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# Postoperative change in the joint-line convergence angle is associated with inaccurate correction in open-wedge high tibial osteotomy

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## Abstract

**Objective** Accurate correction is a prerequisite for the favorable outcomes of open-wedge high tibial osteotomy (OWHTO). However, previous studies have reported disappointing results regarding correction accuracy despite the use of intra-operative navigation, which implies that a certain factor other than bony components is involved in the inaccurate correction (mainly overcorrection). The joint-line convergence angle (JLCA) can represent soft tissue effects in OWHTO. This study tried to determine whether the postoperative change in the JLCA ( $\Delta$ JLCA) led to inaccurate correction.

**Methods** Medical records of 78 OWHTO patients from 2005 to 2021 were retrospectively reviewed. The hip–knee–ankle angle (HKA) was measured with a positive value indicating varus alignment. Inaccurate correction was defined as postoperative HKA  $< -3^\circ$ . The JLCA was measured before and 6 months after surgery on long-standing hip-to-ankle radiographs, and  $\Delta$ JLCA was defined as the difference between the preoperative and 6-month postoperative JLCA.  $\Delta$ JLCA was compared between the accurate correction group and the inaccurate correction group, and a receiver operating characteristic (ROC) curve was used to obtain the cutoff  $\Delta$ JLCA at which the sensitivity and the specificity for inaccurate correction were maximized. Clinical outcomes were also compared between the groups using the knee injury and osteoarthritis outcome score (KOOS) at final follow-up (60.9  $\pm$  53.3 months postoperatively).

**Results** Of the 78 patients, inaccurate correction was noted in 10 patients. The overall preoperative and postoperative HKAs were  $7.0 \pm 3.1^\circ$  and  $-0.4 \pm 1.5^\circ$ , respectively. The accurate correction group and the inaccurate correction group had a difference in  $\Delta$ JLCA ( $p = 0.010$ ). However, no significant difference was found in the preoperative HKA ( $p = 0.529$ ). An ROC curve showed that the cutoff  $\Delta$ JLCA was  $1.9^\circ$ . In the patients having  $\Delta$ JLCA  $\geq 1.9^\circ$ , the mean JLCA was  $4.9 \pm 1.6^\circ$  preoperatively and  $1.7 \pm 1.2^\circ$  postoperatively. In the other patients having  $\Delta$ JLCA  $< 1.9^\circ$ , the mean preoperative and postoperative JLCA were  $2.5 \pm 1.8^\circ$  and  $2.3 \pm 1.8^\circ$ , respectively. The difference in the preoperative JLCA was significant ( $p < 0.001$ ). The postoperative KOOS subscales did not differ according to correction accuracy.

**Conclusion** Inaccurate correction in OWHTO, specifically valgus overcorrection, is associated with large  $\Delta$ JLCA which represents the postoperative change of soft tissue effects. Overcorrection should be checked in cases of large preoperative JLCA.

**Keywords** Open-wedge high tibial osteotomy, Joint-line convergence angle, Alignment correction, Soft tissue laxity

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## Introduction

Open-wedge high tibial osteotomy (OWHTO) realigns the limb alignment and alleviates the load on the medial compartment [1–4]. Its well-documented efficacy depends on the accurate correction of the limb alignment [5–7]. Preoperative planning is focused on the osteotomy gap or the medial proximal tibial angle (MPTA), aiming for a hip–knee–ankle angle (HKA) of 183°–186° [8–10]. Despite advanced surgical techniques and intra-operative navigation in OWHTO, previous studies have reported that correction accuracy was unexpectedly low [6, 11]. Several studies attributed discrepancies between preoperative planning and postoperative alignment to soft tissue effects that were not reflected in correction parameters, such as the osteotomy gap and the MPTA [7, 12, 13].

