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Effect of soft tissue laxity of the knee joint on limb alignment correction in open-wedge high tibial osteotomy

Dae-Hee Lee[1] · Sung-Chul Park[2] · Hyung-Joon Park[2] · Seung-Beom Han[2]

Abstract

Purpose   Open-wedge high tibial osteotomy (HTO) cannot always accurately correct limb alignment, resulting in under- or over-correction. This study assessed the relationship between soft tissue laxity of the knee joint and alignment correction in open-wedge HTO.

Methods   This prospective study involved 85 patients (86 knees) undergoing open-wedge HTO for primary medial osteoarthritis. The mechanical axis (MA), weight-bearing line (WBL) ratio, and joint line convergence angle (JLCA) were measured on radiographs preoperatively and after 6 months, and the differences between the pre- and post-surgery values were calculated. Post-operative WBL ratios of 57–67 % were classified as acceptable correction. WBL ratios <57 and >67 % were classified as under- and over-corrections, respectively.

Results   Preoperative JLCA correlated positively with differences in MA ($r = 0.358$, $P = 0.001$) and WBL ratio ($P = 0.003$). Difference in JLCA showed a stronger correlation than preoperative JLCA with differences in MA ($P < 0.001$) and WBL ratio ($P < 0.001$). Difference in JLCA was the only predictor of both difference in MA ($P < 0.001$) and difference in WBL ratio ($P < 0.001$). The difference between pre- and post-operative JLCA differed significantly between the under-correction, acceptable-correction, and over-correction groups ($P = 0.033$).

Preoperative JLCA, however, did not differ significantly between the three groups. Neither preoperative JLCA nor difference in JLCA correlated with change in posterior slope.

Conclusions   Preoperative degree of soft tissue laxity in the knee joint was related to the degree of alignment correction, but not to alignment correction error, in open-wedge HTO. Change in soft tissue laxity around the knee from before to after open-wedge HTO correlated with both correction amount and correction error. Therefore, a too large change in JLCA from before to after open-wedge osteotomy may be due to an overly large reduction in JLCA following osteotomy, suggesting alignment over-correction during surgery.

Level of evidence   II.

Keywords   High tibial osteotomy · Joint line convergence angle · Alignment correction

✉ Seung-Beom Han
   oshan@korea.ac.kr

1   Department of Orthopaedic Surgery, Samsung Medical
    Center, Sungkyunkwan University School of Medicine,
    Seoul, Korea

2   Department of Orthopaedic Surgery, Anam Hospital, Korea
    University School of Medicine, 126-1, Anam-dong 5-ga,
    Seongbuk-gu, Seoul 136-705, Republic of Korea

Introduction

Medial opening-wedge high tibial osteotomy (HTO) is an established procedure for medial compartment osteoarthritis of the knee joint [11, 13, 34]. Clinical outcomes are dependent on the accurate correction of lower limb alignment, as planned preoperatively [3, 4, 7, 25]. Over- and under-corrections of varus deformity have been shown to be associated with poor clinical outcomes [26]. Adequate correction of lower limb alignment during the surgery can be accomplished using various intraoperative techniques, such as fluoroscopy using an electrocautery cord or computer navigation [21, 23].

Despite accurate preoperative planning and careful surgical techniques, including intraoperative assessment of

limb alignment correction, many HTOs do not result in accurate correction, inevitably resulting in correction errors that can include under- or over-correction. Alignment correction errors may be due to high intraobserver variations and the low reproducibility of intraoperative assessment tools, including fluoroscopy-based methods and navigation [6, 19, 20, 24].

Alignment correction errors may also be due to soft tissue laxity around the knee joint [9]. Because all surgical procedures and intraoperative assessments of alignment are performed under non-weight-bearing conditions, with the patient in the supine position, discrepancies arise between intraoperative prediction of alignment correction and real alignment assessed in standing patients by lower limb radiography [22, 31]. This discrepancy may be increased by severe soft tissue laxity due to the effects of weight-bearing conditions on alignment changes in lax knees [2]. Although soft tissue laxity around the knee may contribute to correction errors and may be correlated with the degree of limb alignment correction in HTO [29], few studies have evaluated the effects of soft tissue laxity of the knee joint on alignment correction in HTO.

