



Preoperative latent medial laxity and correction angle are crucial factors for overcorrection in medial open-wedge high tibial osteotomy

Do kyung Lee¹ · Joon Ho Wang^{2,3} · Yougun Won¹ · Young Ki Min¹ · Sagar Jaiswal⁴ · Byung Hoon Lee⁵ · Jong-Yeup Kim⁶

Received: 10 October 2018 / Accepted: 1 April 2019 / Published online: 12 April 2019
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Abstract

Purpose This study aimed to determine which preoperative factors affect the postoperative change in the joint line convergence angle (JLCA) by preoperatively quantifying soft tissue laxity.

Methods Thirty-four patients who underwent medial open-wedge high tibial osteotomy (HTO) with a navigation were analysed. The JLCA change after HTO was calculated using standing long-bone anteroposterior radiographs taken preoperatively and 6 months postoperatively. Latent soft tissue laxity was defined as the amount of soft tissue that can be extended to valgus or varus from the weight-bearing position, and calculated by subtracting the JLCA on weight-bearing standing radiographs from that on stress radiographs. Multiple linear regression was performed to determine the preoperative factors that statistically correlated with the postoperative JLCA change.

Results In multiple linear regression, JLCA change had a statistically significant correlation with latent medial laxity ($R=0.6$) and a statistically borderline significant correlation with correction angle ($R=0.2$). These imply that the postoperative JLCA change increased by 0.6° per 1° increase in latent medial laxity, and increased by 0.2° per 1° increase in correction angle. Latent medial laxity was the most crucial factor associated with postoperative JLCA changes.

Conclusion The JLCA change could be larger in patients with large latent medial laxity or severe varus deformity requiring a large correction, which could lead to unexpected overcorrection in HTO. Postoperative JLCA change should be considered in preoperative surgical planning. Target point shifting within the hypomochlion point could be a strategy to prevent overcorrection, especially in patients with large latent medial laxity.

Level of evidence Level IV.

Keywords High tibial osteotomy · Soft tissue laxity · Joint line convergence angle (JLCA) · Latent medial laxity · Correction error · Overcorrection

Introduction

Medial open-wedge high tibial osteotomy (HTO) is an effective surgical option for medial compartment osteoarthritis that causes a shift of the weight-bearing axis from medial to lateral. Appropriate alignment in HTO is essential to achieve good surgical outcomes [4, 30]. To obtain accurate alignment, several techniques in preoperative planning [2, 17,

20, 28, 32] have been introduced. Nonetheless, unexpected correction errors have been reported in previous studies [5, 10, 16, 17, 20].

The factors associated with correction errors in HTO are unknown. Kyung et al. [16] reported that the extent of bony correction does not correlate with changes in alignment. They suggested that this lack of correlation is affected by soft tissue laxity. Other studies [11, 14, 16, 20, 27, 29] suggested that soft tissue laxity is associated with correction errors. Although several authors have reported that soft tissue laxity affects the changes in alignment and the correction error, no study has identified which preoperative factors are associated with changes in soft tissue laxity.

The most common method for quantifying soft tissue laxity is evaluating the joint line convergence angle (JLCA).

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s00167-019-05502-6>) contains supplementary material, which is available to authorized users.

✉ Joon Ho Wang
mdwang88@gmail.com

Extended author information available on the last page of the article

Lee et al. [19] reported that the change in the JLCA was correlated with correction errors, and that a large JLCA change was correlated with overcorrection. Heijens et al. [11] also reported that bony correction in HTO is accompanied by additional JLCA changes in the range of 0° – 5° by shifting the weight-bearing portion from medial to lateral, and stretching the medial soft tissue (Fig. 1). The postoperative change in the JLCA, which reflects soft tissue laxity, is a crucial factor for achieving appropriate alignment and preventing correction errors.

However, few studies have reported on preoperative factors associated with the postoperative change in the JLCA, and methods of preventing correction errors in HTO that could result in poor surgical outcomes [8, 12, 13, 30]. The purpose of this study was to determine the preoperative factors that affect the postoperative change in the JLCA after medial open-wedge HTO by quantifying soft tissue laxity. The hypotheses of this study were as follows: (1) the postoperative change in the JLCA can be predicted by evaluating the preoperative soft tissue laxity, and (2) the preoperative medial soft tissue laxity is associated with overcorrection in HTO.

