal tibial angle.

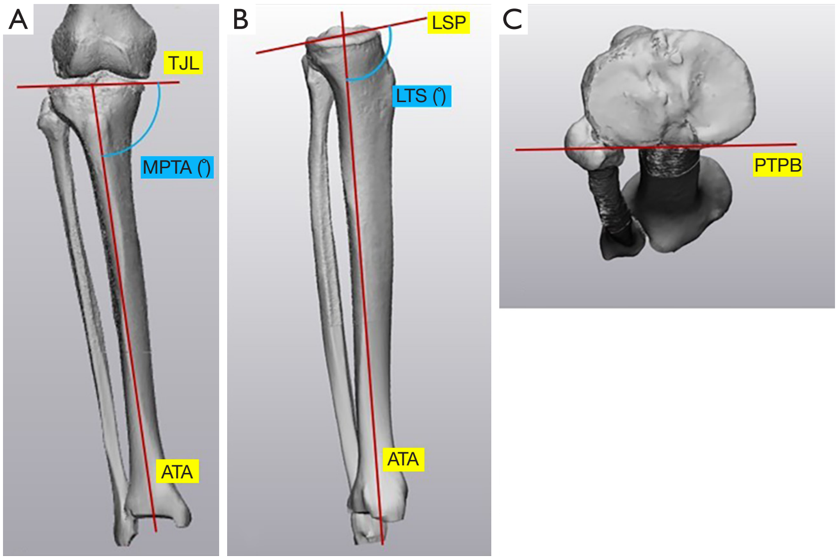

Figure 1 Axes and angle definitions in the coronal (A), the sagittal (B) and the axial (C) plane. ATA, anatomical tibial axis; TJL, tibial joint line; LSP, lateral slope plane; PTPB, posterior tibial plateau boundary; MPTA, medial proximal tibial angle; LTS, lateral tibial slope.

the line between the tip of the medial and lateral tibial spine. This point was connected to the center of the tibial dome which was determined by the middle of the medial and lateral malleolus. During osteotomy simulation, the new tibial axis was redefined by the new center of the tibial dome after translation of the distal tibia.

Tibial joint line (TJL)

The deepest point on the medial and lateral tibia plateau were determined and connected to define the TJL.

Posterior tibial plateau boundary (PTPB)

The most posterior point on the medial and lateral tibial condyle were determined and connected to define the posterior condylar line. In case of medial posterior osteophytes, the point was redefined as to the original bony anatomy of the patient.

Posterior tibial plane (PTP)

The posterior condylar line (2 points) was connected to the center of the tibial dome to create the PTP. The MPTA (coronal alignment) was measured in this plane.

Lateral slope plane (LSP)

The lateral tibia plateau was separately marked ‘free hand’ in an anteroposterior way with the lasso tool. A ‘best fitting plane’ was created which represented the LSP.

Tibial slope plane (TSP)

This plane was created by using the ATA (2 points) as baseline and was set perpendicular to the PTP. The medial and lateral tibial slope angles were measured in this TSP.

The baseline axial position of the hinge axis was created parallel to the TSP and in neutral position in the sagittal plane according to the world coordinate system.

Hinge axis translations and rotations

The hinge axis was sequentially translated in the (I) coronal and rotated in (II) the sagittal and (III) the axial plane in order to assess the effect on coronal (MPTA) and sagittal (lateral tibial slope) alignment. The MPTA was formed by the ATA and the TJL and measured in the PTP. The lateral tibial slope was formed by the ATA and the LSP and measured in the TSP. Osteotomy plane thickness was set at 1.35 mm in all simulations. Medial opening-wedge osteotomies were simulated with respectively 5, 10 and 15 mm gap distraction measured at the posteromedial cortex of the 3D model (the most medial point on a strict anteroposterior view). Corrections were obtained by rotating the distal tibial including the tibial dome center point over the desired hinge axis. After each simulation, a new ATA was created which was used to measure the obtained MPTA and the lateral tibial slope.

