Kumagai *et al. Journal of Orthopaedic Surgery and Research* (2024) 19:598
https://doi.org/10.1186/s13018-024-05096-x

Journal of Orthopaedic Surgery and Research

RESEARCH ARTICLE | Open Access

Adjusted planning based on the joint line convergence angle improves correction accuracy in the standing position after opening wedge high tibial osteotomy

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Abstract

Background Postoperative change of the joint line convergence angle (JLCA) is known to be a factor affecting correction error in opening wedge high tibial osteotomy (OWHTO). The purpose of this study was to assess whether preoperative planning that considers change of the JLCA can achieve accurate correction in the standing position after OWHTO.

Methods OWHTO was performed for 109 knees with osteoarthritis of the knee. The amount of angular correction was planned aiming to achieve mechanical valgus of 5° in 55 knees (conventional planning), and it was adjusted in 54 knees (adjusted planning) according to the preoperative JLCA as follows: not changed with JLCA ≤ 3°; decreased 1° with JLCA 4–6°; decreased 2° with JLCA 7–8°; and decreased 3° with JLCA ≥ 9°. The hip-knee-ankle (HKA) angle, JLCA, and medial proximal tibial angle (MPTA) were measured on standing long-leg radiographs. Correction error ≤ 2º was defined as the acceptable range, and correction error > 2º was defined as an outlier.

Results The conventional planning group had a significantly greater postoperative HKA angle than the adjusted planning group (6.1º and 4.9º, respectively). The mean JLCA decreased from 4.8º to 2.6º in the conventional planning group and from 4.6º to 2.7º in the adjusted planning group. The conventional planning group had significantly greater postoperative MPTA than the adjusted planning group (96.2º and 94.7º, respectively). The rate of outliers with correction error > 2º was significantly lower in the adjusted planning group (9%) than in the conventional planning group (24%). The rate of the MPTA > 95º was significantly lower in the adjusted planning group (30%) than in the conventional planning group (69%).

Conclusions This study demonstrated that preoperative planning with adjustment of the correction angle according to the preoperative JLCA improved correction accuracy in the standing position after OWHTO.

Keywords Opening wedge high tibial osteotomy, Preoperative planning, Correction accuracy, Standing position, Joint line convergence angle

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Introduction

High tibial osteotomy (HTO) is an established procedure to optimize lower limb alignment for medial compartmental osteoarthritis (OA) of the knee. While the primary goal of HTO is to provide pain relief and improvement in activities of daily living, it also has the potential to maintain or even improve sports activity levels [1]. Opening wedge HTO (OWHTO) has recently been increasingly performed because it allows for more precise correction of the angle than the closed wedge technique [2], and good mid- to long-term clinical outcomes have been demonstrated [3]. OWHTO Additionally, OWHTO can be effectively combined with other cartilage restoration procedures such as bone marrow stimulation, osteochondral autograft transplantation and autologous chondrocyte implantation [4, 5].

Recent studies suggested that change of soft tissue balance is an important factor affecting correction error in OWHTO [6–8]. Even if accurate target al.ignment is obtained intraoperatively and the plate is optimally positioned [9], it could be lost by postoperative early change of the joint line convergence angle (JLCA) [10]. Multiple regression analysis suggested that postoperative JLCA on the day of surgery was the factor related to early postoperative change of knee alignment [10]. Unexpected overcorrection is likely to occur in cases with a preoperatively large JLCA [11]. Moreover, intraoperative soft tissue management, such as the release of the medial collateral ligament (MCL), can significantly impact JLCA and influence the final alignment outcome [12–14]. Thus, the amount of correction should be planned with consideration of a postoperative change of the JLCA. Several studies have proposed predictive approaches to calculate changes in JLCA [6, 8, 15]. Nevertheless, their applicability in clinical practice has not been sufficiently validated yet.

The purpose of this study was to assess whether preoperative planning that considers change of the JLCA can achieve accurate correction in the standing position after OWHTO. It was hypothesized that preoperative planning with adjustment of the correction angle according to the preoperative JLCA improves correction accuracy in the standing position after OWHTO.

Materials and methods

Patients

A total of 109 knees of 96 patients with medial compartmental OA of the knee who underwent OWHTO by a single surgeon (K.K.) between 2012 and 2021 were included in this retrospective study. The patients had a mean age of 67.2 ± 8.4 years (median age 68 years, range 42–84 years). The inclusion criteria were based on our surgical indications: painful OA localized in the medial compartment of the knee, with no functional instability of the anterior cruciate ligament. The exclusion criteria were severe varus deformity (mechanical varus alignment > 10°), flexion contracture > 15°, osteonecrosis of the knee, concomitant procedures such as meniscal repair and cartilage repair, or a history of inflammatory arthritis, joint infection, or immunosuppressive therapy. This study was approved by the institutional review board of our hospital (#B180200061).

Preoperative planning

The amount of angular correction was planned using digital planning software (OP-A software, Fujifilm Co. Ltd., Tokyo, Japan) aiming to achieve mechanical valgus of 5° on weight-bearing long-leg radiographs in the first half of the cases (conventional planning, n = 55) [3, 16, 17]. The amount of angular correction was adjusted in the latter half of the cases (adjusted planning, n = 54) according to the preoperative JLCA, based on a previous report [10, 11], as follows: the amount of correction after conventional planning was not changed with the JLCA ≤ 3°; it was decreased by 1° with the JLCA 4–6°; decreased by 2° with the JLCA 7–8°; and decreased by 3° with the JLCA ≥ 9°.