Materials and methods

This study was a retrospective review of 40 patients who underwent medial open-wedge HTO from 2014 to 2016 for symptomatic medial compartment osteoarthritis with Kellgren–Lawrence grade III or IV and a varus alignment of $> 5^{\circ}$. Of the 40 patients, 6 were excluded from the study

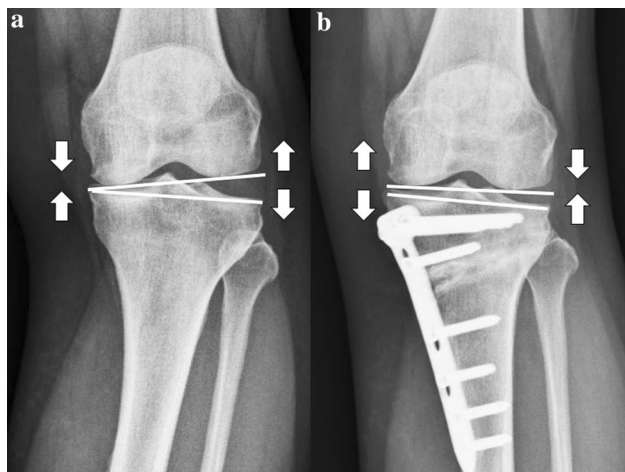


Fig. 1 Perioperative change in the joint line convergence angle (JLCA). The medial joint space was opened and the lateral joint space was closed by shifting the weight-bearing axis in medial open-wedge high tibial osteotomy (**a** preoperative standing long-bone radiograph, **b** postoperative standing long-bone radiograph). The JLCA was also changed owing to the change in soft tissue tension

owing to lack of navigation information or preoperative and postoperative radiographs. A total of 34 patients (7 men and 27 women) were thus included in the study. The postoperative hip–knee–ankle (HKA) angle was larger than valgus 2° (range, valgus 2° – 10°) in all involved patients [11]. The patients' demographic characteristics are listed in Table 1.

Data collection

Data were obtained from the navigation information and from preoperative and postoperative radiographs. Full-length standing anteroposterior radiographs of both legs were obtained preoperatively and at 6 months postoperatively. The Telos stress device (Metax GmH, Hungen-Obbornhofen, Germany) was used in all patients for evaluating soft tissue laxity. The preoperative varus and valgus stress views were obtained in full extension and supine position with a varus and valgus force of 15 kgf to the knee joint at the joint line level, respectively.

The correction angle was preoperatively determined using the Miniaci method [22] (Fig. 2a), and the target point was the weight-bearing line passing through 62.5% of the tibial plateau [32]. The osteotomy site was opened according to the preoperatively determined correction angle, which was confirmed from the difference between the preoperative and postoperative HKA angles in the navigation system (Fig. 2b, c).

Latent soft tissue laxity was defined as the amount of soft tissue that can be extended to valgus or varus from the weight-bearing position. The latent soft tissue laxity was divided into latent medial laxity and latent lateral laxity, and was calculated by subtracting the JLCA on the weight-bearing standing radiograph from the JLCA on the valgus or varus stress radiograph (Fig. 3a, b).

The following radiographic parameters were considered: HKA angle (between the femoral and tibial mechanical axes); change in the HKA angle (difference of the HKA angle between preoperative and postoperative long-leg standing radiographs) [17, 18]; JLCA (angle formed by two articular lines of the distal femur and the proximal tibia) [24]; change in the JLCA (difference of JLCA between preoperative and postoperative long-leg standing radiographs)

Table 1 Patient demographics

Parameter	Total (N=34)
Age (years) ^a	51.6 (32–63)
Sex, male/female	7:27
Height (cm) ^a	164.0 (148–184)
Weight (kg) ^a	66.9 (47.8–98.6)
Body mass index (kg/m ²) ^a	24.6 (19.6–29.7)

^aMedian (range)