The joint-line convergence angle (JLCA) represents soft tissue tension of the medial side of the knee joint with varus deformity [14, 15]. Because intra-articular pressure is affected by the soft tissue tension, OWHTO is performed after releasing the superficial medial collateral ligament (sMCL) [16]. As a result, the JLCA changes postoperatively, which alters the whole limb alignment. When the JLCA became parallel, the limb alignment moves to more valgus than preoperatively planned [12, 17].

Seo et al. measured the tension of the medial structure in OWHTO, concluding that the medial laxity after releasing the sMCL was restored with the osteotomy site being opened [18]. If so, the postoperative change in the JLCA ( $\Delta$ JLCA) would reach an end or be reversed when an opening gap is large and the release of the sMCL is insufficient [19].  $\Delta$ JLCA is worth investigating because it could be associated with both overcorrection and undercorrection. Therefore, the present study tried to determine whether  $\Delta$ JLCA led to inaccurate correction. It was hypothesized that  $\Delta$ JLCA would be associated with inaccurate correction.

## Methods

Medical records of patients who underwent OWHTO from 2005 to 2021 were retrospectively reviewed after approval was obtained from our institutional review board. OWHTO was indicated in physically active patients who aged < 65 years and complained of medial-sided walking pain that did not respond to conservative treatments. The contraindications included medial compartment arthritis of Ahlbäck grade  $\geq 3$ , flexion contracture more than 10°, active inflammatory arthritis, and symptomatic osteoarthritis of the lateral compartment and the patellofemoral joint. The severity of varus deformity was evaluated before surgery using long-standing hip-to-ankle radiographs, and correction

accuracy was checked 6 months after surgery. Clinical outcomes were assessed using the knee injury and osteoarthritis outcome score (KOOS) at final follow-up (60.9  $\pm$  53.3 months postoperatively).

The inclusion criteria of the present study were (1) primary OWHTO, (2) follow-up duration  $\geq 6$  months, and (3) 6-month postoperative long-standing hip-to-ankle radiograph to measure the JLCA. Patients were excluded if they had complications that could affect correction accuracy, such as metal failures and collapse of the osteotomy site. Of the 80 patients undergoing the index surgery during the study period, 2 patients who did not take postoperative radiographs were excluded. No patients were excluded owing to metal failures or collapse of the osteotomy site. Accordingly, 78 patients met the inclusion criteria.

## Surgical technique

All OWHTOs were performed by a single senior surgeon. The correction angle was assessed on a long-standing hip-to-ankle radiograph using the Miniaci method [20]. The target weight-bearing point was Fujisawa point that corresponded to the HKA of 3° valgus [21, 22]. The correction amount was adjusted based on the severity of degenerative changes in each compartment. A 4–5 cm vertical incision was made on the anteromedial side of the tibia. The distal fibers of the sMCL and the pes anserinus tendon were released. Two guide wires were inserted with the visual assistance of an image intensifier, and osteotomy was performed, leaving 5–10 mm of the lateral cortex intact as a hinge. The ascending part of biplanar osteotomy was made behind the patella tendon, at an angle of around 110° to the previous osteotomy line. Then, the osteotomy site was opened using a laminar spreader and fixed with a locking anatomic plate. Weight-bearing was gradually allowed from toe-touch to full weight-bearing at 6–8 weeks postoperatively. The locking plate was removed at around 12 months postoperatively after verifying solid bone union at the osteotomy gap.

## Study design

The JLCA was defined as the angle between the two articular lines of the distal femur and proximal tibia, with positive values indicating varus convergence. The JLCA was measured before and 6 months after surgery on long-standing hip-to-ankle radiographs.  $\Delta$ JLCA was defined as the difference between the preoperative and 6-month postoperative JLCAs.

The hip–knee–ankle angle (HKA) was measured with a positive value indicating varus alignment. Inaccurate correction was defined as postoperative HKA < –3°.  $\Delta$ JLCA was compared between the accurate correction group and the inaccurate correction group, and a receiver

operating characteristic (ROC) curve was used to obtain the cutoff  $\Delta$ JLCA at which the sensitivity and the specificity for inaccurate correction were maximized.