Surgical procedure and postoperative management

HTO was performed using the opening-wedge technique with rigid plate fixation [3]. The superficial layer of the medial collateral ligament (MCL) was released with subperiosteal elevation. The osteotomized gap was gradually opened until the preoperatively planned opening distance was obtained, and it was then filled with two wedged bone substitutes composed of beta-tricalcium phosphate with 60% porosity (Osferion, Olympus Terumo Biomaterials. Corp., Tokyo, Japan). A TomoFix plate (DePuy Synthes, Zuchwil, Switzerland) was placed on the osteotomy site and fixed with locking screws.

Patients started a postoperative rehabilitation program including isometric quadriceps exercise and range-of-motion exercise the day after surgery. A non-weight-bearing regimen was prescribed for 1 week, followed by full weight-bearing exercise. Casts or supportive devices were never applied.

Radiographic measurements

Full-length anteroposterior radiographs of the lower limb were taken in the standing position preoperatively and one and 12 months postoperatively. Limb alignment was expressed as the hip-knee-ankle (HKA) angle, measuring the angle between the mechanical axes of the femur and tibia, with negative values for varus and positive values for valgus (Fig. 1a). The JLCA was measured as the angle formed between a line tangent to the distal femoral condyle and the proximal tibial plateau (Fig. 1b). The medial proximal tibial angle (MPTA) was measured

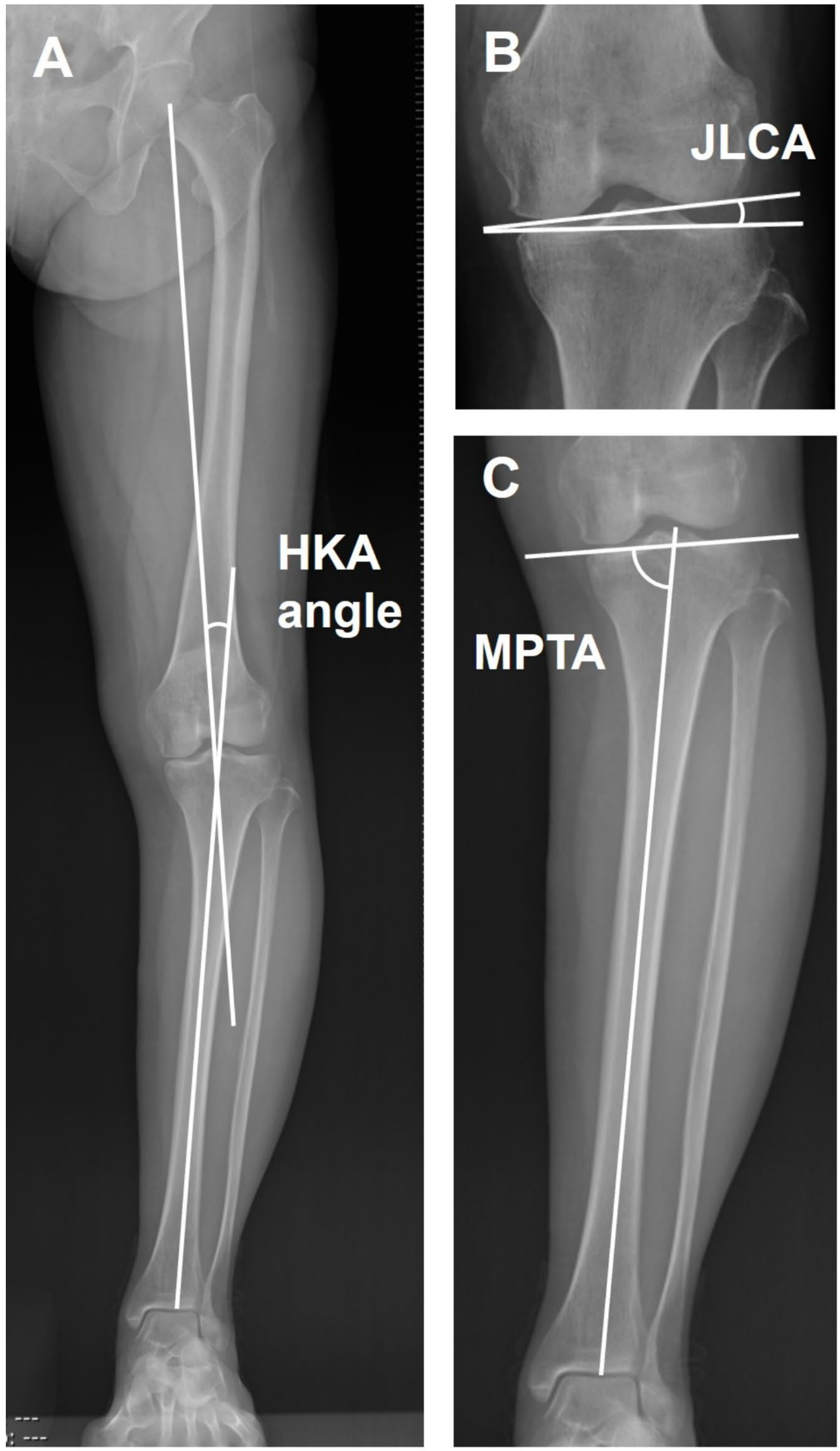

Fig. 1 Radiographic measurements. (**A**) Hip-knee-ankle (HKA) angle. (**B**) Medial proximal tibial angle (MPTA). (**C**) Joint line convergence angle (JLCA)

as the medial angle formed between the tibial mechanical axis and the knee joint line of the tibia (Fig. 1c). Two board-certified orthopaedic surgeons (K.K. and S.Y.) independently performed radiographic measurements and interpretation twice at an interval of more than two months. The correction error was calculated by the difference between the target al.ignment (HKA angle of 5°) and the postoperative HKA angle at one month.