Fig. 2 Measurement of the correction angle in the navigation system. The correction angle was preoperatively determined using the Miniaci method. **a** The osteotomy site was opened according to the preoperatively determined correction angle, which was confirmed from the difference between the preoperative and postoperative hip–knee–ankle angle in the navigation system (**b, c**)

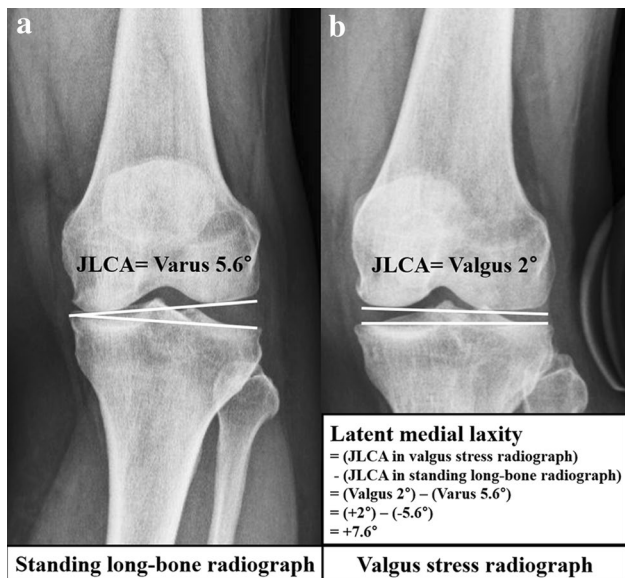
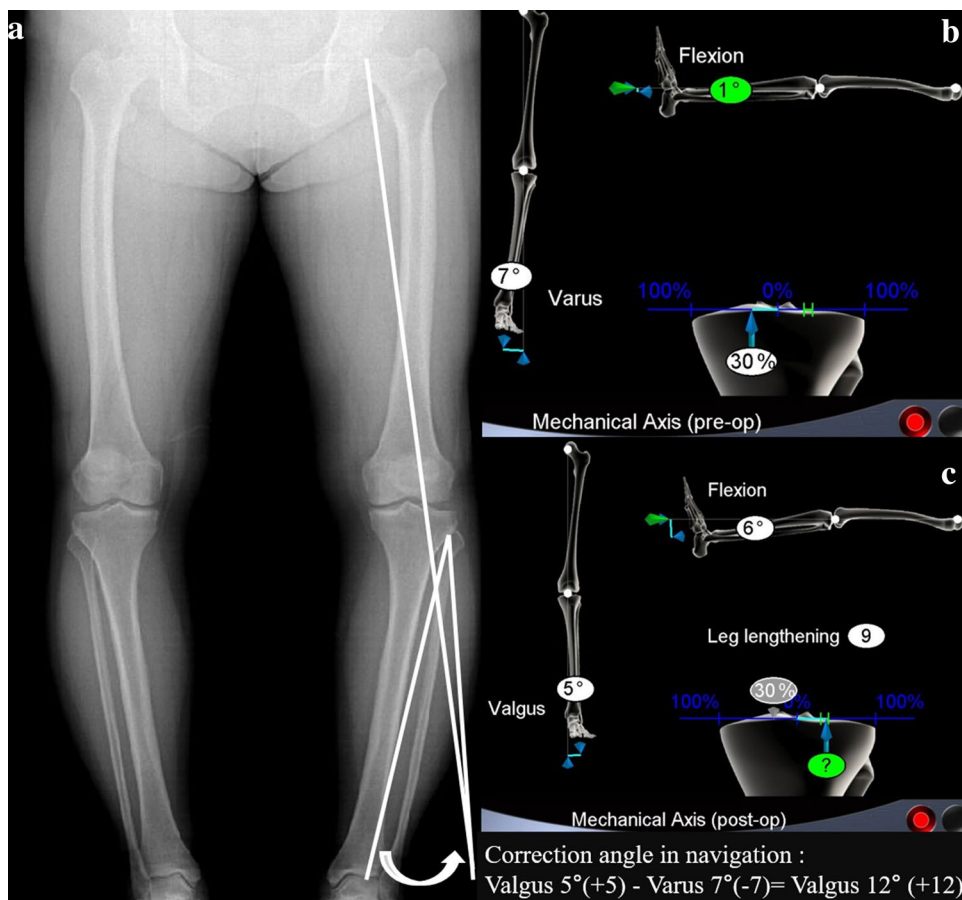


Fig. 3 Calculation of latent medial laxity. The latent medial laxity was calculated by subtracting the joint line convergence angle (JLCA) on the weight-bearing standing radiograph (**a**) from the JLCA on the valgus stress radiograph (**b**)

[24]; and correction error (difference of the postoperative HKA angle between the long-standing radiograph and the navigation system). These factors were measured in the picture archiving communication system of our institution. The measures were categorised as varus and valgus deformity and denoted by a negative (–) and positive (+) value, respectively [24].

