SICOT-J 2024, **10**, 41
© The Authors, published by EDP Sciences, 2024
https://doi.org/10.1051/sicotj/2024042

Available online at:
www.sicot-j.org

ORIGINAL ARTICLE OPEN ACCESS

Comparative biomechanical analysis of tibial posterior slope in medial open wedge high tibial osteotomy vs. distal tuberosity osteotomy with and without anterior-posterior screw: a study using porcine tibia

Yoshiya Nibe[1], Tsuneari Takahashi[1,*], Hironari Hai[2], Tomohiro Matsumura[3], and Katsushi Takeshita[1]

[1] Department of Orthopaedics Surgery, Jichi Medical University, 3311-1 Yakushiji, Shimotsuke, 329-0498, Japan
[2] Department of Orthopaedic Surgery, Toyokawa City Hospital, 23 Noji, Toyokawa, 442-0857, Japan
[3] Department of Emergency and Critical Care Medicine, Jichi Medical University, 3311-1 Yakushiji, Shimotsuke, 329-0498, Japan

Received 11 April 2024, Accepted 15 September 2024, Published online 21 October 2024

Abstract – *Purpose* While increased posterior tibial slope (PTS) is a concern post-medial open wedge high tibial osteotomy (MOWHTO), the ability of distal tuberosity osteotomy (DTO) to maintain postoperative PTS after cyclic loading remains unverified. This study aims to determine whether PTS alterations significantly differ between DTO and MOWHTO following cyclic loading. *Methods*: Biomechanical evaluations were conducted on thirty porcine tibias using MOWHTO and DTO, with and without an anterior-posterior (AP) screw. To investigate PTS changes, cyclic testing was carried out for MOWHTO and DTO. Displacement along the mechanical axis during cycles 10th, 100th, 500th, 1000th, 1500th and 2000th, variations in anterior and posterior gaps after 2000 cycles and increased PTS after 2000 cycles, were compared across the three groups. The displacement was evaluated by repeated-measures analysis of variance (ANOVA), and changes in AG and PG and increased PTS were evaluated by one-way ANOVA. The sample size for α and β errors were <0.05 and <0.20, and the effect size was 0.60 for one-way ANOVA and 0.46 for repeated-measures ANOVA. *Results*: There were no significant differences in displacement and anterior gap changes among the groups. A significant difference was observed in the posterior gap changes (P < 0.001) and increased PTS (P = 0.013) among the groups. Post hoc analysis indicated substantial disparities between MOWHTO and DTO without the AP screw (P = 0.035), as well as between MOWHTO and DTO with the AP screw (P = 0.021) concerning the increased PTS. Conclusion: After cyclic loading, MOWHTO exhibited a notably smaller PTS change than DTO regardless of the presence of an AP screw.

Key words: Biomechanical study, High tibial osteotomy, Distal tuberosity osteotomy, Porcine tibia, Posterior tibial slope.

Introduction

Medial open wedge high tibial osteotomy (MOWHTO) is a common treatment for medial knee osteoarthritis [1]. Unfortunately, this treatment is associated with several complications, including postoperative patella baja [2, 3], potentially resulting in the progression of patellofemoral (PF) joint osteoarthritis. Gaasbeek et al. introduced an open wedge distal tuberosity osteotomy known as distal tuberosity osteotomy (DTO) to address this issue [4]. In the MOWHTO method, the tibial tuberosity remains on the proximal fragment. In contrast, the DTO method retains it on the distal fragment. This allows the osteotomy to remain open while preserving patellar height. Since Gaasbeek et al.'s 2004 report on DTO, several studies have found that DTO preserves patellar height [5, 6].

Another complication of MOWHTO involves an increased posterior tibial slope [7, 8]. However, no studies have tried to determine if DTO influences the posterior tibial slope (PTS) after cyclic loading. Therefore, we aimed to investigate whether MOWHTO, DTO without an anteroposterior (AP) screw and DTO with AP screw would provide maintenance of anterior gaps (AG), posterior gaps (PG), and PTS. We hypothesized that MOWHTO would result in less PTS increase than DTO and that a significant difference in PTS increase would be observed between DTO with and without an AP screw.