### Statistical analysis

The following factors were assessed to identify risk factors for inaccurate correction: age, sex, body mass index, preoperative HKA, preoperative and postoperative JLCA, and  $\Delta$ JLCA. Comparative analyses were performed between the accurate correction group and the inaccurate correction group. Continuous variables were compared using *t* test for normal distribution and Mann–Whitney *U* test for non-normal distribution. Data normality was tested using Shapiro–Wilk test. Categorical variables were analyzed using Chi-square test if the expected value of the cell was  $\geq 5$  in at least 80% of the cells; otherwise, Fisher exact test was applied. All statistical analyses were conducted using R software version 4.1.1 (R foundation for Statistical Computing, Vienna, Austria), with a *p* value  $< 0.05$  considered statistically significant.

### Results

Seventy-eight patients with a mean age of  $52.0 \pm 4.8$  years (range, 35–63 years) were followed for a mean duration of  $60.9 \pm 53.3$  months (range, 9–102 months). Of these,

inaccurate correction was noted in 10 patients. The overall preoperative and postoperative HKAs were  $7.0 \pm 3.1^\circ$  and  $-0.4 \pm 1.5^\circ$ , respectively. The accurate correction group and the inaccurate correction group had a difference in  $\Delta$ JLCA ( $p=0.010$ ). However, no significant difference was found in the preoperative HKA ( $p=0.529$ ). The patient characteristics between the groups are summarized in Table 1.

### Evaluation of $\Delta$ JLCA and inaccurate correction

An ROC curve for inaccurate correction showed that the cutoff  $\Delta$ JLCA was  $1.9^\circ$  with the area under curve being 0.72 (sensitivity, 70.0%; specificity, 77.9%; Fig. 1). In the patients having  $\Delta$ JLCA  $\geq 1.9^\circ$ , the mean JLCA was  $4.9 \pm 1.6^\circ$  preoperatively and  $1.7 \pm 1.2^\circ$  postoperatively. In the other patients having  $\Delta$ JLCA  $< 1.9^\circ$ , the mean preoperative and postoperative JLCA were  $2.5 \pm 1.8^\circ$  and  $2.3 \pm 1.8^\circ$ , respectively (Table 2). The difference in the preoperative JLCA was significant ( $p < 0.001$ ). The postoperative KOOS subscales did not differ according to correction accuracy (Table 1).

### Discussion

The most important findings of the present study were that 1) the postoperative decrease of the JLCA ( $\Delta$ JLCA of  $1.9^\circ$ ) could lead to valgus overcorrection, and 2) the