Several factors, such as age, weight, correction angle in the navigation system, JLCA in the valgus and varus stress radiographs, latent medial and lateral laxity, and preoperative HKA angle in standing long-bone radiographs, were analysed to determine their effect on the postoperative change in the JLCA.

Surgical technique

A single surgeon performed biplane medial open-wedge HTO using the Orthopilot navigation system (HTO version 1.3, Orthopilot; Aesculap, Tuttlingen, Germany). Two bony transmitters on the distal femur and proximal tibia and a foot reference marker, which was wrapped around the foot by a rubber strap, were set up before the surgery. Anatomical landmarks of the distal femur, proximal tibia, patella, and ankle were registered with a pointer on the skin. The HKA

angle could be monitored in real time using the HKA centres, which were defined as the centres of three-dimensional ranges of motion. During the procedure of the navigation-assisted HTO, the HKA angle from the navigation system was obtained before and after correction. The superficial medial collateral ligament (MCL) was cut transversely along the osteotomy line without detachment of the proximal portion of the MCL above the osteotomy line. The osteotomy site was opened according to the preoperatively determined correction angle, using a laminar spreader, and fixed with a Tomofix plate and locking screw (Synthes, Bettlach, Switzerland). The gap in the osteotomy site was filled with a cancellous bone chip allograft.

This study was approved by the institutional ethics committee at Seoul Samsung Medical Center and received institutional review board approval (SMC IRB No. 2016-07-114-001).

Statistical analysis

Two independent observers who are fellows in sport medicine (LBH, LDK) conducted the measurements. They were blinded to each other's measurements and their prior measurements. To evaluate the intraclass correlation coefficients (ICCs), two independent orthopaedic surgeons measured each of the radiological parameters twice with a minimum interval of 2 weeks to determine the intraobserver and interobserver reliabilities. ICC values > 0.75 were considered good; values between 0.40 and 0.75, fair; and values < 0.40 , poor [7]. For the reliability of the statistical analysis, ICC > 0.75 was adopted as the data-inclusion criterion. All measurements showed good correlation. The results of the interobserver and intraobserver reliabilities of each measurement are described in Online Resource 1.

A Pearson correlation analysis was performed to confirm the correlation between the change in the JLCA and

the correction error, and to determine the factors affecting the JLCA change. Statistical significance was defined as a p value of < 0.05 . Statistically correlated factors were selected and analysed in a multiple linear regression analysis to rule out confounding factors. Multiple linear regression with a stepwise method was performed with the selected statistically significant factors, and the eligibility criterion for the predicting model was a p value of < 0.10 . If the p value of the variable was > 0.10 , the variable was considered an explicative variable, and was excluded from the model. In multiple linear regression analysis, alpha (α) is a constant and the beta coefficient (β) denotes the affecting power of each variable. The regression equation [23] is expressed as follows:

$$Y = \alpha + (\beta_1 \times \chi_1) + (\beta_2 \times \chi_2) + \dots + (\beta_k \times \chi_k).$$

The histogram of the residuals was evaluated for normal distribution of the established model. The discrepancy between the expected value and the observed value was evaluated using standardised residuals. Statistical analysis was performed using IBM SPSS version 20 (IBM, Armonk, NY, USA). A post hoc test was performed to determine the sample size, using a multiple linear regression test at a level of 0.05 and a power of 0.8. The calculations based on the sample size of 34 patients indicated adequate power (0.99) to detect a significant difference in the measurement outcomes in the present study.