Correction error ≤ 2° was defined as acceptable range, and correction error > 2° was defined as an outlier. The rate of the MPTA > 95° was assessed, since previous studies have indicated that an MPTA > 95° may negatively impact the clinal outcomes [18, 19].

Statistical analysis

Statistical analysis was carried out using BellCurve for Excel version 4.05 (Social Survey Research Information, Tokyo, Japan). The Mann-Whitney U test and the Kruskal-Wallis test were used to analyse differences in continuous variables. Pearson's chi-squared test was used to analyse independence of categorical variables. An adjusted p value < 0.05 was considered significant. A power calculation showed that a sample size of 53 in each preoperative planning group could detect differences with an effect size of 0.5, α error of 0.05, and power of 0.8. Thus, the required sample was determined to be 54 or 55 knees in each group. The intra-rater and inter-rater reliabilities of radiographic measurements were assessed by calculating intraclass correlation coefficients (ICCs).

Results

Patient characteristics and postoperative complications

There were no significant differences in patient characteristics between the conventional planning group and the adjusted planning group (Table 1). Surgical site infections occurred in one knee of the conventional planning group and two knees of the adjusted planning group. A lateral cortical hinge fracture (Takeuchi type I) [20] was observed in three knees of the conventional planning group and three knees of the adjusted planning group. No loss of correction was found in these patients with complications.

Assessment of radiographic outcomes

Radiographs of representative cases are shown in Fig. 2. Preoperative and postoperative measurements of the HKA angle, JLCA, and MPTA are summarized in Table 2. The mean HKA angle was increased from preoperative −7.1° to postoperative 6.1° in the conventional planning group and from preoperative −6.9° to postoperative 4.9° in the adjusted planning group, but it was not significantly changed from postoperative 1 to 12 months in both groups. The conventional planning group had a significantly greater postoperative HKA angle than the adjusted planning group. The mean JLCA decreased from preoperative 4.8° to postoperative 2.6° in the conventional planning group and from preoperative 4.6° to postoperative 2.7° in the adjusted planning group, but it was not significantly changed from postoperative 1 to 12 months in both groups. The mean JLCA was not significantly different between the two groups at each time point. The mean MPTA was significantly increased from preoperative 84.0° to postoperative 96.2° in the conventional planning group and from preoperative 84.2° to postoperative 94.7° in the adjusted planning group, but it was not significantly changed from postoperative 1 to 12 months in both groups. The conventional planning group had a greater mean postoperative MPTA than the adjusted planning group (96.2° and 94.7°, respectively). The ICCs for each radiographic measurement ranged from 0.82 to 0.93 for inter-rater reliabilities and from 0.91 to 0.98 for intra-rater reliabilities, indicating good reliability.

Table 1 Patients' characteristics

	Conventional planning	Adjusted planning	P value
Knees (patients), n	55 (50)	54 (47)	
Female, n (%)	41 (75)	38 (70)	0.63
Age, years *	67.8 ± 9.0	66.7 ± 7.9	0.44
Body mass index, kg/m^2 *	25.1 ± 3.0	25.8 ± 3.3	0.14
Radiographic classification† : Grade 1/2/3/4/5, n	0/36/19/0/0	0/31/23/0/0	0.39

* The values are given as means ± standard deviation

†OA grade modified from the Ahlbäck classification

Distribution of correction error and MPTA

The distributions of correction error at postoperative 1 month are summarized in Fig. 3; Table 3. The rate of outliers with correction error > 2° was significantly lower in the adjusted planning group (9%) than in the conventional planning group (24%). The distributions of the MPTA at postoperative 1 month are summarized in Fig. 4; Table 4. The rate of the MPTA > 95° was significantly lower in the adjusted planning group (30%) than in the conventional planning group (69%).

Discussion

The most important finding of the present study was that correction error > 2° in OWHTO was significantly decreased by adjusting the correction angle according to the preoperative JLCA. This novel planning method could improve the correction accuracy of limb alignment in the standing position. In addition, the rate of postoperative MPTA > 95° was significantly decreased by adjusting the correction angle considering change of the JLCA. These results suggested that the novel planning method can achieve targeted correction with reduced overcorrection regarding the MPTA.

Recent studies discussed the issue of an increased MPTA after isolated OWHTO [19, 21], since an MPTA greater than 95° is associated with excessive shear stress on the articular cartilage [18]. When performing total knee arthroplasty after HTO, in cases with an increased MPTA, the tibial resection tends to be thicker on the medial side, leading to medial compartment laxity [22].

