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Appropriate patient selection based on joint line convergence angle minimizes the difference between the mechanical axis in the standing and supine positions after open-wedge high tibial osteotomy and distal tuberosity osteotomy

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Abstract

Background This study aimed to evaluate the differences between the mechanical axis (MA) in standing and supine positions in patients who underwent high tibial osteotomy (HTO) or distal tuberosity osteotomy (DTO) based on the surgical indication for the joint line convergence angle (JLCA).

Methods Seventy-one knees of 69 patients with JLCA of < 6° in standing position and a difference of < 3° between the JLCA in the standing and supine positions who had undergone medial open-wedge HTO or DTO were included in this study. The %MA in the standing and supine positions (%MAst and %MAsp, respectively) and JLCA in the standing and supine positions (JLCAst and JLCAsp, respectively) were determined using preoperative and postoperative long-leg-view radiographs. The difference between %MA and JLCA in the standing and supine positions (Δ%MA and ΔJLCA, respectively) was calculated by subtracting the measurement value in the supine position from that in the standing position.

Results The preoperative %MAst, %MAsp, JLCAst, and JLCAsp were 23.8 ± 9.5%, 28.7 ± 8.0%, 2.9 ± 1.4°, and 1.6 ± 1.4° respectively. The preoperative Δ%MA and ΔJLCA were − 4.9 ± 5.9% and 1.3 ± 1.0° respectively. The postoperative %MAst, %MAsp, JLCAst, and JLCAsp were 58.8 ± 6.9%, 59.0 ± 6.2%, 1.7 ± 1.0°, and 1.5 ± 1.1°, respectively. No significant differences were observed between the postoperative %MAst and %MAsp. The postoperative Δ%MA and ΔJLCA were − 0.2 ± 3.0% and 0.3 ± 0.6°, respectively. The postoperative Δ%MA was − 5 to 5% in 68 knees (95.8%).

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Conclusion Minimal differences were observed between the Δ%MA after HTO and DTO among patients with preoperative JLCAst of < 6° and ΔJLCA and of < 3°, respectively. Appropriate surgical indications could minimize this difference.

Keywords High tibial osteotomy, Distal tuberosity osteotomy, Mechanical axis, Joint line convergence angle, Standing position, Supine position

Introduction

Knee osteotomy has demonstrated good long-term postoperative outcomes in younger or active patients with knee osteoarthritis (OA) [1–3]. Open-wedge high tibial osteotomy (OWHTO) yields stable results in patients with varus-aligned knees when patient selection criteria and postoperative alignment are appropriate [4, 5]. Despite postoperative alignment being one of the most important factors affecting clinical outcomes, correction errors may occur owing to various factors: inaccurate preoperative planning, intraoperative errors, and differences between the coronal alignment of the knee in the standing and supine positions [6–8]. Regarding alignment changes, the coronal alignment differs in different positions, such as supine, double-leg standing, or single-leg standing; thus, changes in the positioning of the patient induce differences in the coronal alignment [9, 10]. Coronal alignment differences between standing and supine positions were affected by intra-articular deformity and lateral soft tissue laxity in patients with varus knees [11, 12]. Particularly, recent studies have focused on the effect of soft tissue laxity on the preoperative planning for HTO. However, the difference in coronal alignment between standing and supine positions after HTO has not yet been fully clarified.

The joint line convergence angle (JLCA) is an angle between the tangential line to the distal femoral condyles and the line parallel to the tibial joint surface on anteroposterior view radiographs. It is widely used as an indicator for estimating joint laxity in patients with varus knees, and serves as a key indicator for predicting postoperative patient-reported outcomes [13]. Previous studies have suggested that preoperative joint laxity determined by JLCA is one of the most significant factors associated with postoperative coronal limb alignment [14, 15]. In particular, a large preoperative JLCA in the standing position (JLCAst) has been reported to be a predictive factor for overcorrection after OWHTO owing to joint laxity [7]. Additionally, the difference in preoperative JLCA between the supine and standing positions has been reported as the most important predictive factor of correction error after OWHTO [16]. Since limb alignment is usually checked in the supine position during surgery, the alignment difference between standing and supine positions should ideally be minimal. If the difference in limb alignment between supine and standing positions is small, similar limb alignment to that during surgery can be obtained after surgery, and correction error can be minimized. Therefore, determining the appropriate JLCA range to obtain an acceptable difference in MA between the postoperative standing and supine alignments is crucial for minimizing the correction error. However, the degree of preoperative JLCA required to achieve acceptable differences between MA in the postoperative standing and supine alignments remains unknown.

Therefore, this study aimed to evaluate the difference between the postoperative MA in the standing and supine positions in patients who underwent OWHTO or DTO based on the surgical indication for JLCA and determine whether acceptable differences between the postoperative MA in the standing and supine alignments could be achieved.

Materials and methods

Demographics

The study protocol was reviewed and approved by the Institutional Review Board of our hospital (approval no. 170176). Patients who had undergone OWHTO or distal tuberosity osteotomy (DTO) between August 2016 and December 2021 at our university hospital were included in this retrospective study. All surgeries were performed by attending orthopedic surgeons with extensive experience in performing OWHTO and DTO.