Results

Correction error and JLCA change

The change in the JLCA was $2.2^\circ \pm 1.9^\circ$. The correction error was $2.6^\circ \pm 2.2^\circ$ (Table 2). In the Pearson correlation analysis, the correction error was highly correlated with

Table 2 Preoperative and postoperative radiological parameters and correction errors

	Preoperative	Postoperative	Difference
Long-standing bone radiographs			
HKA angle (global correction)	-8.5 (2.5)	3.6 (2.2)	12.1 (3.4)
JLCA (soft tissue correction)	-3.4 (2.2)	-1.3 (1.9)	2.2 (1.9)
MPTA (bony correction)	84.4 (2.3)	94.3 (2.9)	9.6 (2.9)
Navigation			
HKA angle (bony correction)	-4.9 (3.5)	4.7 (2.8)	9.6 (2.6)
Correction error			
= Δ HKA angle in standing long-bone radiograph - Δ HKA angle in navigation			
= global correction - bony correction			2.6 (2.2)

The measures were categorised as varus and valgus deformity and denoted by a negative (-) and positive (+) value, respectively

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

Table 3 Pearson correlation analysis of factors affecting the change in the JLCA

	Preoperative factors	Coefficient of correlation	<i>p</i> value*
Factors affecting the JLCA change	Age	0.3	ns
	Weight	0.2	ns
	Correction angle	0.4	0.04 [†]
	JLCA in varus stress radiograph	0.4	0.03 [†]
	JLCA in valgus stress radiograph	−0.1	ns
	Latent lateral laxity	0.1	ns
	Latent medial laxity	0.7	0.01 [†]
	HKA angle in preoperative standing long-bone radiograph	0.5	0.01 [†]

JLCA joint line convergence angle, HKA hip–knee–ankle

*Pearson correlation test was performed to determine the associated preoperative factors that affect the change in the JLCA

[†]A *p* value of <0.05 indicates statistical significance

Table 4 Multiple linear regression analysis of the change in the JLCA ($R=0.72$, $R^2=0.52$, $R^2_{adj}=0.49$, $p<0.05$)

Dependent variable	Explicative variable(s)	Unstandardized coefficients		Standardised coefficients	
		<i>B</i>	SE (<i>B</i>)	β	<i>p</i> value
JLCA change	(Constant)	−1.7	0.9		ns [‡]
	Latent medial laxity	0.6	0.1	0.6	<0.05 [†]
	Correction angle	0.2	0.1	0.2	ns [‡]

JLCA joint line convergence angle

The variables that are statistically correlated with the change in the JLCA were determined using multiple regression analysis with a step-wise method. The criterion for enrollment in the model was a *p* value of <0.1. If the variable has a *p* value of >0.1, the explicative variable was excluded from the model

[†]Statistically significant: $p < 0.05$

[‡]Statistically borderline significant: $0.05 < p < 0.1$

the change in the JLCA [correlation coefficient (R)=0.7, $p < 0.05$].

Factors affecting the postoperative JLCA change

The statistically correlated factors for the postoperative change in the JLCA in the Pearson correlation test are shown in Table 3. In multiple linear regression analysis, the latent medial laxity had a statistically significant correlation and the correction angle had a statistically borderline significant correlation with the change in the JLCA (Table 4). The other factors (JLCA on the varus stress radiograph, preoperative HKA angle) were not statistically correlated with the change in the JLCA and were thus confirmed as confounding factors.

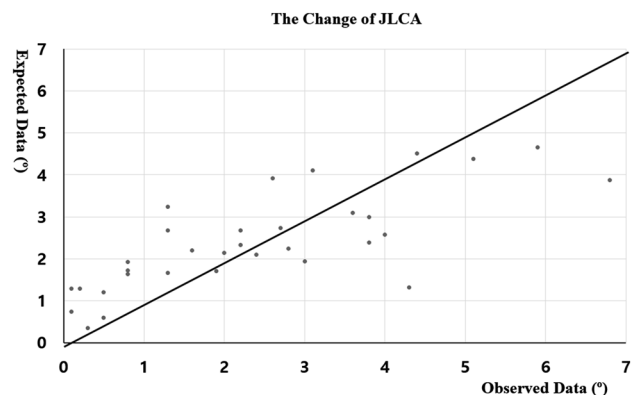


Fig. 4 The observed data were highly correlated with the expected data for the change in the joint line convergence angle (JLCA) ($R=0.72$, $R^2=0.52$, $R^2_{adj}=0.49$, $p < 0.05$)