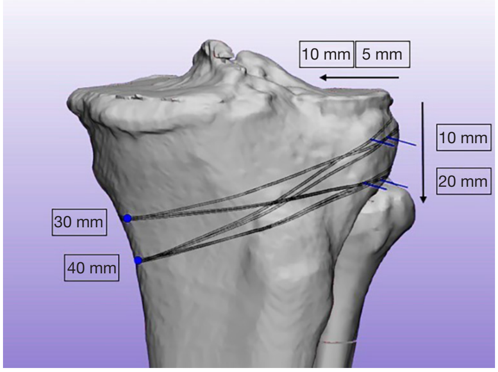

Figure 2 Eight osteotomies were simulated by translating the starting point and hinge axis (blue) in the coronal plane (2×2×2).

Coronal plane hinge translations (*Figure 2*)

The osteotomy starting point was set 30 or 40 mm (2) inferior to the medial tibial plateau at the posteromedial cortex. The hinge axis was translated at 10 or 20 mm (2) inferior to the lateral tibial plateau and at 5 or 10 mm (2) from the lateral cortex. In total, eight osteotomy cuts were simulated (2×2×2). In all simulations, the hinge axis was kept perpendicular to the PTP and parallel to the TSP (= neutral hinge axis). The mediolateral osteotomy length from the posteromedial starting point to the hinge axis was also determined.

Sagittal plane hinge rotations (*Figure 3*)

A fixed osteotomy starting point (35 mm inferior to the medial tibial plateau) and fixed hinge axis location (15 mm inferior to the lateral tibial plateau and 7.5 mm from the lateral cortex) were maintained during sagittal osteotomy plane simulations. The neutral osteotomy plane (0°), defined as the plane formed by the starting point and neutral hinge axis, was rotated stepwise by 10° from the center to perform five simulations (+20°, +10°, 0°, −10°, −20°) (*Figure 3A*). The hinge axes were kept parallel to the TSP (*Figure 3B*).

Axial plane hinge rotations (*Figures 4,5*)

Similar to the sagittal simulations, the osteotomy starting

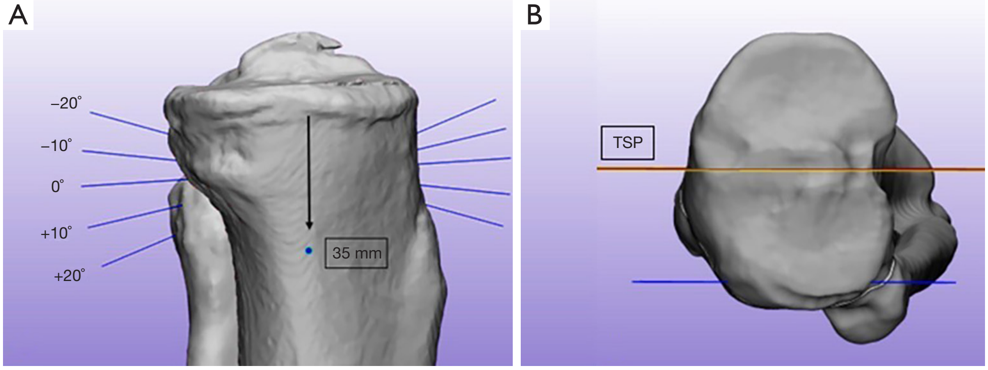

Figure 3 Osteotomy simulations in the sagittal plane. (A) Five osteotomies were simulated by rotating the hinge axis (blue) in the sagittal plane. The starting point (35 mm) and coronal hinge axis position (15 mm × 7.5 mm) were fixed. (B) Superior view of the hinge axis rotations that were kept parallel to the TSP. TSP, tibial slope plane.