Surgical indications for OWHTO included varus knee alignment accompanied by medial compartmental OA, such as low-grade OA with Kellgren–Lawrence (KL) grade 0 and 1, or associated cartilage injuries and medial meniscal tears [17, 18]. In addition to the indications for OWHTO, the surgical indications for DTO included patellofemoral OA [6, 18, 19]. Furthermore, OWHTO or DTO was also indicated for patients with a preoperative JLCA of < 6° in the standing position and a difference of < 3° between the preoperative JLCA in the standing and supine positions, considering our previous cases and other studies [9, 20]. Tibial condylar valgus osteotomy (TCVO), or hybrid closed wedge osteotomy (HCWO), was indicated for patients with a preoperative JLCA of > 6° in the standing position and a difference between the preoperative JLCA in the standing and supine positions of > 3° [21, 22]. Double-level osteotomy (DLO) was indicated for patients with mechanical lateral distal femoral and knee flexion angles of > 90° and < 90°, respectively [23]. Contraindications for knee osteotomy included flexion contracture of > 20° and the presence of joint diseases such as rheumatoid arthritis.

Patients who underwent OWHTO or DTO, with available preoperative and 1-year postoperative anteroposterior (AP) long-leg-view radiographs (standing and supine positions) were included in the study. Patients with insufficient data were excluded. Those who received HTO or DTO combined with autologous chondrocyte implantation (ACI) were also excluded due to the potential periosteal graft hypertrophy effects on JLCA.

Radiographic measurements

The whole-leg alignment was evaluated by acquiring plain AP long-leg-view radiographs in the double-leg standing and supine positions preoperatively and 1 year postoperatively. The long-leg view radiographs were evaluated to determine whether full extension of the knee was achieved. MA was defined as the line extending from the center of the femoral head to the center of the ankle. The point of intersection of MA with the tibial plateau was defined as the percentage of the total length of the tibial plateau (%MA), with the medial and lateral edges set to 0% and 100%, respectively (Fig. 1). JLCA was defined as the angle between the line tangential to the

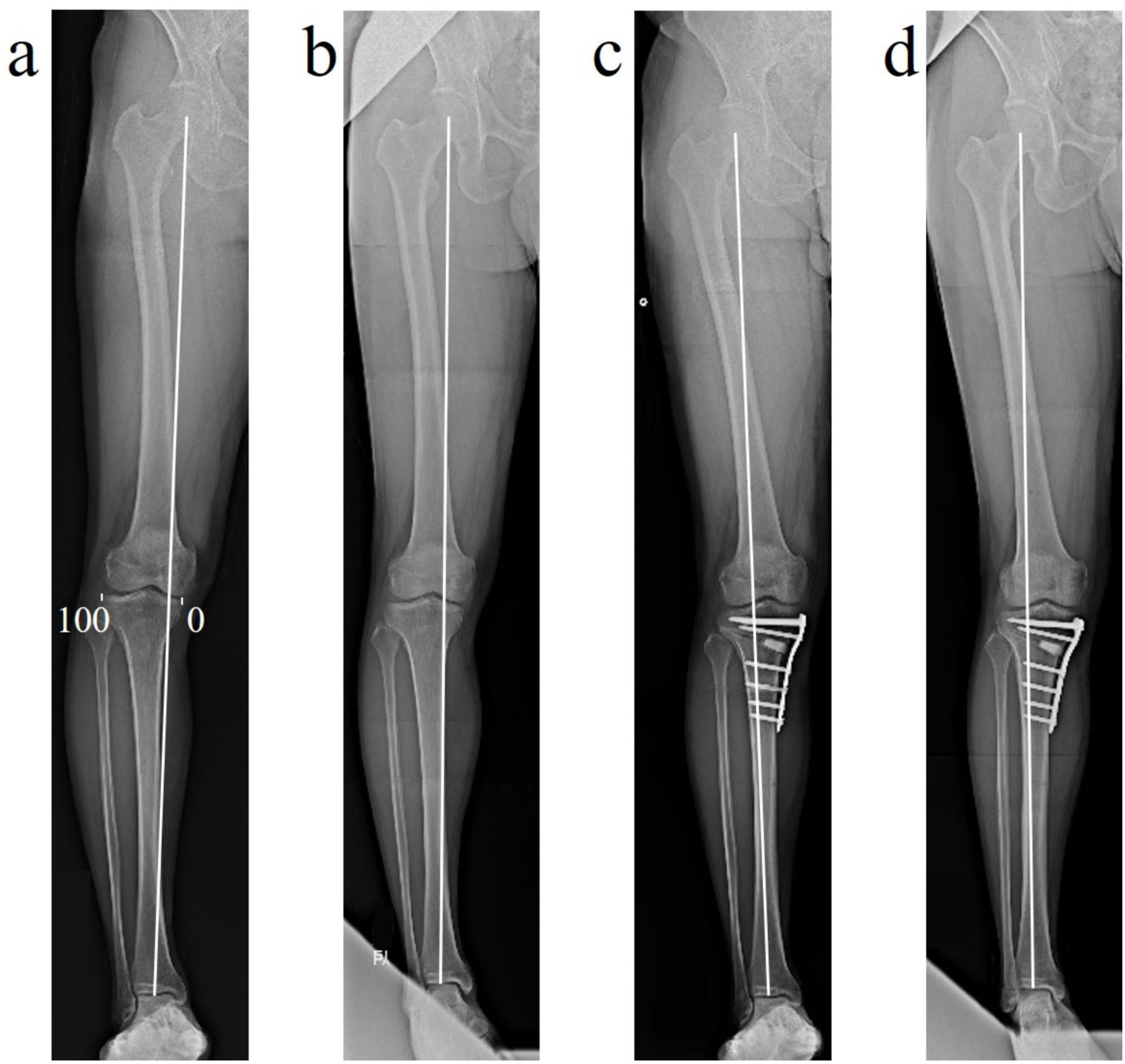

Fig. 1 Radiographic analysis of mechanical axis (MA). **a** preoperative MA in the standing position. **b** preoperative MA in the supine position. **c** postoperative MA in the standing position. **d** postoperative MA in the supine position