Prediction model for the JLCA change

The predicting equation was established with statistically correlated factors in multiple regression test as follows:

$$\text{JLCA change} = -1.7 + (0.6 \times \text{latent medial laxity}) + (0.2 \times \text{correction angle}).$$

The observed data were highly correlated with the expected data for the change in the JLCA in the standardised residuals (Fig. 4). The predictive models showed that the latent medial laxity and the correction angle account for 49% of the change in the JLCA. These results indicate that the change in the JLCA was positively correlated with the latent medial laxity and the correction angle. For example, if the latent medial laxity was increased by 1°, the JLCA change was increased by 0.6°, and when the correction angle was increased by 1°, the JLCA change was increased by 0.2°.

Discussion

The first principal finding of this study was that correction errors were highly correlated with the JLCA change. This result suggests that the change in the JLCA could be the reason for the correction errors in HTO. Several studies [11, 16, 19, 24] have already reported similar results demonstrating that the correction error was related to the change in the JLCA. Ogawa et al. [24] reported that the change in the JLCA led to correction errors in HTO. Lee et al. [19] reported statistically significant differences in the JLCA change in the overcorrection, acceptable correction, and undercorrection groups. Heijens et al. [11] reported that bony correction in HTO followed the additional change in the JLCA in a range of 0°–5°, which is consistent with our results. A possible explanation for this phenomenon is that the shift of the weight-bearing axis with bony correction in HTO changes the tension in the soft tissue (Fig. 1). Furthermore, the release of the superficial MCL during medial open-wedge HTO could affect the tension in the medial soft tissue. Thus, unintended additional change in the JLCA can occur in medial open-wedge HTO.

The second principal finding is that the change in the JLCA was statistically correlated with the latent medial laxity in multiple linear regression analysis (Table 4). Previously, Ogawa et al. [24] reported that varus laxity was correlated with the change in the JLCA, and that the JLCA change increased by 0.59° for every 1° increase in the preoperative varus laxity; the change in the adduction moment was suggested as the reason in their study. Our results also showed that varus laxity was correlated with the change in the JLCA in the Pearson correlation test. However, varus laxity was found to be a confounding factor in multiple linear regression analysis. A possible explanation is that the latent medial laxity reflects not only the adduction moment but also the medial soft tissue laxity, as the latent medial laxity refers to the amount of the soft tissue that can be extended to valgus from the weight-bearing position. Ogawa et al. [24] also reported that the JLCA can be changed by shifting the weight-bearing axis from medial to lateral, and by stretching the medial soft tissue. Although the correction error can be larger in patients with medial soft laxity, varus laxity could not reflect the medial soft tissue laxity. Latent medial laxity that reflected medial soft tissue laxity and adduction moment turned out to be crucial factor for correction error in our results.

The third principal finding is that the change in the JLCA was statistically correlated with the correction angle in multiple linear regression analysis (Table 4). Lee et al. [19] reported that the change in the mechanical axis was statistically correlated with the change in the JLCA. In our

study, the change in the JLCA was affected by the degree of correction, which was consistent with the previous study. The correlation between the correction angle and the change in the JLCA suggests that a larger correction angle is accompanied by a larger change in the JLCA. This is possibly because a larger correction angle is accompanied by a larger change in the weight-bearing axis, which increases the tension in the medial soft tissue. Although age and the preoperative HKA angle were correlated with the change in the JLCA in Pearson correlation analysis, no statistical correlation was found in multiple regression analysis. Considering the need for a larger correction angle in older patients because of their more severe varus deformity, the correlation between these indices and the change in the JLCA can be understood. Heijens et al. [11] also reported a similar result, in which the postoperative change in the JLCA tended to be larger depending on the severity of osteoarthritis.