*Corresponding author: tsuneari9@jichi.ac.jp

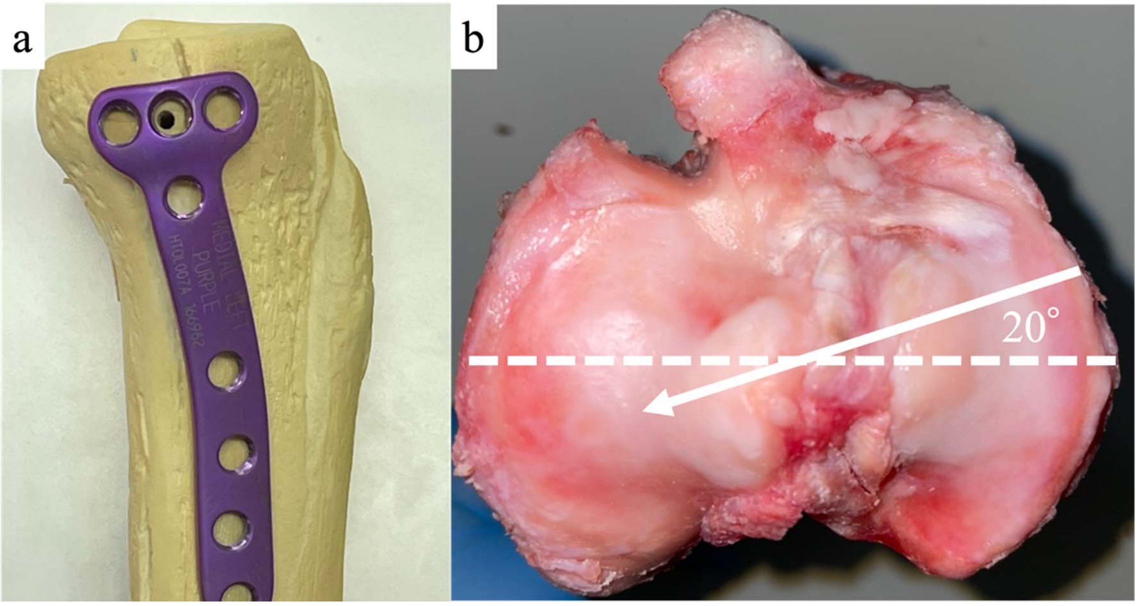

Figure 1. (a) TriS plate (Olympus Terumo Biomaterials, Tokyo, Japan). (b) Anteromedial plate positioning (left knee), with the screw positioned (white arrow) 20° from the transverse diameter of the tibial plateau (dotted line).

Materials and methods

Study design

All animal experiments were conducted in our institution's biomechanics laboratory following all Animal Care and Use Committee regulations, although the requirement for ethical approval was waived due to the study's *ex vivo* design. Thirty fresh porcine knees (age: 6 months; weight range: 180–200 kg; Tokyo Shibaura Zouki, Japan) were divided into three groups. The first group was MOWHTO (Group H) (n = 10); the second was DTO without an anteroposterior (AP) screw (Group D1) (n = 10); and the third was DTO with an AP screw (Group D2) (n = 10). All specimens were fitted with a TriS plate (Olympus Terumo Biomaterial, Tokyo, Japan) (Figure 1a) that was fixed to the medial tibia with the thread direction of the tibial diaphysis set at 20° (anteromedial position) from the transverse diameter of the tibial plateau (Figure 1b), as per a previous study by Takeuchi et al. [9]. The specimens were thawed at room temperature for at least 24 h before use. The medial proximal tibial angle (MTPA) of specimens before MOWHTO and DTO was not excessively valgus or varus macroscopically.

MOWHTO and DTO procedures

MOWHTO was performed on Group H specimens using standard surgical methods [10] (Figure 2a). First, we inserted a 1.6-mm K-wire 45 mm from the medial joint line and directed it towards the tip of the fibula. We confirmed the K-wire's direction by puncturing the opposite cortex and touching the fibula's tip. Further, an oscillating saw was used to perform the osteotomy, following the path of the K-wire from the posterior to the anterior medial tibial cortex. The osteotomy ended 5 mm from the lateral tibial cortex, leaving a hinge for opening. An additional osteotomy of the anterior third of the tibial cortex, including the tibial tuberosity fragment, was executed in the anterior forehead plane at an angle of 110° to the axial plane. We opened the osteotomy with three chisels while applying a bulging gas force to the distal end. A 6-mm gap was identified, and the osteotomy line was maintained parallel. A TriS plate was positioned medially on the proximal tibia and then fixed. Four locking monocortical screws and four bicortical screws were used to secure the proximal and distal bone fragments, respectively. We used a sleeve to guide the screws and ensure they were placed in the same direction. Group 1 had no artificial bone inserted into the open wedge.

DTO was performed on D1 and D2 specimens according to Ogawa et al.'s method [11] (Figures 2b and 2c). We initially conducted a distal tibial tuberosity osteotomy with a thickness of 7–8 mm at the thickest point of the tibial tuberosity [12]. The length of the osteotomised tibial tuberosity was 50 mm. The proximal part of the tibial tuberosity was attached to the proximal fragment of the tibia. Before the transverse osteotomy, a 1.6-mm K-wire was placed 50 mm from the medial joint line and directed towards the tip of the fibula. We then performed a transverse osteotomy at a right angle to the descending osteotomy in the sagittal plane, starting from the tibia's posteromedial corner (35 mm below the joint line to 7.5 mm from the lateral cortical margin at the level of the fibula head). We were careful to not disrupt the continuity of the tibial tuberosity and the proximal fragment of the tibia. This transverse osteotomy followed the direction of the K-wire from the posterior to the anterior medial tibial cortex. We carefully opened the osteotomy using three chisels while applying a bulging gas force to the distal end. A 6-mm gap was identified, and the osteotomy line was kept parallel. A TriS plate was placed medially on the proximal tibia and then fixed. Four locking monocortical screws and four bicortical screws were used to secure the proximal and distal bone fragments, respectively. We used a sleeve to guide the screws and ensure they were placed in the same direction. No