This study was therefore designed to assess the relationships between soft tissue laxity of the knee and alignment correction error and amount in open-wedge HTO. It was hypothesized that increased preoperative soft tissue laxity around the knee would increase the likelihood of alignment correction errors in open-wedge HTO and that soft tissue laxity around the knee may correlate with correction amount before and after surgery.

Materials and methods

This study enrolled patients with primary medial osteoarthritis who underwent primary navigation open-wedge HTO from 2009 to 2011. Patients considered ineligible for HTO included those aged >65 years, and patients with symptomatic osteoarthritis of the patellofemoral joint and lateral compartment, rheumatoid arthritis, a knee range of movement <100°, grade ≥3 lateral collateral ligament laxity, and a flexion contracture >10°. Patients were included if they had undergone open-wedge HTO for medial osteoarthritis, with navigation performed by allografting and plate fixation, and were followed up for a minimum of 6 months after surgery. Patients were excluded if they experienced complications, such as bone graft collapse, broken screws, or malunion or non-union after surgery, as such conditions could adversely affect limb alignment. All of the 90 patients (92 knees) initially approached agreed to take part in the study. After assessing eligibility, 88 patients (89 knees) were enrolled. Two patients (two knees) were lost to follow-up, and another one patient (one knee) was excluded

because of bone graft collapse due to lateral tibial cortex breakage. Thus, our study cohort consisted of 85 patients (86 knees) who underwent navigation-assisted open-wedge HTO. The study was approved by the Institutional Review Board of Korea University Anam Hospital (AN11133-002), and written informed consent was obtained from all patients.

Surgical techniques

The preoperative degree of correction and the size of the osteotomy gap were assessed on standing lower leg radiography, as described previously [26]. An anteromedial vertical skin incision was made from the superomedial aspect of the patellar inferior pole to 4–5 cm below the tibial tubercle. The medial hamstring tendon and the distal fibres of the medial collateral ligament were released, and the site of distal insertion of the patellar tendon was identified. A guide wire was inserted with the visual assistance of an image intensifier in the above-described plane, and osteotomy was performed with a saw, under the guidance of an image intensifier, for a distance up to 1 cm from the lateral cortex. In each knee, the oblique osteotomy part of the biplane osteotomy was intended to commence at the medial tibial cortex along the metaphyseal flare (approximately 5–6 cm distal to the joint line) and was angled such that it terminated at the level of the tip of the fibular head laterally. Efforts were made to keep the lateral cortex and lateral capsular hinge intact, thus not violating the bony portion to which the patellar tendon was attached. The vertical osteotomy part of biplane osteotomy was performed at the posterior aspect of the tibial tubercle, to which the patellar tendon was attached, thus avoiding violation of the bony portion to which the patellar tendon was attached and leaving most of the ligament attached to the distal tibial fragment. Using a double chisel, the bone at the site of the osteotomy was forced to open gradually to its target width, taking care not to induce lateral cortex breakage. When the MA passed through 62 % of the tibial plateau, as assessed by intraoperative fluoroscopy, and the target osteotomy width was achieved, the osteotomy was stabilized using a fixed-angle plate with interlocking screws (TomoFix™, Synthes, Bettlach, Switzerland or Synthes GmbH, Solothurn, Switzerland). An allogenic bone graft (Junyoung Medical, Seoul, South Korea) was inserted into the osteotomy gap to minimize post-operative loss of correction. The amount of correction was also determined by aiming for a mechanical femorotibial axis with a valgus over-correction of 4°–5° (range 2°–8°). The amount of correction and the size of the posterior opening gap at the osteotomy site in knees with a preoperative varus deformity were planned to result in a post-operative valgus of 5° (e.g. a varus of 5° would require a 10° correction and a 10-mm posterior