Therefore, a large latent medial laxity and severe varus deformity requiring a large correction angle might be risk factors for overcorrection. In patients with high-risk factors, target point shifting within the coronal hypomochlion point (weight-bearing line passing through 57.5% of the total width of the proximal tibia; corresponding mechanical tibiofemoral angle [mTFA], 2°) [9] could be considered to prevent overcorrection. Recent biomechanical studies [21, 31] showed that overcorrection beyond 3° mechanical valgus has no advantage for unloading the medial peak pressure. Other studies [1, 26] also showed that even a neutral mechanical alignment (corresponding mTFA, 0°) could decrease the mean contact pressure of the medial compartment. Furthermore, a value greater than the valgus of 2° in the mTFA (coronal hypomochlion point) is also accompanied by additional change in the JLCA and alignment [11]. As our results showed, the postoperative change in the JLCA could be larger depending on the latent medial soft laxity and the correction angle, resulting in unexpected overcorrection. Considering that overcorrected HTO causes the sequential total knee arthroplasty to be technically demanding [3, 6, 15, 25] and the change in the JLCA could be unpredictable beyond the coronal hypomochlion point, target point shifting might be the solution to prevent overcorrection.

Our study had several limitations. The first limitation is the small sample size. Nevertheless, the calculations based on the sample size of 34 patients indicated adequate power in the post hoc test. Additional prospective studies with larger patient numbers are thus required to confirm the models. Second, surgical procedures [24] such as medial soft tissue release, different techniques for stress radiograph acquisition, and racial differences in soft tissue laxity may have affected the results. These discrepancies result in differences in the JLCA change. Lastly, navigation data were used

as the reference; however, navigation could lead to mistakes if some of the references are not adequate.

Despite these limitations, this is the first study to analyse the preoperative factors associated with correction errors in HTO. Correction error and postoperative change of JLCA were correlated with latent medial laxity and correction angle in our results. In preoperative surgical planning, latent medial laxity should be considered to prevent overcorrection in HTO. Furthermore, in the above condition of the coronal hypomochlion point (weight-bearing line passing through 57.5% of the total width of the proximal tibia; corresponding mTFA, 2°), the change in the JLCA could be larger in patients with large latent medial laxity or needing a large correction. Therefore, in these cases, especially in patients with large latent medial laxity, target point shifting within the coronal hypomochlion point could be an optional strategy to prevent overcorrection after HTO.

Conclusion

The change in the JLCA could be larger in patients with a large latent medial laxity or severe varus deformity requiring a large correction, which could lead to unexpected overcorrection in HTO. Postoperative change in the JLCA should be considered in preoperative surgical planning, and target point shifting within the hypomochlion point could be an optional strategy to prevent overcorrection especially in patients with a large latent medial laxity.

Acknowledgements We appreciate Dae-Hee Lee for his effort in providing medical advice in this study.

Funding This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF-2017R1A2B3007362).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest in the authorship and publication of this contribution.

Ethical approval Ethical approval for the present study was obtained from the institutional review board of Samsung Medical Center (Study no. 2016-07-114-001)

Informed consent For this retrospective study, formal consent is not required.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Affiliations

Do kyung Lee¹ · Joon Ho Wang^{2,3} · Yougun Won¹ · Young Ki Min¹ · Sagar Jaiswal⁴ · Byung Hoon Lee⁵ · Jong-Yeup Kim⁶

Do kyung Lee
dr-lee331@hanmail.net

Yougun Won
yougunwon@gmail.com

Young Ki Min
Genius0078@nate.com

Sagar Jaiswal
jaiswalsagar007@gmail.com

Byung Hoon Lee
oselite@naver.com

Jong-Yeup Kim
k@kyuh.ac.kr

¹ Department of Orthopaedic Surgery, Konyang University Hospital, Konyang University School of Medicine, Daejeon, South Korea

² Department of Orthopaedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, South Korea

³ Department of Health Sciences and Technology and Department of Medical Device Management and Research, SAIHST, Sungkyunkwan University, Seoul, South Korea

⁴ Department of Orthopaedic Surgery, Konkuk University Hospital, Konkuk University School of Medicine, Seoul, South Korea

⁵ Department of Orthopaedic Surgery, Gachon University, Gil Medical Center, Incheon, South Korea

⁶ Department of Biomedical Informatics, College of Medicine, Konyang University School of Medicine, Daejeon, South Korea