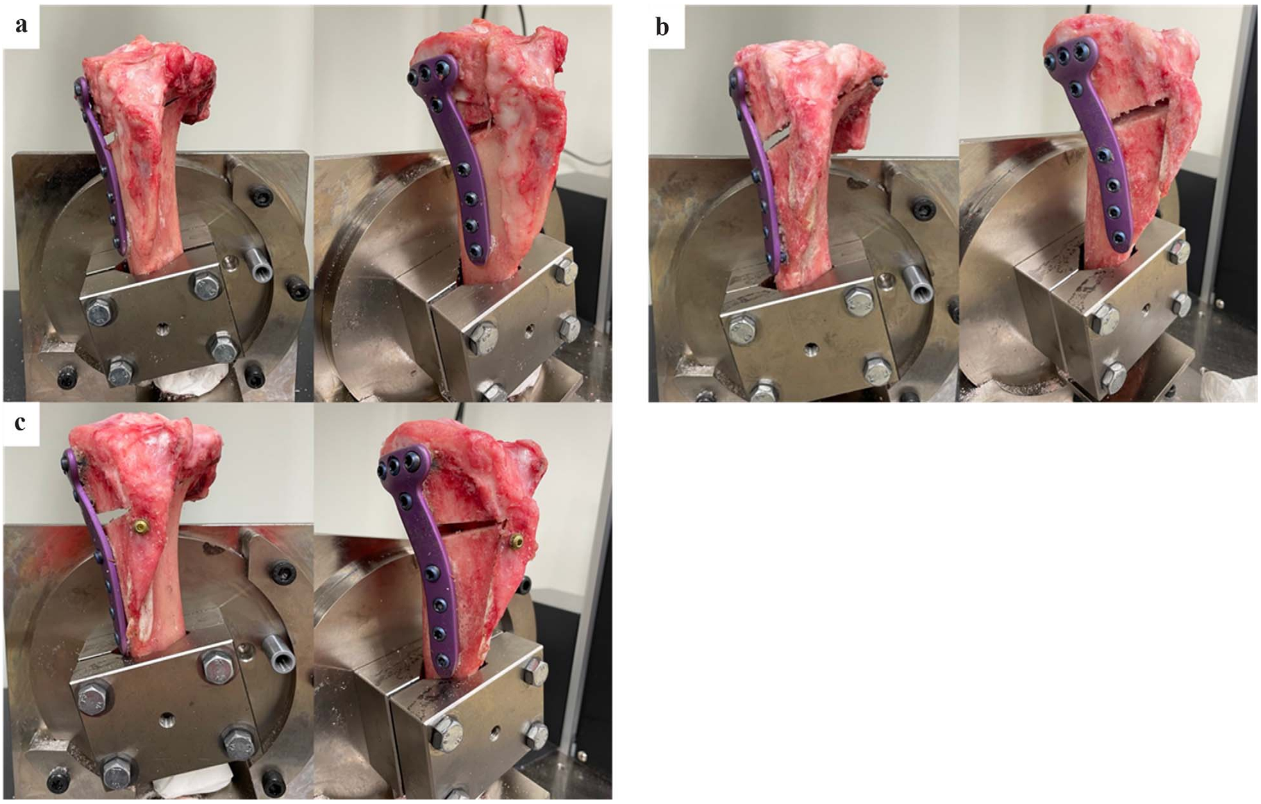

Figure 2. Specimen preparation: (a) specimen after MOWHTO to the left knee; (b) specimen after DTO without AP screw to the left knee; (c) specimen after DTO with AP screw to the left knee. AP: anteroposterior; DTO: distal tuberosity osteotomy; MOWHTO: medial open wedge high tibial osteotomy.

artificial bone was inserted into the open wedge in Groups D1 and D2. Finally, the tibial tuberosity was fixed to the distal fragment of the tibia with an AP screw in the case of Group D2. Group D1 specimens were not fitted with AP screws.

Biomechanical evaluation

We used cyclic testing to investigate the translation patterns of the three fixation constructs. This testing was performed along the postoperative mechanical axis of the tibia using a tensile testing machine (Tensilon RTG 1310, Orientec Co. Ltd., Tokyo, Japan) equipped with a specially designed set of grips. This measurement system aligned with the one used in a prior biomechanical study [13–15]. After removing 10 cm of the distal tibia, 4 cm of the distal portion of each tibia was clamped using a custom-made jig (Figure 3). MTPA after MOWHTO and DTO was about 90°, and the proximal tibial articular after setting was level with the lane of loading macroscopically. Load-displacement curves were generated with specific software (Tensilon Advanced Controller for Testing, Orientec Co., Japan). The tibia was then subjected to cyclic loading up to 800 N (2000 cycles, 0.5 Hz) as previously described by Takeuchi et al. [9]. The displacements in the machine's axial direction at the 10th, 100th, 500th, 1000th, 1500th, and 2000th cycles were calculated by the software, measuring actuator displacement during the cycle (Figures 4a and 4b). The alignment of specimens after cyclic loading was not excessively altered macroscopically. The AG and PG changes in the osteotomy site were measured using a precision calliper with an accuracy of 0.1 mm. Measurements of the AG and PG changes were taken by two researchers and averaged over three measurements. Therefore, intra- and inter-rater reliability was improved. Increased PTS was calculated by subtracting AG from PG and using the anteroposterior diameter of the proximal tibial articular surface (average 50 mm). The AP diameter of the porcine's proximal tibial articular was measured at an average of 50 mm; therefore, the AP diameter was calculated at 50 mm in this study.