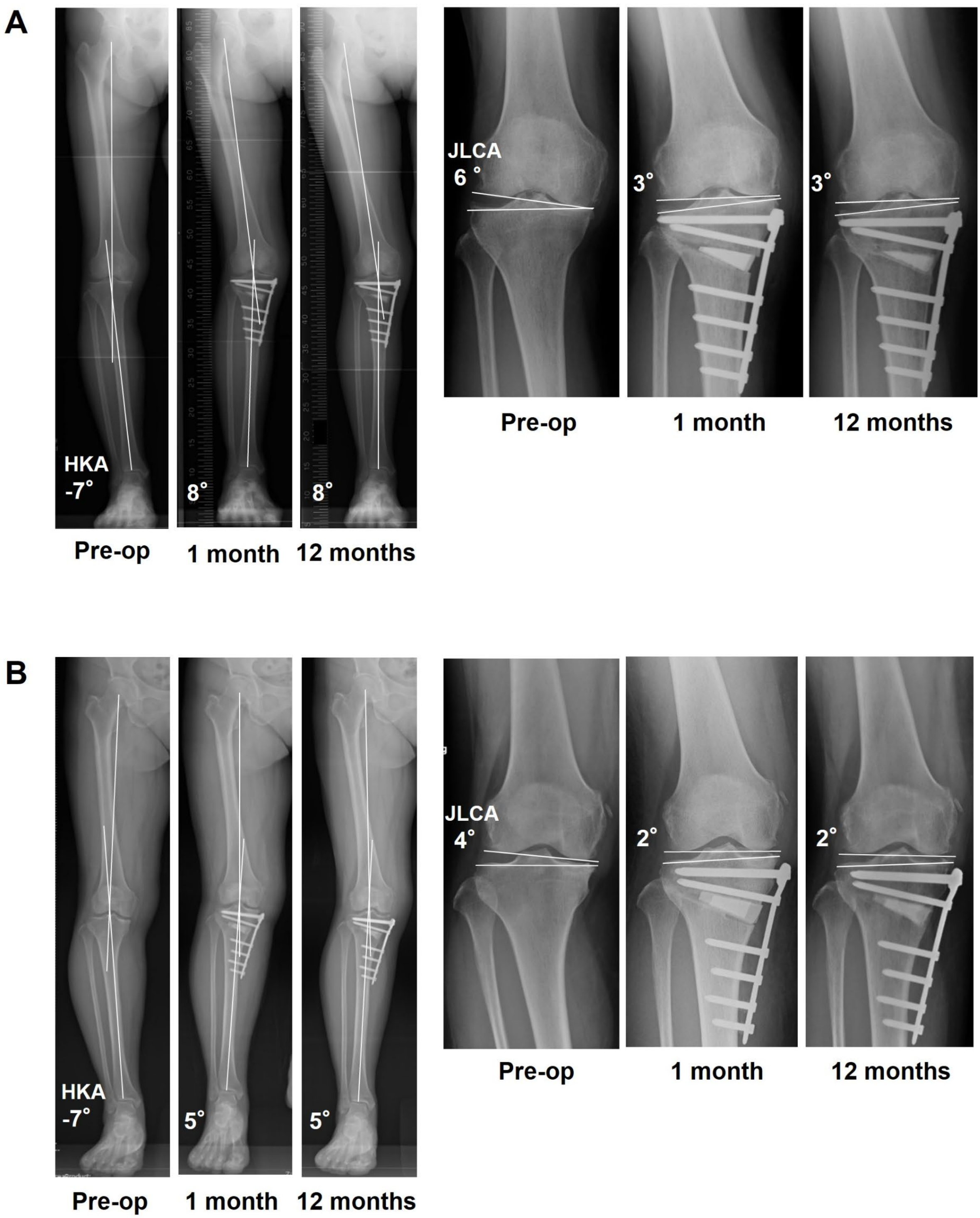

Fig. 2 Radiographs of representative cases in conventional planning (**A**) and adjusted planning (**B**). (**A**) The postoperative hip-knee-ankle (HKA) angle is 8°, indicating an overcorrection of 3°. The joint line convergence angle (JLCA) decreases postoperatively by 3°. (**B**) The postoperative HKA angle is 5°, indicating accurate correction. The JLCA decreases postoperatively by 2°

Double-level osteotomy (DLO) in the distal femur and proximal tibia is done to avoid an increased MPTA [23, 24]. The present study demonstrated that adjusted preoperative planning, which considers change of the JLCA, could reduce the excessive increase of MPTA. The results underscore the importance of anticipating changes in the JLCA during preoperative planning to reduce the cases that would require a correction over 95° or need for DLO.

Table 2 Pre- and postoperative measurement parameters on weight-bearing radiographs

		Conventional planning	Adjusted planning	*P* value
HKA angle (º)	Preoperative	-7.1 ± 2.0	-6.9 ± 2.1	0.504
	1 month	6.1 ± 1.9	4.9 ± 1.7	0.002
	12 months	5.8 ± 2.1	4.8 ± 1.7	0.031
JCLA (º)	Preoperative	4.8 ± 1.8	4.6 ± 1.8	0.584
	1 month	2.6 ± 1.6	2.7 ± 1.4	0.757
	12 months	2.5 ± 1.6	2.5 ± 1.5	0.885
MPTA (º)	Preoperative	84.0 ± 3.0	84.2 ± 2.4	0.913
	1 month	96.2 ± 3.1	94.7 ± 2.2	< 0.001
	12 months	95.9 ± 3.2	94.6 ± 2.1	0.006

The values are given as means ± standard deviation

HKA hip-knee-ankle, JLCA joint line convergence angle, MPTA medial proximal tibial angle