Fig. 1 Measurement of limb alignment. **a** The mechanical axis was defined as the angle subtended by a *line* drawn from the *centre* of the femoral head to the *centre* of the knee and a *line* drawn from the *centre* of the knee to the *centre* of the talus. **b** The weight-bearing *line* was defined as a *line* drawn from the *centre* of the femoral head to the *centre* of the superior articular surface of the talus. **c** The weight-bearing line ratio was defined as the tibial insertion of the weight-bearing line/tibial width, with the medial tibial edge at 0 % and the lateral tibial edge at 100 %
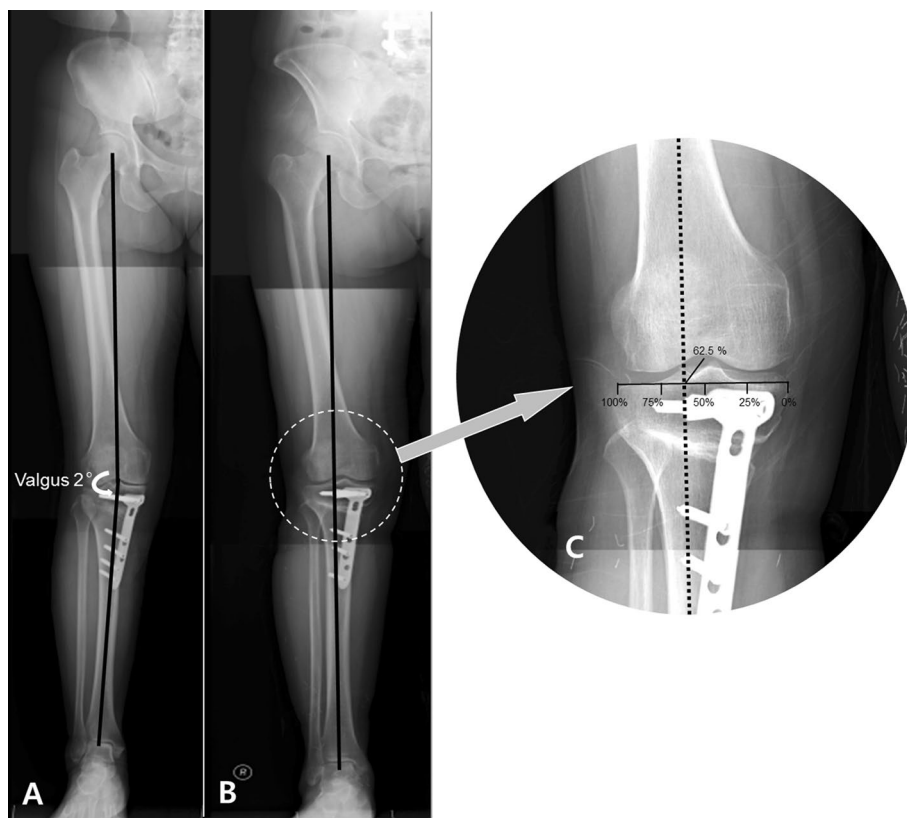
osteotomy gap). This estimated opening gap was confirmed by matching the calculated opening gaps using the Miniaci method. To avoid increasing the tibial posterior slope, we attempted to make the anterior gap of the osteotomy site behind the tibial tuberosity approximately 1/2–2/3 of the posterior opening gap at the posteromedial corner of the proximal tibia.

Radiographic measurements

Radiographs were obtained both pre- and post-operatively (6 months after surgery) and were used to calculate the MA, defined as the angle subtended by a line drawn from the centre of the femoral head to the centre of the knee and a line drawn from the centre of the knee to the centre of the talus (Fig. 1a). Radiographs were also used to calculate the WBL, defined as a line drawn from the centre of the femoral head to the centre of the superior articular surface of the talus. Full-length hip-to-ankle radiographs with patients standing were used to calculate the WBL ratio at the tibial intersection (Fig. 1b). The denominator was the width of the tibia, and the numerator was the tibial intersection of the WBL (with the medial tibial edge at 0 % and the lateral tibial edge at 100 %; Fig. 1c). Preoperative bony deformities were evaluated by measuring the lateral distal femoral angle (LDFA), defined as the angle between

the mechanical axis of the femur and the articular surface of the distal femur, and the medial proximal tibial angle (MPTA), defined as the angle between the tibial mechanical axis and the articular surface of the proximal tibia (Fig. 2a). The angle of the posterior tibial slope on lateral radiographs was defined as the angle formed by the line connecting the highest anterior and posterior points of the medial plateau and a line drawn perpendicular to the tibial shaft axis (Fig. 2b). Arthritic changes in the knee joint were evaluated using Kellgren–Lawrence (KL) grades. To evaluate soft tissue laxity on the coronal plane, the joint convergence angle (JLCA) was measured as the angle between the line connecting the distal femur and the proximal tibial articular surfaces on anteroposterior radiographs of standing patients (Fig. 3). If the apex of the JLCA was medial, it was recorded as positive (+) and denoted as varus, and if it was lateral, it was recorded as negative (−) and denoted as valgus.