medial and lateral femoral condyles and a line parallel to the tibial joint surface (Fig. 2). Picture archiving and communication system (PACS) software was used to perform all measurements. The angle and length measurements were expressed up to two decimal points in PACS; however, the data analyzed in this study were rounded to one decimal point. %MA and JLCA were measured in the double-leg standing (%MAst and JLCAst, respectively) and supine (%MAsp and JLCAsp, respectively) radiographs. The differences between %MA and JLCA in the standing and supine positions were calculated subsequently by subtracting the measurement values in the supine position from those in the standing positions and expressed as Δ%MA and ΔJLCA, respectively. A difference of up to 5% between the %MA in the standing and supine positions was considered acceptable [24, 25].

Clinical evaluations

Clinical outcomes were evaluated using the Knee Injury and Osteoarthritis Outcome Score (KOOS) [26]. KOOS comprises five subscales: symptoms, pain, activities of daily living, sports activities, and quality of life. Each response was scored between 0 and 4 points. Each subscale was converted to a 100-point scale, with 0 and 100 indicating extreme and no symptoms, respectively. KOOS was recorded preoperatively and 1 year postoperatively.

Preoperative planning and surgical procedure

The preoperative planning and surgical procedures for OWHTO and DTO have been described in previous studies [6, 27, 28]. Plain AP long-leg-view radiographs acquired in the supine position [29, 30] were used for preoperative planning performed in accordance with Miniacci's method [31, 32]. The target al.ignment was determined based on the alignment of the limb, and the change in OA was determined via radiographic and arthroscopic evaluations preoperatively. The target al.ignments were set as 55–60% for knees with relatively mild OA (preoperative %MA: 20–40%, most areas of the medial compartment cartilage: International Cartilage Repair Society (ICRS) grades I–III). The target al.ignment was set as 58–63% for advanced OA knees (preoperative %MA: <20%, medial compartment cartilage: ICRS grade III or IV), and the postoperative mechanical medial proximal tibial angle (MPTA) was limited to < 95° [33].

A straight incision was made over the medial proximal tibia intraoperatively. The pes anserinus, including the hamstring tendons, was detached from the insertion site, and the superficial medial collateral ligament was released to expose the osteotomy site. Biplane frontal and transverse incisions were made during OWHTO and DTO. Ascending or descending incision was made proximally or distally on the tibial tubercle OWHTO and DTO, respectively. The osteotomy site was retracted using a spreader until the intended alignment was achieved. A caliper was used to measure the distance between the posteromedial cortices. Two wedge-shaped β-tricalcium phosphate blocks (Osferion60, Olympus Terumo Biomaterials Corp., Tokyo, Japan) were inserted into the gap according to the size of the gap. The tibia was fixed using a medial locking compression plate (TomoFix; DePuy Synthes, Solothurn, Switzerland) or a TriS plate (Olympus Terumo Biomaterials Corp., Tokyo, Japan). Lastly, a 6.5-mm cannulated screw (Hollyx Co., Ltd., Shizuoka, Japan) was used to fix the distal part of the tibial tubercle to the distal fragment of the tibia in DTO.

Statistical analysis

The measurement values are presented as means, standard deviations (SDs), and 95% confidence intervals (CIs). The normality of the data was assessed using the Shapiro–Wilk test. A priori power analysis based on preliminary results indicated that a minimum of 45 patients were required to detect a 5% difference in postoperative %MA between standing and supine positions, with a

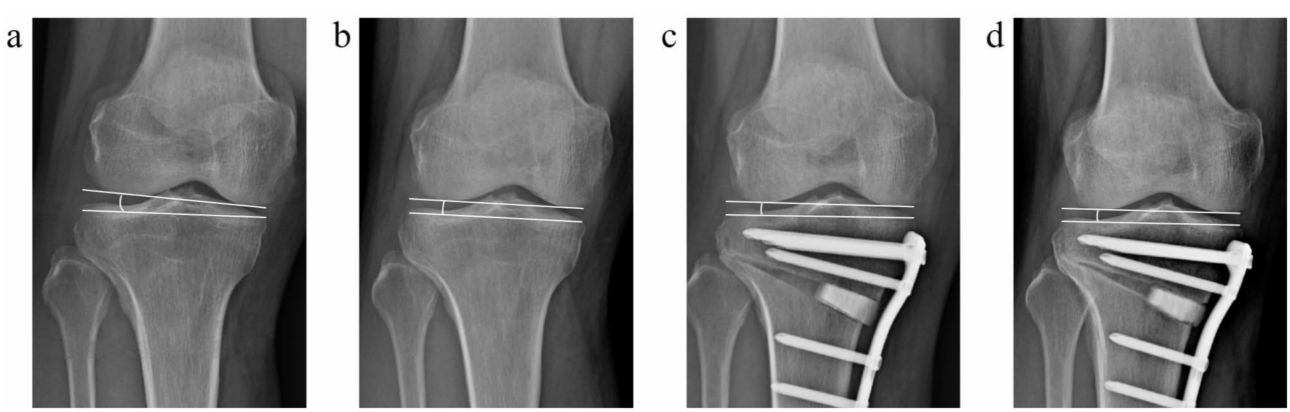

Fig. 2 Radiographic analysis of joint line convergence angle (JLCA). **a** preoperative JLCA in the standing position. **b** preoperative JLCA in the supine position. **c** postoperative JLCA in the standing position. **d** postoperative JLCA in the supine position