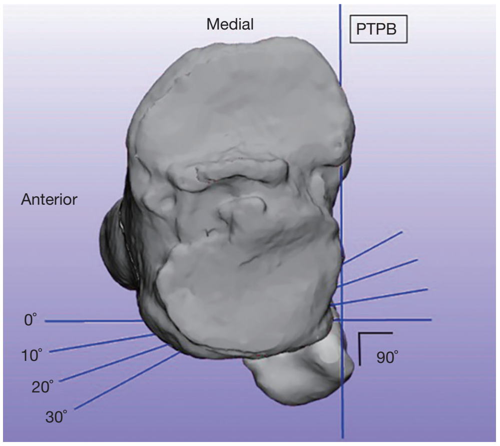

Figure 4 Superior view of the stepwise anterolateral hinge axis rotations (blue) in the axial plane. Rotations were performed in line with the neutral osteotomy plane that was used for every simulation (starting point 35 mm, hinge axis 15 mm × 7.5 mm lateral). The initial hinge axis (0°) was perpendicular to the PTPB. PTTB, posterior tibial plateau boundary.

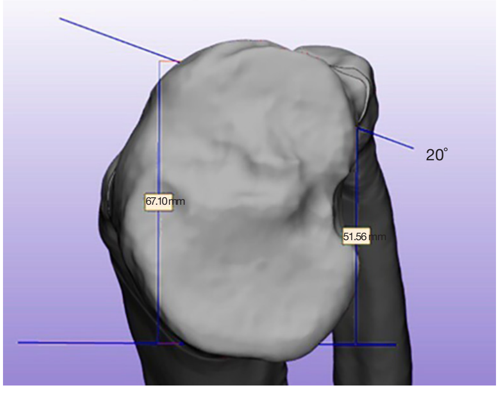

Figure 5 Superior view of the anterior and posterior cortex distances measured from the starting point to the rotating hinge axis in the axial plane.

point (35 mm inferior to the medial tibial plateau) and hinge axis location (15 mm inferior to the lateral tibial plateau and 7.5 mm from the lateral cortex) were fixed in the coronal plane during axial hinge axis rotations. The neutral osteotomy plane (0°) was maintained during all simulations, only the hinge axis was rotated stepwise by 10° from the center towards anterolateral. Four simulations were conducted (hinge axis at 0°, 10°, 20° and 30°). In addition, the anterior and posterior osteotomy distances to the respective hinge axis were measured to outline any relevant differences (*Figure 5*).

Statistics

Case outcomes in the coronal and sagittal plane were described separately. Descriptive statistics were expressed as mean, standard deviation (SD), minimum and maximum values [min; max]. A single observer performed all the simulations. Statistical tests were not performed due to the illustrative nature of the study.

Results

Coronal plane hinge translations

Outcomes of coronal plane hinge translations are shown in *Table 2*. The maximum difference after eight simulations for MPTA was 0.5° in 5 mm distraction, 1.1° in 10 mm distraction and 2.0° in 15 mm distraction. The largest differences were observed in the smallest tibial plateau (case 1). Differences between simulations attenuated with increasing tibial plateau size. The osteotomy length varied by the starting point and position of the hinge axis laterally. In all three cases, the shortest osteotomy was simulated by starting at 40 mm inferior to the tibial plateau and the hinge axis at 20 mm × 10 mm laterally. The deepest osteotomy was found by starting at 40 mm inferior to the tibial plateau and the hinge axis at 10 mm × 5 mm laterally. The maximal difference in mediolateral osteotomy length was found to be 10 mm in all 3D models. The LTS remained unchanged regardless of gap distraction.

Sagittal plane hinge rotations

Outcomes of sagittal plane rotations are shown in *Table 3*. The maximum difference after simulations for MPTA per 10° hinge axis tilt was –0.2° in 5 mm distraction, –0.4° in 10 mm distraction and –0.7° in 15 mm distraction. This maximum was observed in the smallest tibia (case 1) between +10° and +20° hinge axis tilting. The LTS changed by 0.1° or did not change in gap distractions 5 and 10 mm. By opening 15 mm, the LTS did maximally change 0.2° per 10° hinge axis tilt.