All radiographic measurements were taken using a picture archiving and communication system (PACS, PI View STAR, version 5025, Infinitt, Seoul, Korea). MA, WBL ratio, and JLCA were independently evaluated by two experienced orthopaedic surgeons. Each surgeon twice measured these parameters in all 86 knees, with an interval of 2 weeks between measurements. The average of the measurements recorded by the two surgeons was used

Fig. 2 Standing anteroposterior radiography of a lower extremity. **a** The lateral distal femoral angle (LDFA) was defined as the angle between the mechanical axis of the femur and the articular surface of the distal femur; and the medial proximal tibial angle (MPTA) was defined as the angle between the tibial mechanical axis and the articular surface of the proximal tibia. **b** On lateral radiographs, the angle of the posterior tibial slope was measured as the angle formed by the articular tangential line of the medial plateau and a line drawn perpendicular to the axis of the tibial shaft

for analyses. The surgical target was a final WBL ratio of 62.5 ± 5.0 % (range 57–67 %). Post-operative WBL ratios within this target (57–67 %) were classified as acceptable corrections, whereas WBL ratios <57 and >67 % were classified as under- and over-corrections.

Statistical analysis

The primary study outcomes were to determine whether preoperative JLCA was associated with the degree of alignment correction across all subjects and to show whether the difference in JLCA between before to after surgery differed significantly between knees with under-, acceptable-, and over-correction. Using an α level of 0.05 and a power of 0.8, the power analyses showed that 78 knees were required to show a statistically significant relationship between preoperative JLCA and degree of alignment correction, and that 82 knees were necessary to detect significant
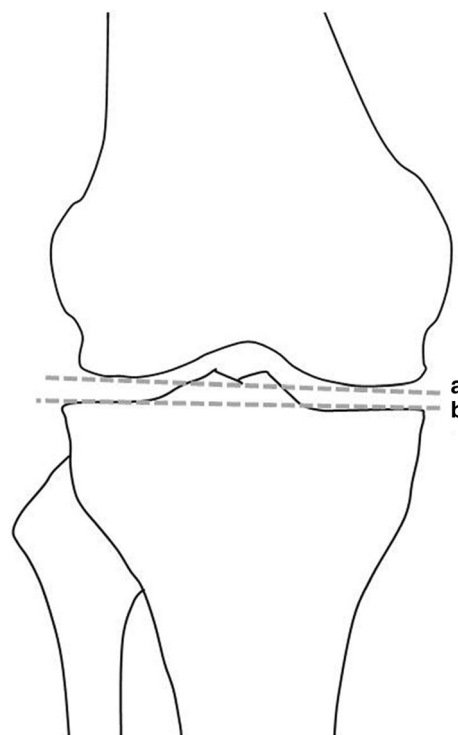

Fig. 3 Drawing showing that joint line convergence angle (JLCA) formed by two articular tangential lines of **a** the distal femur and **b** the proximal tibia

differences in change in JLCA between the three patient groups. This study finally included 86 knees, indicating adequate power (0.874) to detect a significant correlation between preoperative JLCA and degree of alignment correction, and to detect significant differences in change in JLCA between the three groups.

The intraobserver and interobserver reliabilities of each measurement were assessed by determining the intraclass correlation coefficient (ICC).

The single measured ICC was used to determine the intraobserver reliability of measurements obtained on two occasions by each observer. The mean measured ICC was used to evaluate the interobserver reliability by comparing the mean of two measurements of each variable.

All statistical analyses were performed using IBM SPSS Statistics version 20 software (IBM Corporation, USA). A P value <0.05 was considered statistically significant. All data are presented as means and standard deviations. One-way analysis of variance (ANOVA) was used to compare pre- and post-operative JLCA, and differences in JLCA between the under-, acceptable-, and over-correction groups, with statistically significant differences assessed using post hoc Tukey tests to determine which two of the three groups differed significantly.

Correlations between JLCA and differences in MA, WBL ratio, and posterior slope were assessed using

Pearson correlation analysis. Multiple linear regression analysis was performed to identify which of the three JLCA measurements (preoperative, post-operative, or their difference) was predictive of correction amount, including differences in MA and WBL ratio from before to after surgery. Factors assessed as independent contributors to bony deformity and severity of osteoarthritis included the medial proximal tibial angle, the lateral distal femoral angle, and the Kellgren–Lawrence grade of the medial compartment. Candidate variables were selected for entry into the multiple linear regression model using a stepwise selection method, with the criterion for entry being a P value <0.05.