power of 0.95 and an anα of 0.05. The demographic data of the patients who underwent OWHTO and DTO were compared using the Mann–Whitney U test. A paired t-test was used to compare the pre- and postoperative %MA and JLCA in the standing and supine positions, as well as the pre- and postoperative KOOS. Statistical significance was set at $P<0.05$. The intraclass correlation coefficients (ICCs) were calculated to determine the intra-observer and inter-observer reliabilities. All radiographic parameters were measured twice by two orthopedic surgeons, with a mean interval of 25.6 ± 4.2 days (3–5 weeks) between measurements. The measurements were performed by the same orthopedic surgeon twice at an interval of >2 weeks to determine the intra-observer reliability. The measurements were performed by two orthopedic surgeons to determine the inter-observer reliability. The intra-observer ICCs (95% confidence interval [CI]) for %MA and JLCA were 0.98 (0.96–0.99) and 0.93 (0.82–0.97), respectively. The inter-observer ICCs (95% CI) for %MA and JLCA were 0.98 (0.94–0.99) and 0.88 (0.70–0.95), respectively. All statistical analyses were performed using EZR (Easy R)(https://www.jichi.ac.jp/saitama-sct/SaitamaHP.files/windowsEN.html) [34].

Results

Among the 158 patients who underwent AKO for varus knee OA with preoperative and 1-year postoperative long-leg radiographs in both standing and supine positions, exclusions were made for six patients who underwent TCVO, 14 who underwent CWHTO, 22 who underwent DLO, five who received concomitant autologous chondrocyte implantation (ACI) with OWHTO or DTO, and 42 with insufficient radiographic data. Thus, 71 consecutive knees of 69 patients (male, 37; female, 32; mean age at the time of surgery, 58.5 ± 7.8 years; mean BMI, 26.0 ± 3.8; KL grade I/II/III/IV, 21/20/23/7) who had undergone OWHTO (46 cases) and DTO (25 cases) were included in the study (Fig. 3).

The demographic data for the OWHTO and DTO groups were comparable (Table 1). Twenty-six, five, and two patients underwent medial meniscal repair, osteochondral autograft transfer, and anterior