Axial plane hinge rotations

Outcomes of axial plane rotations are shown in *Table 4*. For 5 and 10 mm gap distractions, the MPTA decreased

Table 2 Case by case outcomes of the average MPTA correction and maximal difference between the eight 3D simulations in the coronal plane

Gap distraction	Outcome	Case 1			Case 2			Case 3		
		Preoperative	Increase	Maximal difference	Preoperative	Increase	Maximal difference	Preoperative	Increase	Maximal difference
5 mm	MPTA (°)	85.8	+3.4	0.5	84.0	+3.2	0.4	85.5	+2.7	0.5
	LTS (°)	92.5	+0	0	98.9	+0	0	95.4	+0	0
10 mm	MPTA (°)	85.8	+8.1	1.1	84.0	+7.6	1.0	85.5	+6.5	0.8
	LTS (°)	92.5	+0	0	98.9	+0	0	95.4	+0	0
15 mm	MPTA (°)	85.8	+12.7	2.0	84.0	+12.0	1.7	85.5	+10.2	1.2
	LTS (°)	92.5	+0	0	98.9	+0	0	95.4	+0	0
Osteotomy length (mm) ± SD [Min – Max]		57.4±3.8 [52.3–62.9]			62.2±3.6 [56.8–66.8]			69.3±3.6 [64.3–74.4]		

MPTA, medial proximal tibial angle; LTS, lateral tibial slope; SD, standard deviation.

Table 3 Case by case outcome of 3D simulations in the sagittal plane

Gap distraction	Outcome	Case 1					Case 2					Case 3				
		+20°	+10°	0°	−10°	−20°	+20°	+10°	0°	−10°	−20°	+20°	+10°	0°	−10°	−20°
5 mm	MPTA (°)	−0.3	−0.1	89.3	0	−0.1	−0.2	−0.1	87.3	−0.1	−0.2	−0.2	0	88.2	−0.1	−0.1
	LTS (°)	−0.1	−0.1	92.5	+0.1	+0.1	−0.1	−0.1	98.9	0	+0.1	−0.2	−0.1	95.4	0	+0.1
10 mm	MPTA (°)	−0.6	−0.2	94.0	0	−0.2	−0.5	−0.2	91.7	−0.1	−0.3	−0.4	−0.1	91.9	0	−0.3
	LTS (°)	−0.2	−0.1	92.5	+0.1	+0.2	−0.1	−0.1	98.9	0	+0.1	−0.3	−0.2	95.4	+0.1	+0.2
15 mm	MPTA (°)	−1.0	−0.3	98.7	0	−0.4	−0.9	−0.3	96.2	−0.2	−0.7	−0.7	−0.2	95.7	−0.2	−0.6
	LTS (°)	−0.1	0	92.5	+0.1	+0.2	0	0	98.9	0	−0.1	−0.4	−0.2	95.4	+0.1	+0.3
Osteotomy length (mm)				56.0					61.4					69.4		

MPTA, medial proximal tibial angle; LTS, lateral tibial slope.

Table 4 Case by case outcome of 3D simulations in the sagittal plane

Gap distraction	Outcome	Case 1				Case 2				Case 3			
		0°	+10°	+20°	+30°	0°	+10°	+20°	+30°	0°	+10°	+20°	+30°
5 mm	MPTA (°)	89.3	0	0	−0.1	87.3	0	0	−0.1	88.2	0	0	−0.1
	LTS (°)	92.5	+0.6	+1.1	+1.8	98.9	+0.5	+1.0	+1.6	95.4	+0.4	+0.8	+1.3
10 mm	MPTA (°)	94.0	0	−0.1	−0.1	91.7	0	−0.1	−0.3	91.9	0	−0.1	−0.2
	LTS (°)	92.5	+1.3	+2.7	+4.4	98.9	+1.2	+2.4	+3.8	95.4	+1.0	+2.0	+3.2
15 mm	MPTA (°)	98.7	0	0	−0.3	96.2	−0.2	−0.3	−0.7	95.7	−0.1	−0.3	−0.4
	LTS (°)	92.5	+2.2	+4.5	+7.0	98.9	+1.9	+4.0	+6.2	95.4	+1.6	+3.3	+5.2
Osteotomy length (mm)			56.0				61.4				69.4		

Hinge axes rotation was performed in the anterolateral direction. MPTA, medial proximal tibial angle; LTS, lateral tibial slope.