Statistical analyses

Repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc analysis was employed to assess displacement among the three groups. A one-way ANOVA with Tukey post hoc analysis was used to evaluate AG and PG changes, and increased PTS among the three groups. All data are presented as mean ± standard deviations. P-values <0.05 were considered statistically significant. An *a priori* power analysis was conducted using G*Power 3.1 (Franz Paul, Kiel, Germany) [16]. The sample size for α error was set at <0.05, for β error at <0.20, and the effect size was 0.46 for repeated-measures ANOVA and 0.60 for one-way ANOVA. All statistical analyses were carried out using the EZR software [17]. The minimum sample size by one-way ANOVA of AG and PG

Figure 3. A tibia after DTO with AP screw was clamped with custom-made jig of a tensile testing machine.

changes and increased PTS was 66, and the minimum sample size by repeated-measures ANOVA of actuator displacement was 291. If a significant difference was found with fewer samples than these, it meant that the difference was quite large. Therefore, the effect sizes for the repeated measures and one-way ANOVA were larger than Cohen's effect size guidelines, indicating that the differences between each group were highly significant.

Results

Displacement during cyclic loading

There were no significant differences in displacement for the 10th, the 100th, the 500th, the 1000th, the 1500th and the 2000th cycle among the three groups, respectively (Table 1).

Changes in the AG and PG

There were no significant differences in anterior gap changes, respectively (Table 2). However, significant differences were observed in posterior gap changes, respectively (P = 0.00042) (Table 2). The post hoc analysis revealed significant differences between Groups H and D1 (P = 0.00090) and Groups H and D2 (P = 0.0021) (Figure 5a).

Changes in increased PTS

Significant differences were observed in increased PTS, respectively (Table 2). The post hoc analysis revealed significant differences between Groups H and D1 (P = 0.035) and Groups H and D2 (P = 0.021) (Figure 5b).

Discussion

In this study, MOWHTO exhibited less of an increase in PTS after cyclic loading than DTO, regardless of the presence or absence of an AP screw. This is the first study to quantitatively compare increases in PTS after cyclic loading following MOWHTO and DTO with and without an AP screw.

We found that the proximal fragment contributed to the increased PTS during cyclic loading after both MOWHTO and DTO. However, the increase in PTS observed following MOWHTO was less pronounced than following DTO regardless of AP screw use. Kim et al. used an anteromedial plate – similar to the TriS plate – and reported an increase in PTS following MOWHTO; however, the increase was less than that observed following DTO in another clinical study [18]. In the previous studies, several investigators generally reported that PTS increased after MOWHTO [19–22], whereas others reported that PTS did not change or decrease after MOWHTO [23, 24] (Table 3).

Greater PTS has been linked to strain on the anterior cruciate ligament (ACL) and greater anterior tibial translation in the knees [1, 7]. Furthermore, patients with ACL tears demonstrate increased PTS than knees with normal ACLs [25]. Therefore, increases in PTS may increase the risk of ACL injury. In a biomechanical study of walking movement, an anterior shear force increased by 30% and anterior tibial translation increased by 2.4 mm when PTS increased by 5° [26]. Hence, minimising PTS changes after surgery is crucial. Our results suggest that MOWHTO helps reduce ACL strain after surgery because it produces less of an increase in PTS.

When axial load was applied to the proximal tibial surface in all three groups, there was a noticeable movement of the proximal surface, increasing the PTS. MOWHTO also moves the proximal surface and PTS increases under axial loading. However, the contact between the tibial tuberosity fragment and the anterior surface of the proximal tibia may have mitigated further increases in PTS. Therefore, when an axial load was applied, PTS increased slightly, contacting and pressing against the anterior surface of the proximal tibia and the tibial tuberosity fragment. This contact and compression between the two fragments may have helped accelerate the early bony union.