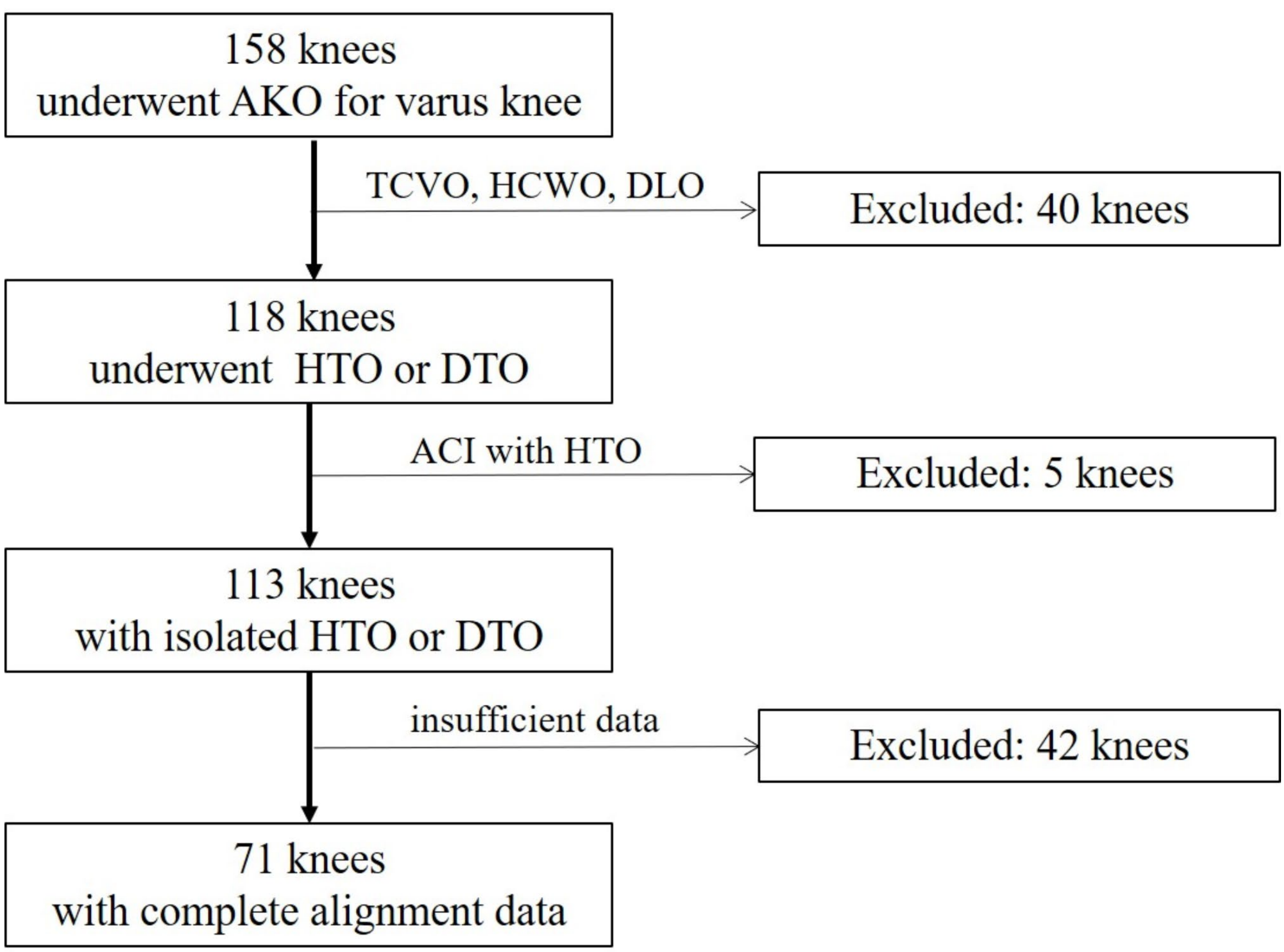

Fig. 3 Flowchart of patient inclusion/exclusion for the study. HTO, high tibial osteotomy; DTO, distal tuberosity osteotomy; TCVO, Tibial condylar valgus osteotomy; HCWO, hybrid closed wedge osteotomy; DLO, double-level osteotomy

Table 1 Demographic data of the patients

	Total	HTO	DTO	*P*-value
Patients, n	69	44	25	
Knees, n	71	46	25	
Age, years	58.4 ± 7.9 (39–75)	59.0 ± 8.3 (39–75)	57.6 ± 7.3 (43–71)	0.46
Male / Female	37 / 32	21 / 23	16 / 9	0.22
Height, cm	164.6 ± 8.6 (144.0–183.0)	164.2 ± 8.9 (144.0–182.0)	165.3 ± 8.2 (148.7–183.0)	0.65
Body weight, kg	70.9 ± 13.8 (46.0–108.3)	70.4 ± 15.3 (46.0–108.3)	71.9 ± 10.9 (52.0–93.8)	0.66
BMI, kg/m^2	26.1 ± 3.8 (18.6–37.3)	25.9 ± 3.8 (18.9–37.3)	26.4 ± 3.9 (18.6–36.5)	0.42
KL grade I/ II/ III/ IV	21/ 20/ 23/ 7	15/ 12/ 15/ 4	6/ 8/ 8/ 3	0.85

Values are expressed as numbers or means with standard deviations or ranges. BMI, body mass index; KL, Kellgren-Laurence; HTO, high tibial osteotomy; DTO, distal tuberosity osteotomy

cruciate ligament reconstruction with OWHTO or DTO, respectively.

The mean preoperative %MA in the standing radiographs was significantly lower than that in the supine radiographs (%MAst: 23.8 ± 9.5, %MAsp: 28.7 ± 8.0; $P < 0.001$). Similarly, JLCAst was significantly higher than JCLAsp (JLCAst: 2.9 ± 1.4, JLCAsp: 1.6 ± 1.4; $P < 0.001$). No statistically significant differences were observed between the postoperative %MA in the standing and supine radiographs (%MAst: 58.8 ± 6.9, %MAsp: 59.0 ± 6.2; $P = 0.55$). The mean postoperative JLCA in the standing radiographs was significantly higher than that in the supine radiographs (JLCAst: 1.7 ± 1.0, JLCAsp: 1.5 ± 1.1; $P < 0.001$) (Table 2). The mean preoperative and postoperative Δ%MA was − 4.9 ± 5.9% and − 0.2 ± 3.0%, respectively (Table 3). Sixty-eight patients (95.8%) had a postoperative Δ%MA of -5 to 5% (Fig. 4). The mean preoperative and postoperative ΔJLCA was 1.3 ± 1.0° and 0.3 ± 0.6°, respectively (Fig. 5).

The scores of the KOOS subscales exhibited a significant improvement 1 year postoperatively (Table 4). No

Table 3 The differences between %MA and JLCA in the standing and supine positions

	Δ%MA (%)	ΔJLCA (°)
Preop.	-4.9 (-6.3 to -3.5)	1.3 (1.1 to 1.6)
Postop.	-0.2 (-0.9 to 0.5)	0.3 (0.1 to 0.4)

Values are expressed as values with a 95% confidence level in parentheses. MA, mechanical axis; JLCA, joint line convergence angle; Preop, preoperative values; Postop, postoperative values

Table 2 Radiographic limb alignment analysis

	%MA (%)			JLCA (°)		
	Standing	Supine	*P*-value	Standing	Supine	*P*-value
Preop.	23.8 ± 9.5	28.7 ± 8.0	< 0.001	2.9 ± 1.4	1.6 ± 1.4	< 0.001
Postop.	58.8 ± 6.9	59.0 ± 6.2	0.55	1.7 ± 1.0	1.5 ± 1.1	< 0.001

Values are expressed as numbers or means with standard deviations or ranges. MA, mechanical axis; JLCA, joint line convergence angle; Preop, preoperative values; Postop, postoperative values