Table 5 Case by case outcome of the anterior and posterior cortical length from posteromedial osteotomy starting point to the hinge axis with stepwise rotating the hinge axis in the axial plane

Outcome	Case 1				Case 2				Case 3			
	0°	+10°	+20°	+30°	0°	+10°	+20°	+30°	0°	+10°	+20°	+30°
Anterior cortex (mm)	56.7	59.9	62.6	64.2	61.7	64.8	67.1	68.6	73.2	75.4	77.5	78.5
Posterior cortex (mm)	56.3	53.0	49.5	46.4	61.8	57.0	51.6	47.4	73.0	68.2	63.9	59.1
Length difference (mm)	0.4	6.9	13.0	17.9	0.1	7.8	15.5	21.2	0.2	7.2	13.6	19.4

by 0.1° or remained unchanged per shift of 10° hinge axis rotation. The MPTA decreased by 0.1–0.4° per 10° shift when gap distraction was performed up to 15 mm. In the sagittal plane, the LTS increased by 0.4–0.6° in 5 mm gap distraction, by 1.0–1.3° in 10 mm gap distraction and by 1.6–2.5° in 15 mm gap distraction per 10° of hinge axis rotation. The largest increase in LTS was observed in the smallest tibial model (case 1). This determination was further investigated by measuring the anterior and posterior cortical distance from the posteromedial starting point to the respective hinge axis (*Table 5*). When rotating the hinge axis in the axial plane towards anterolateral, the breached anterior cortex becomes larger than posteriorly. At 10° of hinge axis rotation, the anteroposterior cortical difference was 7–8 mm. At 20°, the differences were 13–16 mm while at 30°, the difference was 18–21 mm.

Discussion

The most important findings of this study are that correct determination of the osteotomy length is the main parameter for obtaining bony accuracy in the coronal plane and controlling the hinge axis position in the axial plane is crucial in maintaining the native tibial slope. Correct alignment of the hinge axis can be obtained by creating an equal osteotomy of the anterior and posterior tibial cortices in the lateral metaphysis. A difference of approximately 7 mm (longer anterior cortex) results in 10° of anterolateral hinge axis rotation corresponding to a tibial slope increase of 1.0–1.3° when performing a 10 mm gap distraction.

Given a fixed gap distraction, the MPTA correction and so the coronal bony accuracy was only depended on the osteotomy length during hinge axis translations in the coronal plane (A). Neither the starting point (30 or 40 mm inferior to the medial tibial plateau), nor the osteotomy end point (hinge axis) were found to be independent relevant parameters with regards to coronal accuracy. After the eight performed simulations, the maximum difference in osteotomy length was 10 mm for all cases with maximal MPTA correction differences up to 2° in 15 mm gap distraction in the smallest tibia (case 1). In general, outcomes of the coronal simulations (A) are in line with the published converting tables by Hernigou *et al.* [2001] and Noyes *et al.* [2005] (5,12). The Hernigou table includes osteotomy length in order to reliably determine the required wedge opening (mm) at the medial cortex, but neglects for example thickness of the sawblade, hinge axis position and the oblique orientation of the proximal anteromedial tibial cortex. So, a 3-planar accurate correction cannot be guaranteed when blindly following this conversion table. Of note, the osteotomy plane thickness (i.e., sawblade thickness) was 1.35 mm in our simulation study which should be added to the total gap distraction in order to become the desired correction degree according to these tables. Another discussion point is the location of the osteotomy starting point in order to determine osteotomy length. One might consider using the anteroposterior middle of the medial tibia as a starting point from a convenient surgical perspective [anteromedial approach to the tibia and presence of the superficial medial collateral ligament (MCL)]. Although in this study, the most posteromedial tibial cortical point was used, as this point was coinciding with the location where gap distraction was measured. This is in line with the original paper by Herniqou *et al.*, who stated that the mediolateral osteotomy length of the tibia should be measured on a film/plain Xray without enlargement and at the expected site of the osteotomy (5). Furthermore, the tibial slope did not change during coronal translations of the hinge axis because the axis was constantly maintained perpendicular to the PTPB.