Table 3 Distribution of the acceptable range and outliers in correction error

Correction error	Conventional planning	Adjusted planning	*P* value
	(*n* = 55)	(*n* = 54)	
Acceptable range (≤ 2°)	42 (76%)	49 (91%)	0.03
Outlier (> 2°)	13 (24%)	5 (9%)	

Limb alignment was assessed using long-leg weight-bearing radiographs at postoperative one month

Preoperative planning using a digital software can accurately replicate the target al.ignment during OWHTO surgery [25]. Notably, a starting-point 1 cm more distal or proximal than previously determined through the digital planning does not alter the size of the osteotomy gap needed to produce the desired amount of correction [26]. However, the precise limb alignment achieved during surgery is not always consistent postoperatively [27]. The preoperative planning for the target

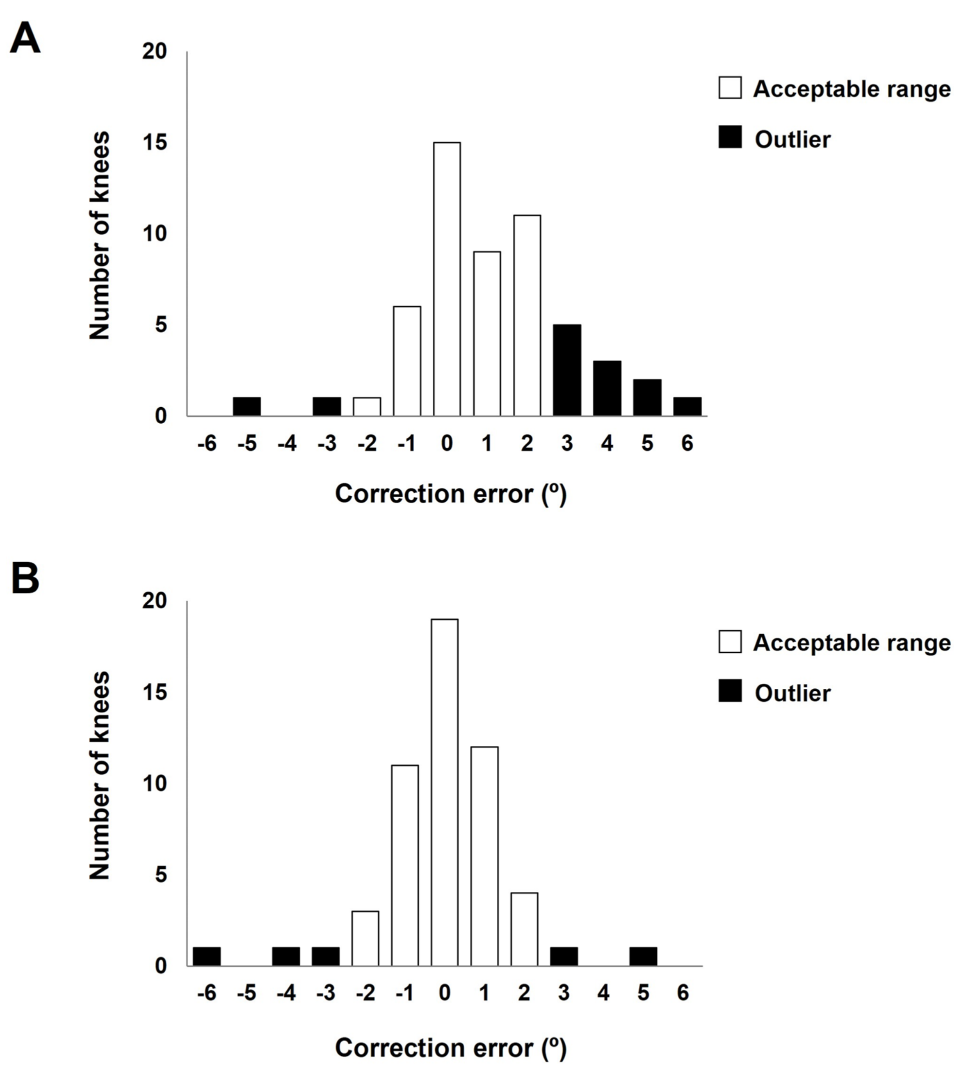

Fig. 3 Distribution of correction error from target alignment in the standing position at postoperative one month. (**A**) Conventional planning. (**B**) Adjusted planning