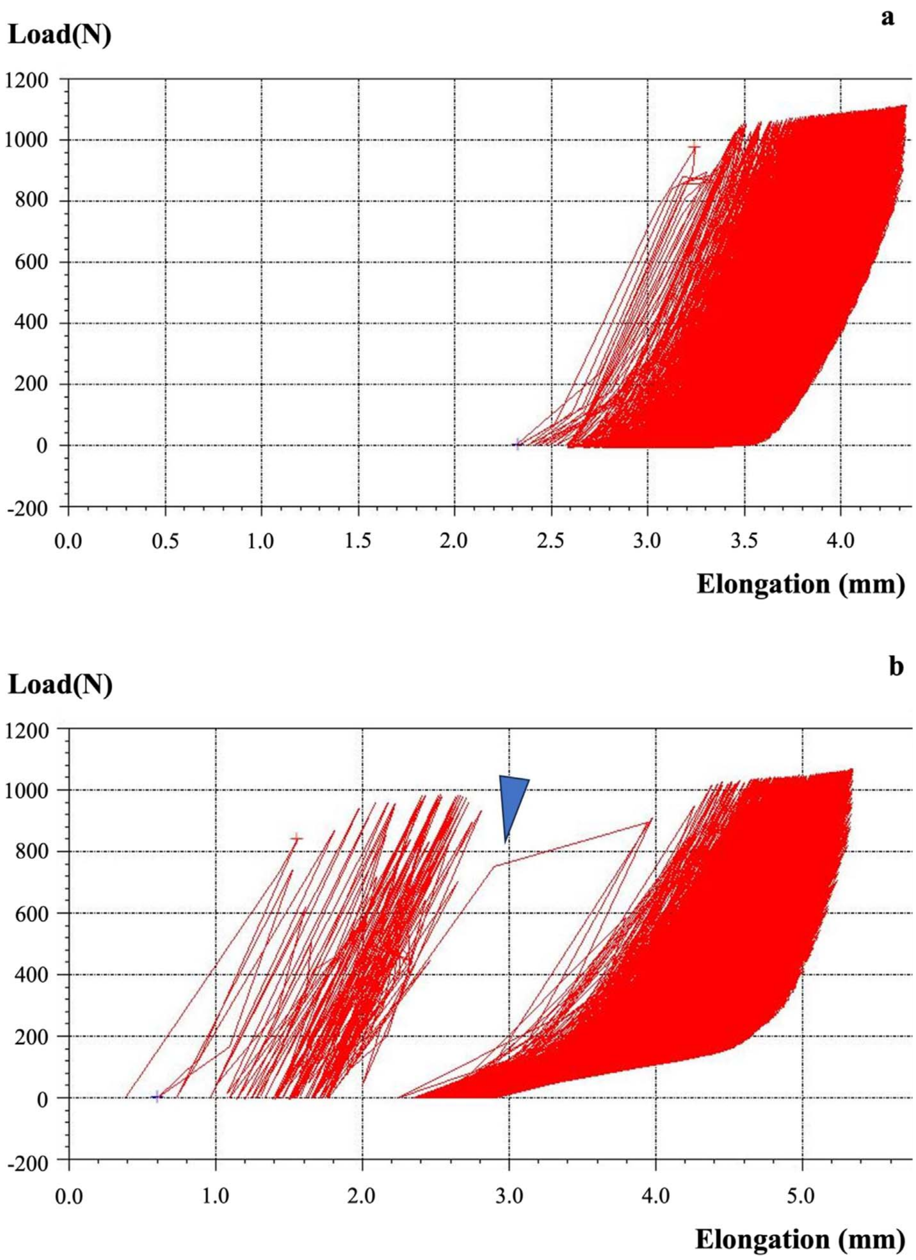

Figure 4. Schematic image of the load-displacement curve generated during cyclic testing with this software. (a) The load-displacement curve of MOWHTO generated during cyclic testing with this software. (b) The load-displacement curve of DTO with AP screw generated during cyclic testing with this software, including a hinge fracture (triangle). AP: anteroposterior; DTO: distal tuberosity osteotomy; MOWHTO: medial open wedge high tibial osteotomy.

Table 1. The displacement among the three groups.

Parameters	Group H (n = 10)	Group D1 (n = 10)	Group D2 (n = 10)
10th (mm)*	0.92 (0.21)	1.08 (0.38)	1.10 (0.28)
100th (mm)*	0.94 (0.24)	1.08 (0.37)	1.23 (0.43)
500th (mm)*	0.93 (0.27)	1.22 (0.52)	1.28 (0.55)
1000th (mm)*	1.01 (0.41)	1.29 (0.56)	1.33 (0.57)
1500th (mm)*	1.02 (0.44)	1.39 (0.61)	1.36 (0.59)
2000th (mm)*	1.02 (0.47)	1.47 (0.60)	1.35 (0.59)

* Data are expressed as mean (standard deviation).

Table 2. The anterior and posterior gap changes and the posterior tibial slope changes among three groups.

Parameters	Group H (n = 10)	Group D1 (n = 10)	Group D2 (n = 10)	P value**
The anterior gap changes*	0.06 (0.32)	0.20 (0.17)	0.11 (0.36)	0.57
The posterior gap changes*	0.00 (0.36)	0.64 (0.32)	0.59 (0.36)	0.00042
The posterior tibial slope changes*	−0.070 (0.41)	0.50 (0.42)	0.55 (0.60)	0.013

* Data are expressed as mean (standard deviation).
** Comparison among Groups by use of one-way analysis of variance.