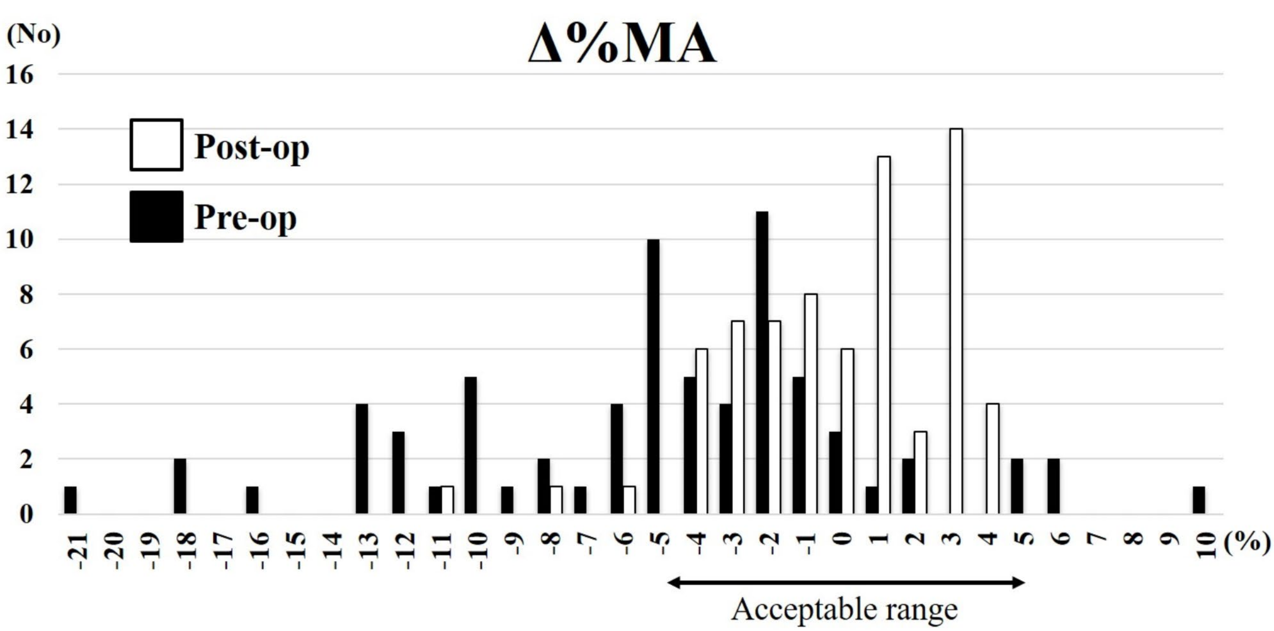

Fig. 4 Preoperative and postoperative Δ% mechanical axis (MA). The data were rounded to one decimal point and expressed as an integral number

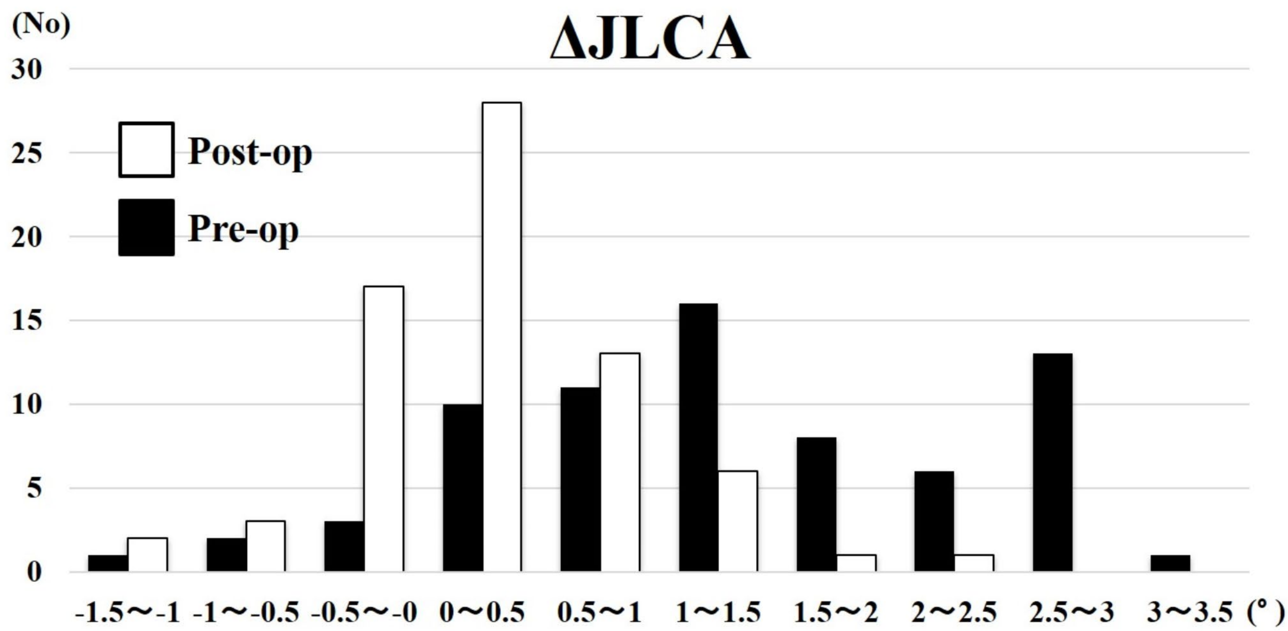

Fig. 5 Difference between the pre- and post-operative joint line convergence angles (JLCAs)

Table 4 Preoperative and postoperative clinical outcomes

KOOS subscale	Preop	Postop	*P*-value
Symptom	50.5 ± 22.9	79.4 ± 15.3	< 0.001
Pain	50.9 ± 19.3	84.5 ± 13.2	< 0.001
ADL	66.2 ± 18.5	89.8 ± 9.1	< 0.001
Sports	28.5 ± 21.9	61.1 ± 25.2	< 0.001
QOL	27.1 ± 20.5	66.1 ± 21.7	< 0.001
Total	44.6 ± 17.5	76.2 ± 14.9	< 0.001

Values are expressed as numbers or means with standard deviations or ranges. ADL, activities of daily living; QOL, quality of living; Preop, preoperative values; Postop, postoperative values

correlation was observed between KOOS and preoperative JLCA or postoperative %MA.