Results

Patient demographics, limb alignment, and deformities around the knee, including proximal tibia and distal femur, are summarized in Table 1. The interobserver and intraobserver reliabilities for radiographic parameters including MA (0.835–0.901), WBL ratio (0.787–0.868), and JLCA (0.765–0.835) were satisfactory. The mean pre- and post-operative MAs were varus $8.0 \pm 3.9°$ (range $1°–15°$) and valgus $3.4° \pm 2.3°$ (range, valgus $7°$ to varus $2°$), respectively. The mean MA correction (difference between pre- and post-operative mechanical axis) was 9.78. The mean pre- and post-operative WBL ratios were 17.7 ± 12.8 % (range 2–46 %) and 63.6 ± 12.8 % (range 2–46 %), respectively, and the mean change in WBL ratio following HTO was 42.15 % (range 44–81 %). The posterior slope of the medial plateau increased slightly from $8.7° \pm 3.0°$ preoperatively to $9.5° \pm 3.4°$ ($P = 0.025$). The JLCA decreased from $3.4° \pm 2.3°$ (range $7°–2°$) preoperatively to $2.1° \pm 2.3°$ (range $7°–2°$) post-operatively ($P < 0.001$). Evaluation of the severity of osteoarthritis in the medial compartment showed that 11 knees could be classified as KL grade 2, 56 as KL grade 3, and 19 as KL grade 4. In the lateral compartment, 20 knees were classified as KL grade 1, 63 as KL grade 2, and three as KL grade 3.

The WBL ratio surgical target (57–67 %) was achieved in 33 of the 86 knees (38 %). Twenty knees (23 %) had a post-operative WBL ratio <57 % and were classified as under-corrected, whereas 33 knees (38 %) had a post-operative WBL ratio >67 % and were classified as over-corrected.

Preoperative JLCA did not differ significantly between the under-, acceptable- and over-correction groups. However, post-operative JLCA and the difference between pre- and post-operative JLCA differed significantly between the three groups (Table 2). Exploratory analyses showed that only the under- and over-correction groups differed significantly. Differences between pre- and post-operative JLCA differed significantly between the acceptable- and over-correction groups as well as between the under- and over-correction groups (Table 3).

Preoperative JLCA was found to correlate positively with pre- to post-operative differences in MA ($P = 0.001$) and WBL ratio ($P = 0.003$), as well as with preoperative varus deformity, including MA ($P < 0.001$) and WBL ratio ($P < 0.001$). The pre- to post-operative difference in JLCA showed a stronger correlation than preoperative JLCA with pre- to post-operative differences in MA ($P < 0.001$) and WBL ratio ($P < 0.001$), but did not show a significant correlation with pre- to post-operative differences in the posterior slope of the medial tibial plateau ($P = $ n.s.).

Table 1 Preoperative patient characteristics

Parameter	
Male/female	20:66
Age (years)[a]	57 (41–72)
Height (cm)[a]	158 (145–175)
Weight (kg)[a]	65 (47–81)
Body mass index (kg/m²)[a]	25.7 (21.8–34.2)
Deformity (°)[b]	Varus 7.8 ± 3.4 (1–17)
Medial proximal tibial angle (°)[b]	85.1 ± 2.6 (77–89)
Lateral distal femoral angle (°)[b]	89.5 ± 2.4 (82–947)
Posterior slope (°)[b]	8.7 ± 3.0 (3–16)

[a] Median (range)

[b] Mean ± SD (range)

Table 2 Mean joint line convergence angles (JLCAs) in under-, acceptable-, and over-correction groups

	Under-correction group Mean ± SD (range)	Acceptable-correction group Mean ± SD (range)	Over-correction group Mean ± SD (range)	P value[a]
Preoperative JLCA	4.2 ± 2.3 (0.6 to 8.0)	3.6 ± 2.2 (−1.5 to 10.5)	3.8 ± 2.1 (0.5 to 10.4)	n.s.
Post-operative JLCA	2.7 ± 2.1 (−1.2 to 6.8)	2.3 ± 1.9 (−3.1 to 6.6)	1.4 ± 1.4 (−1.1 to 4.4)	<0.031
Difference in JLCA	1.5 ± 1.6 (−2.1 to 3.9)	1.3 ± 1.6 (−1.2 to 5.6)	2.3 ± 1.9 (−0.1 to 8.4)	<0.033