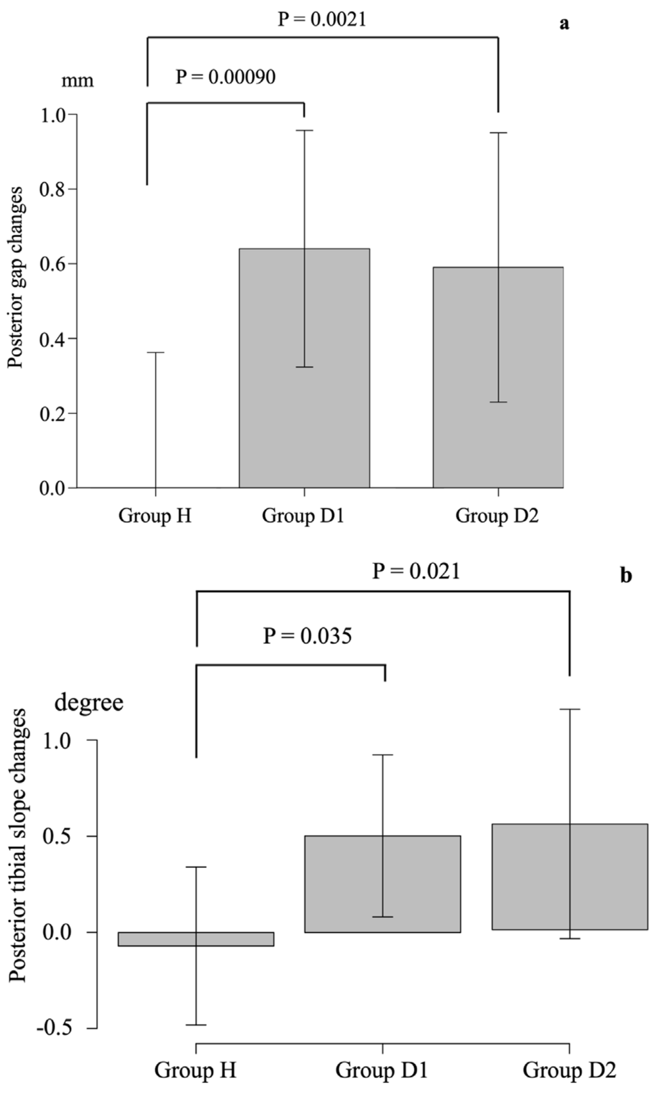

Figure 5. Group-specific displacement: (a) Group-specific changes in the posterior gap, (b) Group-specific changes in the posterior tibial slope.

Nakamura et al. previously reported that MOWHTO with pes anserinus preservation generated natural compression forces between the proximal and tibial tuberous fragments [27]. The authors felt this compression fostered an efficient union involving soft tissues. In this study, soft tissues – including the patellar tendon and pes anserinus – were removed. Despite the absent pes anserinus, which acts as a dynamic stabiliser, MOWHTO still promoted efficient union by transmitting axial loading and the resulting compression forces between the tibial tuberosity fragment and the anterior surface of the proximal tibia.

MOWHTO is an osteotomy designed to reduce the pressure of the medial knee compartment and Habib et al. reported that improvement in femoral and tibial articular cartilage in the medial compartment owing to the unloading effect of MOWHTO and regeneration of fibrocartilage [28]. In contrast, DTO is an osteotomy designed to maintain the patellar height and has been reported to have a lesser impact on the progression of PF osteoarthritis than MOWHTO [5, 6]. Therefore, DTO is a suitable choice in patellar baja or PF osteoarthritis cases [5]. DTO is recommended for young and middle-aged patients with a normal patellar height because it does not alter it [29]. However, Kim et al. reported no significant differences in the occurrence of PF osteoarthritis between MOWHTO and DTO [7, 30]. Double-level osteotomy could be an alternative treatment for DTO because Double-level osteotomy is not a change of patellar height like DTO [31]. Hence, it is debatable which surgical method is better for preventing the progression of PF osteoarthritis. Therefore, a study comparing the clinical outcomes of PF osteoarthritis after MOWHTO and DTO would be valuable.

This study does have several limitations that should be acknowledged. First, results generated from porcine bone experiments may not directly translate into clinical practice as porcine tibias might possess different fixation forces than human tibias. However, it is worth noting that porcine knees are very similar to human knees and, for this reason, are commonly used in biomechanical studies [13, 15, 32]. Second, this study focused solely on time-zero structural characteristics in specimens subjected to MOWHTO or DTO. We did not consider the influence of any biological healing processes. Moreover, the *ex vivo* nature of the study may not fully replicate actual *in vivo* loading conditions. Therefore, future *in vivo* studies are needed to determine if similar results can be achieved in real-life settings. Third, the machine used in this study could only evaluate axial direction. In this study, however, increased PTS can be assessed by measuring the AG and PG. Hence, evaluation in the sagittal direction was also possible. Fourth, there might have been slight malalignment because no radiographic evaluation was performed. Two researchers confirmed that there were no major deformations before and after the cyclic test, and the inter-rater reliability was minimized as much as possible. Finally, the limit of the machine in this study was 2000 cycles. If more cycles had been performed, there might have been differences in displacement and changes in AG.

Despite these limitations, this study represents the first biomechanical comparison of MOWHTO and DTO, both with and without an AP screw, after cyclic loading. From a clinical

Table 3. List of previous clinical studies about PTS after MOWHTO.

Author	Age	Plate	Result (degrees)	
Yoon et al. [19]	63.6 ± 6.9	Anatomical plate	10.2 ± 2.8	11.2 ± 3.9
Ji et al. [20]	50.4 ± 8.5	TOMOFIX	10.2 ± 3.1	10.5 ± 3.1
Yazdi et al. [21]	42.4 ± 10.0	Puddu plate	16.3 ± 4.2	17.1 ± 4.2
	41.0 ± 9.9	TOMOFIX	16.9 ± 4.7	17.7 ± 5.4
Mabrouk et al. [23]	42.1 ± 12.3	Unknown	9.6 ± 3.4	9.4 ± 3.2
Park et al. [24]	<55	TOMOFIX	10.2 ± 4.4	9.7 ± 4.5
	>65	TOMOFIX	12.1 ± 3.6	11.1 ± 4.1
Li et al. [22]	57.2 ± 7.4	TOMOFIX	8.8 ± 3.7	9.0 ± 3.3

perspective of this study, MOWHTO is the preferred treatment for internal knee osteoarthritis and ACL insufficiency. Further, in vivo research is needed to delve deeper into this topic.