**Table 1** Patient characteristics

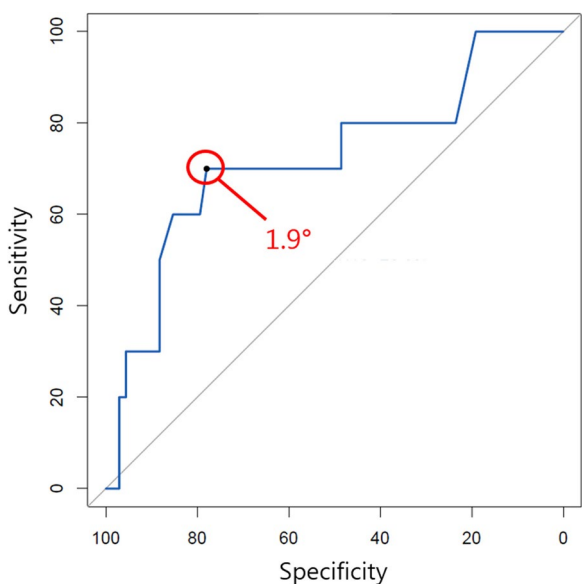
	Overall	Accurate correction (N = 68)	Inaccurate correction (N = 10)	<i>p</i> value
Age, year <sup>a</sup>	52.0 $\pm$ 4.8	52.0 $\pm$ 4.8	52.0 $\pm$ 4.3	0.897
Male/Female, <i>n</i>	18/60	17/51	1/9	0.438
BMI, kg/m <sup>2a</sup>	26.9 $\pm$ 3.8	27.1 $\pm$ 3.7	25.4 $\pm$ 4.0	0.185
Follow-up duration, month <sup>a</sup>	60.9 $\pm$ 53.3	61.2 $\pm$ 52.8	59.4 $\pm$ 60.0	0.973
HKA, deg <sup>b</sup>				
Preoperative <sup>a</sup>	7.0 $\pm$ 3.1	6.9 $\pm$ 3.1	7.6 $\pm$ 2.7	0.529
Postoperative <sup>a</sup>	-0.4 $\pm$ 1.5	-0.3 $\pm$ 1.6	-4.5 $\pm$ 0.8	< 0.001
JLCA, deg <sup>c</sup>				
Preoperative <sup>a</sup>	3.2 $\pm$ 2.0	3.1 $\pm$ 2.0	4.1 $\pm$ 1.9	0.105
Postoperative <sup>a</sup>	2.1 $\pm$ 1.7	2.2 $\pm$ 1.7	1.7 $\pm$ 1.1	0.423
$\Delta$ JLCA <sup>a</sup>	1.0 $\pm$ 1.8	0.8 $\pm$ 1.7	2.4 $\pm$ 1.8	0.010
KOOS				
Pain <sup>a</sup>	81.4 $\pm$ 12.7	80.8 $\pm$ 13.0	85.4 $\pm$ 11.4	0.662
Symptoms <sup>a</sup>	80.7 $\pm$ 15.9	79.7 $\pm$ 16.5	88.4 $\pm$ 8.9	0.340
ADL <sup>a</sup>	87.7 $\pm$ 13.4	86.9 $\pm$ 13.9	93.8 $\pm$ 6.7	0.511
Sports/Rec <sup>a</sup>	53.8 $\pm$ 31.3	52.4 $\pm$ 32.6	63.8 $\pm$ 19.3	0.478
QoL <sup>a</sup>	68.8 $\pm$ 19.7	68.2 $\pm$ 19.6	73.4 $\pm$ 23.0	0.609

BMI body mass index, HKA hip–knee–ankle angle, JLCA joint-line convergence angle, KOOS Knee Injury and Osteoarthritis Outcome, ADL activities in daily living, Sports/Rec sports and recreational function, QoL quality of life

<sup>a</sup> Data are reported as mean  $\pm$  SD unless otherwise indicated

<sup>b</sup> Positive values indicate varus alignment, whereas negative values indicate valgus alignment

<sup>c</sup> Positive values indicate varus convergence, whereas negative values indicate valgus convergence



**Fig. 1** Receiver operating characteristic curve for inaccurate correction showed that the cutoff  $\Delta$ JLCA was  $1.9^\circ$  with the area under curve being 0.72 (sensitivity, 70.0%; specificity, 77.9%)

**Table 2** Analyses according to  $\Delta$ JLCA

JLCA	$\Delta$ JLCA $\geq 1.9^\circ$ (N=22)	$\Delta$ JLCA $< 1.9^\circ$ (N=56)	p value
Preoperative JLCA <sup>a</sup>	4.9 $\pm$ 1.6	2.5 $\pm$ 1.8	< 0.001
Postoperative JLCA <sup>a</sup>	1.7 $\pm$ 1.2	2.3 $\pm$ 1.8	0.125

JLCA, joint-line convergence angle

<sup>a</sup> Data are reported as mean  $\pm$  SD unless otherwise indicated

preoperative JLCA differed significantly according to  $\Delta$ JLCA. Therefore, overcorrection should be checked when a large JLCA was noted preoperatively.