JLCA joint line convergence angle

[a] By one-way analysis of variance (ANOVA)

Table 3 Post hoc multiple comparison test comparing post-operative JLCA and difference in JLCA among the under-, acceptable-, and over-correction groups

Measured view	Comparison	Mean difference	SE	95 % CI		P value
				Lower	Upper	
Post-operative JLCA	Under versus acceptable	0.4	0.5	−0.8	1.6	n.s.
	Acceptable versus over	0.9	0.4	−0.2	1.9	n.s.
	Under versus over	1.27	0.5	0.1	2.5	0.039
Difference in JLCA	Under versus acceptable	−0.2	0.5	−1.3	1.0	n.s.
	Acceptable versus over	−1.1	0.4	−2.1	−0.1	0.040
	Under versus over	−1.2	0.5	−2.4	−0.1	0.038

Table 4 Correlations between differences in mechanical axis and WBL ratio and JLCA parameters

	Difference in MA		Difference in WBL ratio	
	Pearson correlation coefficient (r)	P value	Pearson correlation coefficient (r)	P value
Preoperative JLCA (°)	0.358	0.001	0.317	0.003
Post-operative JLCA (°)	−0.046	0.672	−0.077	n.s.
Difference in JLCA (°)	0.478	<0.001	0.464	<0.001

MA mechanical axis, *WBL* weight-bearing line, *JLCA* joint line convergence angle

Table 5 Multiple linear regression analysis of sagittal plane factors affecting absolute and relative graft extrusion

Dependent variable	Explicative variable(s)	Unstandardized coefficients		Standardized coefficients		
		B	SE (B)	β	P value	R^2
Difference in MA	Difference in JLCA	1.136	0.277	0.478	<0.001	0.229
Difference in WBL ratio	Difference in JLCA	4.088	0.850	0.464	<0.001	0.216

MA mechanical axis, *WBL* weight-bearing line, *JLCA* joint line convergence angle

Post-operative JLCA also did not correlate significantly with pre- to post-operative differences in MA and WBL ratio (Table 4).

Multiple linear regression performed to identify parameters associated with pre- to post-operative differences in MA and WBL ratio found that difference in JLCA was the only predictor independently associated with differences in both MA ($P < 0.001$) and WBL ratio ($P < 0.001$; Table 5). These results indicated that the increased pre- to post-operative difference in JLCA resulted in increased pre- to post-operative differences in MA and WBL ratio.

Discussion

The most important finding of the present study was that JLCA correlated with correction amount but not with correction error of lower limb alignment.

Accurate correction of limb alignment is very important to achieve satisfactory clinical outcomes after HTO [10, 32]. Unfortunately, all patients who undergo HTO do not achieve adequate correction, despite careful surgical techniques, because of the narrow goal of limb alignment correction. Limb alignment correction errors, including under- and over-correction, are due to inaccurate preoperative planning of correction amount and inappropriate intraoperative correction as planned due to a lack of a reliable tool to assess limb alignment during surgery [12, 13, 16, 28]. Soft tissue laxity, as indicated by JLCA, may also be a cause of limb alignment correction error. For example, assessment of mean post-operative JLCAs in 42 knees that underwent open-wedge HTO found that JLCAs in acceptably, over-, and under-corrected knees were 0.9°, 2°, and −2.5°, respectively, indicating that the JLCA itself may contribute to the correction error [3]. However, that study did not measure the JLCA itself, but instead measured the dilatation angle or medial joint space narrowing (or widening) and calculated the JLCA using the femorotibial and tibia vara angles. A study evaluating mechanical axis deviation and joint line convergence angle by comparing 102 sets of supine fluoroscopy images and full-length standing anteroposterior radiographs of the lower extremities found that patients with a JLCA >3° on standing radiographs were significantly more likely to have a >10-mm discrepancy in mechanical axis deviation between intraoperative and post-operative measurements [30]. However, of these

102 patients, 90 (88 %) were aged <18 years and had limb alignment deformity or limb shortening, making their soft tissue status different from that of adult patients with osteoarthritis. In the current study, we showed that a greater difference between pre- and post-operative JLCA was associated with greater over-correction of lower limb alignment, suggesting a correlation between JLCA and correction error. In this study, JLCA was directly measured using an acceptably reliable method. Moreover, only patients who underwent open-wedge HTO for medial compartment osteoarthritis were included. Therefore, JLCA itself was more accurate than when calculated indirectly from bony alignment parameters such as femorotibial and tibia vara angles [3]. In addition, the close relationship we observed between difference in JLCA and correction error after open-wedge HTO is more clinically relevant for patients undergoing open-wedge HTO for medial osteoarthritis.