In conclusion, MOWHTO demonstrated a significantly smaller increase in PTS than DTO, regardless of the presence or absence of AP screws. Considering this result, MOWHTO is the preferred treatment for medial knee osteoarthritis and ACL insufficiency. Therefore, when considering treatment options for knee osteoarthritis in young patients, selecting the appropriate osteotomy method is important, considering other knee joint pathologies.

Funding

This work was supported by the J&J Medical Research Grant [grant numbers AS2022A000070909].

Conflicts of interest

The authors declare that they have no relevant financial or non-financial interest in the report.

Data availability statement

Data and materials of this study are available from the corresponding author on reasonable request.

Author contribution statement

Tsuneari Takahashi: Conceptualization, Methodology, Writing, Reviewing, Editing and Supervision; Yoshiya Nibe: Conceptualization, Methodology, Writing original draft, Visualization, Investigation Reviewing, and Editing; Hironori Hai: Conceptualization, and Methodology, Tomohiro Matsumura and Katsushi Takeshita: Conceptualization, Methodology and Supervision.

Ethics approval

Ethical approval was not required.

Informed consent

This article does not contain any studies involving human subjects.

References

1. Rodner CM, Adams DJ, Diaz-Doran V, Tate JP, Santangelo SA, Mazzocca AD, Arciero RA (2006) Medial opening wedge tibial osteotomy and the sagittal plane: the effect of increasing tibial slope on tibiofemoral contact pressure. Am J Sports Med 34(9), 1431–1441.
2. Gaasbeek R, Welsing R, Barink M, Verdonschot N, van Kampen A (2007) The influence of open and closed high tibial osteotomy on dynamic patellar tracking: a biomechanical study. Knee Surg Sports Traumatol Arthrosc 15(8), 978–984.
3. Kim KI, Kim DK, Song SJ, Lee SH, Bae DK (2017) Medial open-wedge high tibial osteotomy may adversely affect the patellofemoral joint. Arthroscopy 33(4), 811–816.
4. Gaasbeek RD, Sonneveld H, van Heerwaarden RJ, Jacobs WC, Wymenga AB (2004) Distal tuberosity osteotomy in open wedge high tibial osteotomy can prevent patella infera: a new technique. Knee 11(6), 457–461.
5. Akiyama T, Osano K, Mizu-Uchi H, Nakamura N, Okazaki K, Nakayama H, Takeuchi R (2019) Distal tibial tuberosity arc osteotomy in open-wedge proximal tibial osteotomy to prevent patella infra. Arthrosc Tech 8(6), e655–e662.
6. Ren YM, Tian MQ, Duan YH, Sun YB, Yang T, Hou WY (2022) Distal tibial tubercle osteotomy can lessen change in patellar height post medial opening wedge high tibial osteotomy? a systematic review and meta-analysis. J Orthop Surg Res 17(6), 341.
7. Giffin JR, Vogrin TM, Zantop T, Woo SL, Harner CD (2004) Effects of increasing tibial slope on the biomechanics of the knee. Am J Sports Med 32(2), 376–382.
8. Nha KW, Kim HJ, Ahn HS, Lee DH (2016) Change in posterior tibial slope after open-wedge and closed-wedge high tibial osteotomy: a meta-analysis. Am J Sports Med 44(11), 3006–3013.
9. Takeuchi R, Woon-Hwa J, Ishikawa H, Yamaguchi Y, Osawa K, Akamatsu Y, Kuroda K (2017) Primary stability of different plate positions and the role of bone substitute in open wedge high tibial osteotomy. Knee 24(6), 1299–1306.
10. Takahashi T, Handa M, Kimura Y, Takeshita K (2022) Intraoperative laximetry-based selective transtibial anterior cruciate ligament reconstruction concomitant with medial open wedge high tibial osteotomy for treating varus knee osteoarthritis with anterior cruciate ligament deficiency. Arthrosc Tech 11 (6), e959–e963.
11. Ogawa H, Nakamura Y, Sengoku M, Shimokawa T, Ohnishi K, Akiyama H (2023) Effect of medial opening wedge distal tibial tuberosity osteotomy on possible neuropathic pain in patients with osteoarthritis of the knee. Knee 43, 114–121.
12. Ogawa H, Nakamura Y, Sengoku M, Shimokawa T, Sohmiya K, Ohnishi K, Matsumoto K, Akiyama H (2022) Thinner tuberosity osteotomy is more resistant to axial load in medial open-wedge distal tuberosity proximal tibial osteotomy: a biomechanical study. Knee 38, 62–68.
13. Ando J., Takahashi T., Matsumura T., Nibe Y., Takeshita K. (2024) Biomechanical comparisons of plate placement for medial tibial plateau fractures (Schatzker Type IV): a biomechanical study using porcine tibias. Injury 55(6), 111158.
14. Matsumura T, Takahashi T, Ae R, Takeshita K (2022) Biomechanical comparisons of trochanteric hip fracture fixation using short-, mid-, and long-length proximal femoral nails. Geriatr Orthop Surg Rehabil 13, 21514593221111350.