The amount of  $\Delta$ JLCA is hard to predict before performing OWHTO. Albeit delicate preoperative planning and the application of intra-operative navigation, the unexpectedly large  $\Delta$ JLCA often leads to overcorrection. Lee et al. proved that change in soft tissue laxity from before to after OWHTO correlated with both correction amount and correction error [12]. The question is how much  $\Delta$ JLCA would be associated with inaccurate correction. The present study showed that  $\Delta$ JLCA of  $1.9^\circ$  was associated with overcorrection and that amount of  $\Delta$ JLCA occurred when the mean preoperative JLCA was around  $5^\circ$ .

According to a study measuring the joint space width at different time points after OWHTO, the medial joint space width increased 3 months after surgery and the lateral joint space width decreased immediately [15]. Given that lateral joint space narrowing was not associated with the cartilage grades of the medial compartment,

the immediate decrease of the lateral joint width implies  $\Delta$ JLCA which is a representative parameter of soft tissue effects. This change is also the case of double varus syndrome coined by Noyes [23], in which varus deformity is aggravated by the slackness of the lateral soft tissue. Thus, the postoperative decrease of JLCA indicates the change of the lateral soft tissue laxity after the osteotomy gap is opened and the varus aggravation is alleviated.

No consensus has been made on the appropriate extent of medial release in OWHTO. Some studies reported that the release or transection of the sMCL did not increase valgus laxity [18, 24]. On the other hand, another study argued that the sMCL release should be kept to a minimum in cases of small wedge sizes [25]. In the present study, no patient showed the valgus convergence of the joint line (negative JLCA). However, large preoperative JLCA were more likely to decrease larger than  $1.9^\circ$  and lead to overcorrection. Weiping et al. came to similar conclusion that a higher percentage of patients with preoperative JLCA  $\leq 6^\circ$  achieved optimal postoperative JLCA [26]. If the correction amount is moderate and medial tightness is relieved enough before osteotomy, it should be the slackness of the lateral soft tissue that primarily affects  $\Delta$ JLCA. However, to predict  $\Delta$ JLCA in detail, the consistent method and extent of medial release should be established, and individual medial tightness has to be considered. Future studies are expected to give surgeons a predictive formula for  $\Delta$ JLCA.

Some limitations should be noted. First, all OWHTOs were performed by a single senior surgeon. There are several ways to address the medial soft tissue before osteotomy. However, this study could not evaluate the effect of each method on correction accuracy. Second, there might be unrevealed factors influencing  $\Delta$ JLCA. Of those who had large preoperative JLCA, some patients showed large  $\Delta$ JLCA, whereas the others did not. We assumed that different medial tightness of each patient would contribute to the difference. However, it was impossible to prove the assumption in this study. Third, the retrospective design did not allow us to assess the difference between a target alignment and an actual postoperative alignment in each case. Instead, inaccurate correction was defined based on the widely accepted target range of the alignment [9, 27]. Fourth, the sample size could not be tested accurately because of the retrospective design of the study, and there might have been a significant difference in the KOOS subscales if the sample size had been large enough.

**Conclusion**

Inaccurate correction in OWHTO, specifically valgus overcorrection, is associated with large  $\Delta$ JLCA which represents the postoperative change of soft tissue effects.

## Overcorrection should be checked in cases of large pre-operative JLCAs.

### Authors' contributions

YMK was involved in writing, review & editing. YBJ helped in supervision. YCP contributed to data gathering. SL was involved in data gathering. J-HS helped in writing, data gathering, statistical analysis, conceptualization.

### Funding

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### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### Declarations

#### Ethical approval and consent to participate

This retrospective study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Approval for this study was obtained from the institutional review board of Chungnam National University Hospital (No. 2023-06-046). The need for informed consent was waived because of the retrospective nature of the study.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

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