In normal patients, the articular surface of the distal femur is parallel to the tibia plateau, with JLCA ranging from 0° to 2° [5]. However, the parallel JLCA differed in patients with medial osteoarthritis because of the pseudolaxity of the lateral side with varus alignment, resulting from substantial amounts of intra-articular cartilage and subchondral bone loss in the medial compartment [27]. Therefore, JLCA is more likely to be restored to a parallel position after than before HTO, because the pseudolaxity of the lateral side could disappear due to valgus alignment following HTO. The results of the present study were consistent with our expectations, showing that mean JLCA decreased from 3.2° preoperatively to 2.1° post-operatively. Additionally, as the post-operative limb alignment became more valgus, the post-operative JLCA became more parallel, and as preoperative limb alignment became more varus, the preoperative JLCA became more convergent. This close relationship between limb alignment and JLCA may be partly explained by the change in adduction moment of the medial compartment. In neutral alignment, the ground reaction forces pass through just medial to the knee joint centre, creating an adduction moment of the medial compartment when compared with the lateral side. However, this adduction moment was insufficient to open the lateral knee joint space against knee lateral side restraints such as the iliotibial band and lateral collateral ligament, making the JLCA parallel. In varus alignment, however, the adduction moment was increased far more because the ground reaction force vector passed the medial margin of the tibial plateau [1, 15, 35]. Thus, the adduction moment can open up the lateral joint space against knee lateral side restraints, increasing JLCA [14].

In assessing the correlations between JLCA with the degree of alignment correction, expressed as differences between preoperative and post-operative MA and WBL ratio, we found that preoperative, but not post-operative, JLCA significantly correlated with these alignment correction parameters. However, contrary to our expectation, preoperative JLCAs were similar among the under-, acceptable-, and over-correction groups. This finding may be due to correction errors being affected by factors other than soft tissue laxity around the knee joint. Inaccurate preoperative planning of the amount of correction and inappropriate intraoperative correction relative to that preoperatively planned may have resulted in correction errors, such as under- or over-correction. Nevertheless, since preoperative JLCA reflected soft tissue laxity around the knee joint, these results indicated that preoperative soft tissue laxity correlated with correction amount but not with correction error. The difference in JLCA from before to after surgery correlated with the differences in MA and WBL ratio and was the only factor significantly associated with both of the latter. Moreover, the difference in JLCA from before to after surgery differed significantly between the under-, acceptable-, and over-correction groups. These findings indicated that changes in soft tissue laxity from before to after HTO correlated not only with correction amount but with correction error. Therefore, patients with a too parallel or overly decreased JLCA after osteotomy, indicating a too large change in JLCA, should be suspected during surgery of the possibility of alignment over-correction.

This study had several limitations. It mainly focused on the correlation between soft tissue laxity and correction amount or correction error of limb alignment in open-wedge HTO. However, bony deformity or malalignment may also be a potential cause of limb alignment correction error [6, 30]. In addition, any malalignment of the lower limb on the sagittal or axial plane may cause a correction error [33]. A tendency to external rotation of the distal tibial fragment of the osteotomy site in the axial plane has been reported [18]. In addition, remaining flexion contractures during radiography may influence coronal alignment, resulting in a correction error of lower limb alignment after HTO [17]. Finally, dynamic soft tissue laxity was not assessed on varus/valgus stress radiographs. However, the reliability and accuracy of stress radiography are not very high, due to technical limitations or poor cooperation by patients [8]. Failure to fully relax the muscles around the knee joint, especially in knees with severe pain, could result in a high false-negative rate.

Conclusions

In conclusion, preoperative JLCA correlated with limb alignment correction amount before and after open-wedge HTO but not with alignment correction error following surgery. The change in JLCA from before to after open-wedge HTO definitely affected the amount of limb alignment

correction and correlated with the correction error following open-wedge HTO. Therefore, a too large change in JLCA from before to after open-wedge osteotomy may be due to an overly large reduction in JLCA following osteotomy, suggesting alignment over-correction during surgery.

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