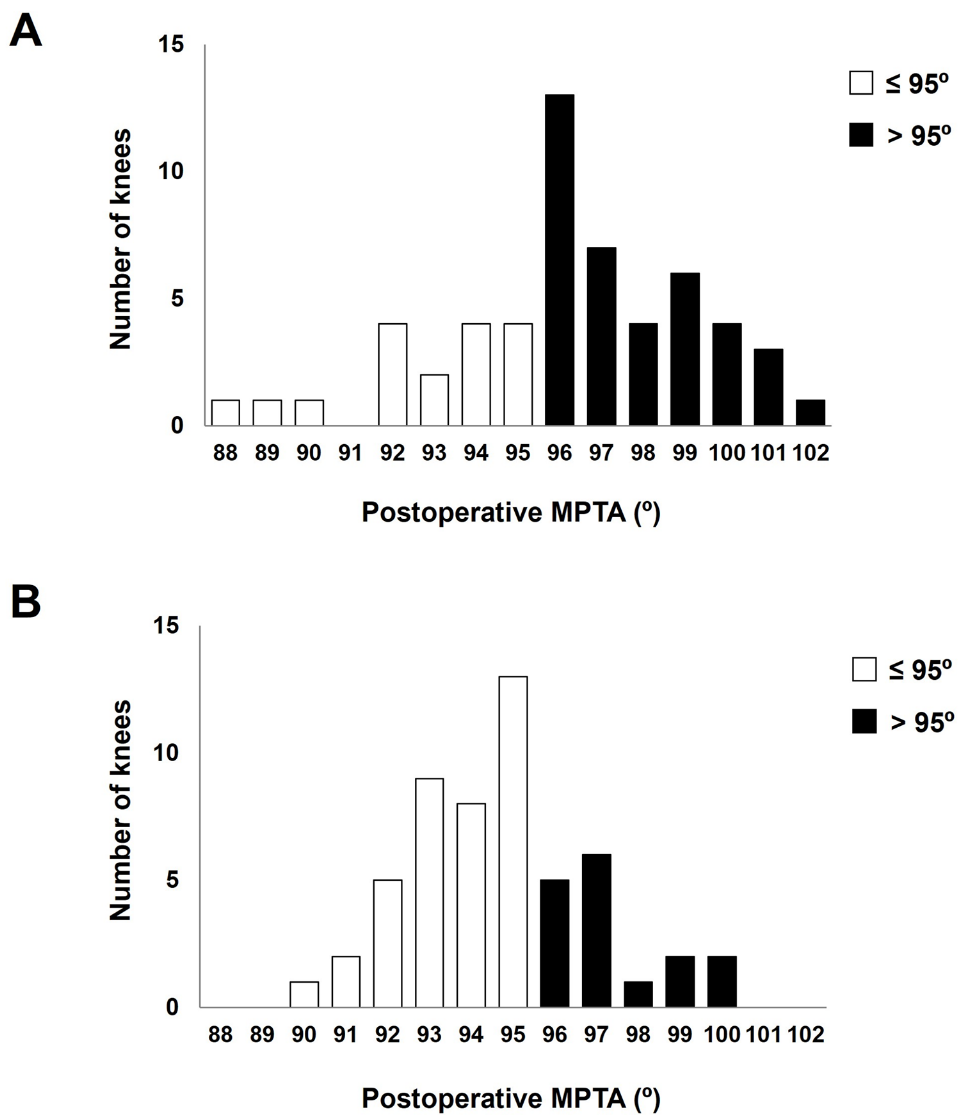

Fig. 4 Distribution of the medial proximal tibial angle (MPTA) at postoperative one month. (**A**) Conventional planning. (**B**) Adjusted planning

Table 4 Distribution of the medial proximal tibial angle (MPTA) ≤ 95º and > 95º at postoperative one month

MPTA	Conventional planning	Adjusted planning	*P* value
	(*n* = 55)	(*n* = 54)	
≤95°	17 (31%)	38 (70%)	< 0.001
>95°	38 (69%)	16 (30%)	

MPTA medial proximal tibial angle

correction angle is usually carried out using weight-bearing radiographs of awake patients. However, limb alignment is intraoperatively assessed in the supine position under general anaesthesia. The discrepancy in the JLCA is attributed to differences in soft tissue balance around the knee between these two conditions. Laxity tends to be greater on the lateral side than the medial side in the OA knee with varus deformity [28, 29]. In OWHTO, opening of an osteotomy gap enhances the tightness on the medial side [30], and lateral laxity is augmented under general anaesthesia [31]. The discrepancy between medial and lateral laxities during surgery is reduced postoperatively under the awake condition [10, 32], and the JLCA is decreased. A lateral shift of the weight-bearing line by valgus correction maintains the reduction in the JLCA, since it maintains increased tension in the medial soft tissue, thereby sustaining the medial joint space opening [33].

Preoperative planning with consideration of a change of the JLCA is necessary to avoid unexpected overcorrection in HTO. Even if a navigation system is used for HTO, a discrepancy occurs between intraoperative and postoperative assessments of limb alignment due to change of the JLCA [7, 27, 34]. The change of the JLCA takes place predominantly in the early postoperative period and is notably affected by the magnitude of the preoperative JLCA [11]. It is likely difficult to maintain target al.ignment in cases with change greater than 2° in the JLCA after HTO [6, 8, 10]. A previous study indicated that a preoperative JLCA of 4º or more in the standing position is the cut-off value to predict a large JLCA decrease of 2º or more [8]. The postoperative change of the JLCA in OWHTO correlates with the preoperative JLCA in the standing position [6, 8, 10, 11, 35]. Therefore, the preoperative planning was adjusted by decreasing the correction angle in the knee with a preoperative JLCA of 4º or more. As a result, the adjusted planning group demonstrated a significant reduction in correction error.

In this study, the current formula for correction was based on the correlation between the extent of postoperative overcorrection and the preoperative JLCA, as reported in the previous studies [10, 11]. While it is feasible to use a multiple regression model to predict corrections more accurately, individual variability in JLCA changes, even among patients with similar preoperative JLCA, present a risk of undercorrection. Given that undercorrection negatively affects long-term outcomes more significantly than overcorrection, our formula is designed to align with the minimum expected JLCA change. However, completely avoiding overcorrection with this formula alone is challenging. Despite this issue, the current formula did not lead to a significant increase in undercorrection cases. In the conventional group, all overcorrected cases had a preoperative JLCA of 4° or more, suggesting that using the current formula could have reduced correction errors. Alternative formula, such as JLCA-2/2 [36] for adjustment of correction, have been proposed and might reduce overcorrection when applied to similar cases. However, this method could lead to a slight undercorrection (1-1.5°) compared to our model. Future research should focus on optimizing the balance between minimizing undercorrection and avoiding overcorrection.