Regarding hinge axis rotations in the sagittal plane, tilting away in either direction from 0° yielded in a minor decrease in MPTA (−0.2° MPTA correction per 10° of hinge rotation at 10 mm opening). The tibial slope was also mildly affected by hinge rotations (0.1° tibial slope change per 10° of hinge rotation at 10 mm opening) in the sagittal plane given that clinically relevant slope changes only start at >2–5° (11,15,16). Interestingly, upsloping the osteotomy plane yielded minor decrease in tibial slope and vice versa. Our results are in line with the study by Teng *et al.* [2021] which equally suggest no tibial slope alternations by hinge axis/osteotomy plane rotations in the strict sagittal plane (9).

Concerning the anterolateral hinge axis rotations in the axial plane, the posterior slope appeared to be strongly affected. A tibial slope increase of 1.0–1.3° per 10° hinge rotation at 10 mm wedge opening was found. Slope increase was higher for the small tibia (case 1) and for incremental gap distractions. A gap distraction of 15 mm in case 3 (largest tibia) yielded 10° of MPTA correction and a gradual tibial slope increase of 1.6° per 10° of anterolateral hinge rotation. This finding is similar to the conclusion by Teng *et al.* who performed a large simulation study on 93 knees (9). As illustrated by our simulations, the axial rotation of the hinge axis is a consequence of unequal anteroposterior cortical breaching/gap distraction during osteotomy (12). The anteromedial tibial approach for MOWHTO, the posterior neurovascular bundle and incomplete transection of the superficial MCL might compromise thorough posterior cortical osteotomy during surgery. In this study, approximately 7mm difference between the anterior and posterior cortical osteotomy was corresponding to 10° of axial hinge rotation. To the authors knowledge, this difference was not previously investigated. Now, when a slope increase is intended, the 7mm stepwise difference might be a useful tool to obtain the desired tibial slope increase, since this is difficult to assess intraoperatively. However, the individualized anteroposterior width of the proximal tibia and the cortical curvature at the lateral tibia plateau might produces variation on this 7 mm-rule. The surgical key step from this finding lies in thorough osteotomy performance of the posterior cortex by chisel or saw, while maintaining 7.5–10 mm of lateral bone stock in order to avoid violation of the proximal tibiofibular joint (13). With regards to coronal accuracy, no relevant differences on MPTA corrections were found during axial hinge axis simulations. Only at 10 and 15 mm wedge opening, the MPTA maximally decreased by 0.1–0.4° per 10° hinge rotation.

Furthermore, two general findings need to be derived from this study. First, larger corrections were associated with more profound differences in MPTA and LTS by hinge axis repositioning. Realistic gap distractions of 5, 10 and 15 mm were tested and measured at the posteromedial tibial cortex. So, when planning on large MOWHTO corrections, a higher risk for correction error in both planes should be anticipated. Secondly, the size of the proximal tibia determines the absolute length of the osteotomy and so the risk for error with regards to coronal accuracy. A small tibia (case 1) with a relatively shallow osteotomy bears higher risk for surgical error in both sagittal and coronal plane compared to a large tibia (case 3). This was reflected by higher 'maximal differences' for the coronal plane simulations (*Table 2*) in case 1 relative to case 3.

Some limitations need to be addressed to this study. A mathematical model could not be delivered because of three included cases. However, this study merely aimed to illustrate relevant key steps for the orthopaedic surgeon to consider during MOWHTO. The outcome in the sagittal plane was limited to the lateral tibial slope. Since no rotational changes were simulated (proximal tibia with respect to distal tibia), medial and lateral tibial slope changes should always be similar as outlined in the study by Teng *et al.* (9).

Conclusions

The study showed that the medio-lateral osteotomy length is the main parameter for obtaining bony accuracy in the coronal plane and maintaining a strict perpendicular axial hinge axis position is crucial in preserving the native tibial slope. Correct axial alignment of the hinge axis can be obtained by creating an equal osteotomy depth of the anterior and posterior tibial cortices in the lateral metaphyseal area.

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Footnote

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-23-1870/dss

Peer Review File: Available at https://atm.amegroups.com/article/view/10.21037/atm-23-1870/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-23-1870/coif).

The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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