Discussion

The most important finding in this study was that in patients with preoperative JLCA of < 6° in standing position and a ΔJLCA of < 3°, postoperative %MA did not significantly differ between standing and supine radiographs after OWHTO or DTO. Additionally, 95.8% of the patients had a postoperative Δ%MA between − 5 and 5%. These findings suggest that preoperative JLCA of < 6° and preoperative ΔJLCA of < 3° could serve as reference criteria for indicating OWHTO and DTO.

Inaccurate preoperative planning and intraoperative errors may result in correction errors in OWHTO and DTO. When planning HTO, the soft tissue balance around the knee joint needs to be carefully evaluated considering the influence of weight bearing on coronal alignment [16]. Preoperative planning is commonly performed using standing radiographs. However, limb alignment is usually checked in supine positions during surgery. Therefore, minimizing the difference in limb alignment between standing and supine positions is ideal to avoid over- or under-correction due to weight bearing. Postoperative minimal differences between the alignment in the supine and standing positions suggest that the osteotomy was performed with adequate consideration of soft tissue involvement. Several studies have reported that weight bearing increased varus alignment in patients with varus knees [6, 12, 35, 36]. Moon et al. compared hip-knee-ankle (HKA) angle in the double-leg standing and supine positions and reported that the differences in HKA angle can be attributed to high BMI or KL grades 3 and 4 [11]. Regarding the differences in postoperative alignment between the standing and supine positions, Jang et al. reported that the difference between the intraoperative post-osteotomy MA deviation (MAD) and postoperative MAD was correlated with the preoperative JLCA and BMI [20]. Thus, the findings of the above studies and this study suggest that JLCA can serve as an index to avoid cases with large differences in MA between the standing and supine positions and highlight the importance of minimizing postoperative MA between these positions.

In this study, Δ%MA and ΔJLCA exhibited a wide distribution, with a tendency for alignment in the standing position to be more varus than in supine position pre-operatively, while the range of distribution was smaller post-operatively. One possible explanation for the reduced variability after surgery is the restoration of medial collateral ligament (MCL) tension. In varus knees, the MCL is typically lax due to loss of cartilage of the medial compartment and meniscus deficiency,

Table 5 The summary of patients with postoperative Δ%MA > 5%

	Age, Sex	BMI (kg/m^2)	KL	Pre %MA (standing/ supine)	Post %MA (standing/ supine)	Pre JLCA (°) (standing/ supine)	Pre JLCA (°) (standing/ supine)
Case 1	54 F	36.5	2	38/ 48	56/ 67	3.9/ 1.0	2.5/ 0.2
Case 2	61 M	27.4	2	14/ 19	51/ 59	2.6/ 1.1	2.2/ 2.0
Case 3	57 M	23.2	2	28/ 33	50/ 56	1.3/ 0.2	2.1/ 1.7

BMI, body mass index; KL, Kellgren-Laurence; MA, mechanical axis; JLCA, joint line convergence angle; F, female; M, male

particularly in standing. In contrast, MCL can be tensed with valgus alignment after surgery and thus, resulted in relatively less change after surgery. In addition, since our cases included patients with early OA while excluding those with large JLCA, appropriate MCL tension may have been achieved post-operatively. In this study, minimal postoperative Δ%MA was achieved after OWHTO or DTO in the patients with a preoperative JLCAst of < 6°. Large JLCAst values were reported to be associated with severe varus OA and/or joint laxity that causes the "teeter effect (seesaw phenomenon)" [37, 38]. Thus, careful patient selection is crucial due to the possibility of correction errors when OWHTO is performed. Weiping et al. reported that the preoperative JLCA was correlated with the postoperative JLCA in patients undergoing OWHTO and that a higher percentage of patients with a preoperative JLCA of ≤ 6° achieved acceptable postoperative ΔJLCA (≤ 5°) [39]. Tsuji et al. evaluated the factors influencing the difference in HKA alignment attained using intraoperative navigation systems and postoperative radiographs and revealed that JCLAst was a significant factor associated with an unacceptable difference of > 1.5° in HKA. The mean preoperative JLCAst in the unacceptable and acceptable groups was 4.8 ± 2.2° and 3.4 ± 2.3°, respectively, in this study [14]. Behrendt et al. reported that osteotomy level divergence and preoperative JLCA were significant factors associated with overcorrection (>Δ%MA of 5%) and that the prevalence of overcorrection among patients with a JLCA of ≥ 4° was higher than that in those with a JLCA of < 4° [25]. Although the cut-off value was not addressed in the previous study, a preoperative JLCA of 4–5° may be a more reliable indication for OWHTO or DTO to minimize the effect of soft tissue laxity than a JLCA of 6° considering the variability in preoperative planning among surgeons. However, the findings of this study also suggest that a preoperative JLCAst of 6° could be the maximum threshold to avoid an unacceptably large difference between postoperative standing and supine positions.