This study has several limitations. First, the follow-up time of one year was short. The current series assessed the early change of knee alignment. Second, the present series did not include data for clinical outcomes. These were not the primary aims.

Conclusions

This study demonstrated that preoperative planning by adjusting the correction angle according to the preoperative JLCA improved correction accuracy in the standing position after OWHTO. This preoperative planning method that predicts changes in soft tissue balance is useful to avoid unexpected overcorrection.

Acknowledgements
Not applicable.

Author contributions
Study design: KK. Study conduct: KK, SY, SN, HC, HI, NK and YI. Data Collection: KK, SY and SN. Data interpretation: KK, SY, SN, HC, HI, NK and YI. Drafting manuscript: KK. KK takes responsibility for the integrity of the data analysis. All authors have read and approved the manuscript.

Funding
There is no funding source.

Data availability
The data and materials used and/or analyzed during the current study are not publicly available but available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the institutional review board at our hospital (#B180200061). Informed consent was obtained from all participants included in the study.

Consent for publication
All authors agree to submit and publish the article.

Competing interests
The authors declare no competing interests.

Received: 15 July 2024 / Accepted: 19 September 2024
Published online: 28 September 2024

References

1. Gougoulias N, Khanna A, Maffulli N. Sports activities after lower limb osteotomy. Br Med Bull. 2009;91:111–21.
2. Lobenhoffer P, Agneskirchner JD. Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2003;11:132–8.
3. Saito T, Kumagai K, Akamatsu Y, Kobayashi H, Kusayama Y. Five- to ten-year outcome following medial opening-wedge high tibial osteotomy with rigid plate fixation in combination with an artificial bone substitute. Bone Joint J. 2014;96–B:339–44.
4. Franceschi F, Longo UG, Ruzzini L, Marinozzi A, Maffulli N, Denaro V. Simultaneous arthroscopic implantation of autologous chondrocytes and high tibial osteotomy for tibial chondral defects in the varus knee. Knee. 2008;15:309–13.
5. Kumagai K, Akamatsu Y, Kobayashi H, Kusayama Y, Saito T. Mosaic Osteochondral Autograft Transplantation Versus bone marrow stimulation technique as a concomitant Procedure with opening-wedge high tibial osteotomy for spontaneous osteonecrosis of the medial femoral condyle. Arthroscopy. 2018;34:233–40.
6. Kim YM, Joo YB, Park YC, Lee SH, Song JH. Postoperative change in the joint-line convergence angle is associated with inaccurate correction in open-wedge high tibial osteotomy. J Orthop Surg Res. 2023;18:773.
7. Lee DH, Park SC, Park HJ, Han SB. Effect of soft tissue laxity of the knee joint on limb alignment correction in open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2016;24:3704–12.
8. Na YG, Lee BK, Choi JU, Lee BH, Sim JA. Change of joint-line convergence angle should be considered for accurate alignment correction in high tibial osteotomy. Knee Surg Relat Res. 2021;33:4.
9. Martinez de Albornoz P, Leyes M, Forriol F, Del Buono A, Maffulli N. Opening wedge high tibial osteotomy: plate position and biomechanics of the medial tibial plateau. Knee Surg Sports Traumatol Arthrosc. 2014;22:2641–7.
10. Kumagai K, Yamada S, Akamatsu T, Nejima S, Ogino T, Sotozawa M, et al. Intraoperatively accurate limb alignment after opening wedge high tibial osteotomy can be lost by large knee joint line convergence angle during surgery. Arch Orthop Trauma Surg. 2021;141:23–8.
11. Kumagai K, Fujimaki H, Yamada S, Nejima S, Matsubara J, Inaba Y. Difference in the early postoperative change of the joint line convergence angle between opening wedge and closed wedge high tibial osteotomies. J Orthop Surg Res. 2021;16:66.