15. Nibe Y., Takahashi T., Kubo T., Matsumura T., Takeshita K. (2023) Effect of plate position on tibial displacement and posterior tibial slope after cyclic loading in medial open wedge high tibial osteotomy: a biomechanical study using porcine tibia. Clin Biomech (Bristol, Avon) 109, 106076.
16. Faul F, Erdfelder E, Lang AG, Buchner A (2007) G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39(2), 175–191.
17. Kanda Y (2013) Investigation of the freely available easy-to-use software "EZR" for medical statistics. Bone Marrow Transplant 48(3), 452–458.
18. Kim JS, Lee JI, Choi HG, Yoo HJ, Jung YS, Lee YS (2021) Retro-tubercle biplanar opening wedge high tibial osteotomy is favorable for the patellofemoral joint but not for the osteotomized tubercle itself compared with supra-tubercle osteotomy. Arthroscopy 37(8), 2567–2578.
19. Yoon J.R., Koh Y.Y., Lee S.H. (2023) Estimation of the proper gap ratio using preoperative radiography for posterior tibial slope maintenance in biplanar open wedge high tibial osteotomy. J Orhops Surg Res 18(1), 219.
20. Ji S, Gao Y, Zhang J, Pan F, Zhu K, Jiang X, Zhou Y (2023) High tibial lateral closing wedge and opening wedge valgus osteotomy produce different effects on posterior tibial slope and patellar height. Front Surg 12, 10.
21. Yazdi HR, Torkaman A, Ebrahimzadeh Babaki A, Soleimani M, Eslami A (2023) Fixation method can affect posterior tibial slope in opening-wedge high tibial osteotomy: a retrospective study. J Orthop Surg Res 18(1), 780.
22. Li K, Guo H, Sun F, Wang H (2024) Less risk of patellofemoral degeneration without significant clinical and survivorship difference for distal tibial tuberosity high tibial osteotomy compared to biplanar high tibial osteotomy over a mid-term follow-up. J Orthop Surg (Hong Kong) 32(2). https://doi.org/10.1177/10225536241273925.
23. Mabrouk A, An JS, Fernandes LR, Kley K, Jacquet C, Ollivier M (2023) Maintaining posterior tibial slope and patellar height during medial opening wedge high tibial osteotomy. Orthop J Sports Med 11(12). https://doi.org/10.1177/23259671231213595.
24. Park JY, Kim JH, Cho JW, Kim MS, Choi W (2024) Clinical and radiological results of high tibial of osteotomy over the age of 65 are comparable to that of under 55 at minimum 2-year follow-up: A propensity score matched analysis. Knee Surg Relat Res 36(1). https://doi.org/10.1186/s43019-024-00214-9
25. Brandon ML, Haynes PT, Bonamo JR, Flynn MI, Barrett GR, Sherman MF (2006) The association between posterior-inferior tibial slope and anterior cruciate ligament insufficiency. Arthroscopy 22(8), 894–899.
26. Shelburne KB, Kim HJ, Sterett WI, Pandy MG (2011) Effect of posterior tibial slope on knee biomechanics during functional activity. J Orthop Res 29(2), 223–231.
27. Nakamura R, Kuroda K, Takahashi M, Katsuki Y (2022) Open wedge high tibial osteotomy with pes anserinus preservation and insertion of bone substitutes. Arthrosc Tech 11(1), e69–e78.
28. Habib MK, Khan ZA (2019) Radiological, functional, and anatomical outcome in patients with osteoarthritic knee undergoing high tibial osteotomy. SICOT J 5, 12.
29. Erquicia J, Gelber PE, Perelli S, Ibañez F, Ibañez M, Pelfort X, Monllau JC (2019) Biplane opening wedge high tibial osteotomy with a distal tuberosity osteotomy, radiological and clinical analysis with minimum follow-up of 2 years. J Exp Orthop 6(1), 10.
30. Yoon WK, Kim KI, Kim JH, Lee SH, Jo MG (2022) Does degeneration of the patellofemoral joint after medial open-wedge high tibial osteotomy affect clinical outcomes? Am J Sports Med. 50(11), 2972–2979.
31. Elbardesy H, McLeod A, Ghaith HS, Hakeem S, Housden P (2022) Outcomes of double level osteotomy for osteoarthritic knees with severe varus deformity. A systematic review. SICOT J 8, 7.
32. Kubo T, Takahashi T, Kimura M, Takeshita K (2022) Biomechanical comparisons of anterior cruciate ligament avulsion fracture fixation using high-strength suture and ultra-high molecular weight polyethylene suture tape in a porcine model. J Knee Surg. 35(11), 1199–1203.

Cite this article as: Nibe Y, Takahashi T, Hai H, Matsumura T & Takeshita K (2024) Comparative biomechanical analysis of tibial posterior slope in medial open wedge high tibial osteotomy vs. distal tuberosity osteotomy with and without anterior-posterior screw: a study using porcine tibia. SICOT-J **10**, 41