In this study, the postoperative Δ%MA was − 5 to 5% after OWHTO or DTO in 95.8% of the patients. Although the definition of the acceptable range of the difference in MA between the standing and supine positions or over/under correction varies among studies [40], the difference in MA of < 5% was used as an acceptable difference in other reports [24, 25]. Therefore, the difference appears to be at least within the generally acceptable range [40]. In this study, the difference between postoperative %MA standing and supine radiographs was > 5% in three cases, and %MAst was lower than %MAsp in all three cases. Regarding the reason for the larger difference, high BMI was suspected to be a cause of the more varus in the standing position in one patient (case 1) [11]. In one patient (case 2), the leg stance of the patient was wide during the acquisition of the standing radiographs and closed during the acquisition of the supine radiographs. Since the varus force may increase in the open-leg standing position and decrease in the close to the neutral leg position [41], the leg position during radiography may be the cause of the large discrepancy. Mild flexion contracture was observed in one patient (case 3), which may have affected the measurement of %MA (Table 5) [42, 43]. No significant correlation was found between target %MA (supine %MA) and either Δ%MA or ΔJLCA. Additionally, Δ%MA and ΔJLCA did not differ significantly between mild (%MA 55–60) and severe (%MA 58–63) OA groups (data not shown). Therefore, the effect of target al.ignment on Δ%MA or ΔJLCA remains unclear. Further studies are warranted to elucidate the underlying mechanism of the large difference in %MA between standing and supine positions after HTO and DTO in patients with relatively low JLCA.

Previous studies have evaluated the difference in JLCA between standing and supine positions [6, 11, 16]. Most studies compared the differences in JLCA between varus and valgus stress radiographs to determine soft tissue laxity [7, 10, 14, 44–46]. Lee et al. defined latent soft tissue laxity as the amount of soft tissue extension that could be detected by valgus or varus stress [44]. Latent medial and lateral laxity are calculated by subtracting the JLCA on the standing long-leg radiograph from the JLCA on the valgus or varus stress radiographs, respectively [16]. Jung et al. reported that preoperative JLCAst and preoperative JLCA on valgus stress radiograph were important predictors of postoperative alignment [47]. However, the method of stress radiographs, including the magnitude of stress, has not been standardized. Differences may arise from variations in the direction or magnitude of force applied during stress radiographs, complicating the objective quantification of soft tissue laxity. In contrast, the acquisition of long-leg-view radiographs in the standing and supine positions is relatively easy, and the ΔJLCA are reproducible. So et al. reported that preoperative ΔJLCA was the most important preoperative factor predicting coronal correction discrepancies between the actual preoperative and postoperative MA in the standing position and the amount of coronal correction by navigation [16], suggesting that preoperative ΔJLCA can be used as an index to minimize the difference in coronal alignment between the standing and supine radiographs. Meanwhile, a statistically significant difference in postoperative JLCA was also observed (JLCAst: 1.7 ± 1.0° vs. JLCAsp: 1.5 ± 1.1° $P < 0.001$). However, Kim et al. reported that every 2.5° of JLCA predicted one degree of valgus overcorrection [48]. Thus, the mean JLCA difference of 0.2° observed in this study may not correlate with changes in mechanical axis and is likely clinically negligible.

This study has some limitations. First, the sample size was relatively small. Further studies with larger sample sizes must be conducted to confirm the findings of this study. Second, the potential influence of confounding factors, including BMI, KL grade on Δ%MA, Coronal Plane Alignment of the Knee phenotype and joint line obliquity [49], radiographic parameters involving the ankle and hip joints [50], and the correction angle, was not examined. Finally, JLCA was determined to be < 6° in the standing position, and ΔJLCA was determined to be < 3°. These values were determined subjectively based on the findings of previous studies and the cases included in this study. Values determined via statistical calculations may be ideal; however, JLCA is a parameter with various elements. Thus, determining its value may be challenging using a single statistical formula. This study highlights the importance of considering JLCA during preoperative planning and provides a value that may aid in successful postoperative alignment. Nevertheless, this study provides valuable insights into patient selection based on JLCA for medial open wedge proximal tibial osteotomy, including OWHTO and DTO, to minimize post-operative differences between standing and supine positions.

Conclusion

Δ%MA after HTO was minimal in patients with a preoperative JLCAst of < 6° and ΔJLCA of < 3°. Appropriate patient selection based on the preoperative JLCAst and ΔJLCA minimized the Δ%MA after HTO. Therefore, surgeons should consider using these values to achieve good postoperative knee alignment.

Abbreviations

ACI	Autologous chondrocyte implantation
AP	Anteroposterior
CI	Confidence intervals
DTO	Distal tuberosity osteotomy
HKA	Hip-knee-ankle
HTO	High tibial osteotomy
ICCs	Intraclass correlation coefficients
ICRS	International Cartilage Repair Society
JLCA	Joint convergence angle
KOOS	Knee Injury and Osteoarthritis Outcome Score
MA	Mechanical axis
MAD	MA deviation
MPTA	Medial proximal tibial angle
OA	Osteoarthritis
OWHTO	Open-wedge high tibial osteotomy
PACS	Picture archiving and communication system
SD	Standard deviation

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Author contributions
NN, SW, and TM contributed to the study concept and design. TM, SW, YN, and KN contributed to the acquisition, analysis, and interpretation of the data. NN drafted the article, and YN, KN, NK, YH, TM, and RK critically revised it for important intellectual content. All authors had final approval of the version to be submitted for publication.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study protocol was reviewed and approved by the Institutional Review Board of our hospital (approval no. 170176).

Generative AI and AI-assisted technologies in the writing process
No.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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