12. Bagherifard A, Jabalameli M, Mirzaei A, Khodabandeh A, Abedi M, Yahyazadeh H. Retaining the medial collateral ligament in high tibial medial open-wedge osteotomy mostly results in post-operative intra-articular gap reduction. Knee Surg Sports Traumatol Arthrosc. 2020;28:1388–93.
13. Pape D, Duchow J, Rupp S, Seil R, Kohn D. Partial release of the superficial medial collateral ligament for open-wedge high tibial osteotomy. A human cadaver study evaluating medial joint opening by stress radiography. Knee Surg Sports Traumatol Arthrosc. 2006;14:141–8.
14. Seo SS, Kim CW, Seo JH, Kim DH, Lee CR. Does superficial medial collateral ligament release in Open-Wedge High Tibial Osteotomy for Varus osteoarthritic knees increase Valgus Laxity? Am J Sports Med. 2016;44:908–15.
15. Lee DK, Wang JH, Won Y, Min YK, Jaiswal S, Lee BH, et al. Preoperative latent medial laxity and correction angle are crucial factors for overcorrection in medial open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2020;28:1411–8.
16. Koshino T, Yoshida T, Ara Y, Saito I, Saito T. Fifteen to twenty-eight years' follow-up results of high tibial valgus osteotomy for osteoarthritic knee. Knee. 2004;11:439–44.
17. Kumagai K, Yamada S, Nejima S, Sotozawa M, Inaba Y. Cartilage degeneration of the lateral compartment of the knee at second-look arthroscopy is Associated with deterioration of 10-Year clinical outcomes after opening-Wedge High Tibial Osteotomy. Arthroscopy. 2023;39:2354–62.
18. Nakayama H, Schroter S, Yamamoto C, Iseki T, Kanto R, Kurosaka K, et al. Large correction in opening wedge high tibial osteotomy with resultant joint-line obliquity induces excessive shear stress on the articular cartilage. Knee Surg Sports Traumatol Arthrosc. 2018;26:1873–8.
19. Xie T, Brouwer RW, van den Akker-Scheek I, van der Veen HC. Clinical relevance of joint line obliquity after high tibial osteotomy for medial knee osteoarthritis remains controversial: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2023;31:4355–67.
20. Takeuchi R, Ishikawa H, Kumagai K, Yamaguchi Y, Chiba N, Akamatsu Y, et al. Fractures around the lateral cortical hinge after a medial opening-wedge high tibial osteotomy: a new classification of lateral hinge fracture. Arthroscopy. 2012;28:85–94.
21. Ollivier M, An JS, Kley K, Khakha R, Fernandes LR, Micicoi G. A significant rate of tibial overcorrection with an increased JLO occurred after isolated high tibial osteotomy without considering international consensus. Knee Surg Sports Traumatol Arthrosc. 2023;31:4927–34.
22. Cerciello S, Vasso M, Maffulli N, Neyret P, Corona K, Panni AS. Total knee arthroplasty after high tibial osteotomy. Orthopedics. 2014;37:191–8.
23. Nakayama H, Iseki T, Kanto R, Kambara S, Kanto M, Yoshiya S, et al. Physiologic knee joint alignment and orientation can be restored by the minimally invasive double level osteotomy for osteoarthritic knees with severe varus deformity. Knee Surg Sports Traumatol Arthrosc. 2020;28:742–50.
24. Schroter S, Nakayama H, Yoshiya S, Stockle U, Ateschrang A, Gruhn J. Development of the double level osteotomy in severe varus osteoarthritis showed good outcome by preventing oblique joint line. Arch Orthop Trauma Surg. 2019;139:519–27.
25. Elson DW, Petheram TG, Dawson MJ. High reliability in digital planning of medial opening wedge high tibial osteotomy, using Miniaci's method. Knee Surg Sports Traumatol Arthrosc. 2015;23:2041–8.
26. Mederake M, Eleftherakis G, Schull D, Springer F, Maffulli N, Migliorini F, et al. The gap height in open wedge high tibial osteotomy is not affected by the starting point of the osteotomy. BMC Musculoskelet Disord. 2023;24:373.
27. Lee DH, Nha KW, Park SJ, Han SB. Preoperative and postoperative comparisons of navigation and radiologic limb alignment measurements after high tibial osteotomy. Arthroscopy. 2012;28:1842–50.
28. Okamoto S, Okazaki K, Mitsuyasu H, Matsuda S, Iwamoto Y. Lateral soft tissue laxity increases but medial laxity does not contract with varus deformity in total knee arthroplasty. Clin Orthop Relat Res. 2013;471:1334–42.
29. Sasanuma H, Sekiya H, Takatoku K, Takada H, Sugimoto N. Evaluation of soft-tissue balance during total knee arthroplasty. J Orthop Surg (Hong Kong). 2010;18:26–30.
30. Agneskirchner JD, Hurschler C, Wrann CD, Lobenhoffer P. The effects of valgus medial opening wedge high tibial osteotomy on articular cartilage pressure of the knee: a biomechanical study. Arthroscopy. 2007;23:852–61.
31. Tsukeoka T, Tsuneizumi Y. Varus and valgus stress tests after total knee arthroplasty with and without anesthesia. Arch Orthop Trauma Surg. 2016;136:407–11.
32. Sekiya H, Takatoku K, Takada H, Sasanuma H, Sugimoto N. Postoperative lateral ligamentous laxity diminishes with time after TKA in the varus knee. Clin Orthop Relat Res. 2009;467:1582–6.
33. Heijens E, Kornherr P, Meister C. The coronal hypomochlion: a tipping point of clinical relevance when planning valgus producing high tibial osteotomies. Bone Joint J. 2016;98–B:628–33.
34. So SY, Lee SS, Jung EY, Kim JH, Wang JH. Difference in joint line convergence angle between the supine and standing positions is the most important predictive factor of coronal correction error after medial opening wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2020;28:1516–25.
35. Ji W, Luo C, Zhan Y, Xie X, He Q, Zhang B. A residual intra-articular varus after medial opening wedge high tibial osteotomy (HTO) for varus osteoarthritis of the knee. Arch Orthop Trauma Surg. 2019;139:743–50.
36. Behrendt P, Akoto R, Bartels I, Thurig G, Fahlbusch H, Korthaus A, et al. Preoperative joint line convergence angle correction is a key factor in optimising accuracy in varus knee correction osteotomy. Knee Surg Sports Traumatol Arthrosc. 2023;31:1583–92.

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