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The effects of different hinge positions on posterior tibial slope in medial open-wedge high tibial osteotomy

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Abstract

Purpose The purpose of this study was to determine the standard hinge position to minimize effects from medial open-wedge high tibial osteotomy (HTO) on the posterior tibial slope.

Methods Sixteen cadaveric knees underwent medial open-wedge osteotomy using either the standard or the low hinge position. To define the standard hinge position, a line 3 cm inferior to the medial tibial plateau towards the fibular head and located its intersection with a longitudinal line 1 cm medial to the fibular shaft was drawn. Low hinge position was defined as the point 1 cm inferior to the standard position. After tibial osteotomy, computed tomography scans of each knee were taken and three-dimensional models were constructed to characterize hinge position orientation and measure the osteotomy site effects on posterior tibial slope, medial proximal tibial angle, and gap ratio (the ratio of the anterior to posterior gap in the opened wedge).

Results In two low hinge position specimens, the tibial lateral cortex hinge fracture occurred. Osteotomy through the low hinge position resulted in significantly greater posterior tibial slope compared to the standard hinge position (mean ± standard deviation) (11.2 ± 3.0° and 5.6 ± 2.5°, respectively; $p < 0.001$). Medial proximal tibial angle was also significantly greater for low compared to standard hinge position (95.4 ± 3.5° and 88.0 ± 3.5°, respectively; $p < 0.001$). Gap ratio was not significantly different between the two groups.

Conclusion Hinge position significantly affects the posterior tibial slope and medial proximal tibial angle following medial open-wedge HTO. Accurate hinge position is crucial to prevent complications from changes in posterior tibial slope and medial proximal tibial angle after surgery.

Keywords Hinge position · Medial open-wedge HTO · Osteotomy · Osteoarthritis

Introduction

In patients older than 60 years with symptomatic medial compartment knee osteoarthritis, the general treatment for refractory symptomatic osteoarthritis is total knee arthroplasty (TKA), but there is still controversy over the optimal treatment approach for younger patients. Alternative treatments for TKA in younger patients include high tibial osteotomy (HTO) or unicompartmental knee arthroplasty (UKA). There are two techniques for HTO: open-wedge HTO and closed-wedge HTO. In particular, open-wedge HTO offers the advantages of easier surgical techniques and less risk of neurovascular injury [1–7]. Medial open-wedge HTO has become an established operative procedure for the correction of varus deformity in relatively active, young patients with medial compartment osteoarthritis. It is also used to correct coronal alignment of the proximal tibia. However, this correction may also unintentionally alter the posterior tibial slope (PTS). Many studies report that the PTS increases after medial open-wedge HTO [6, 10–15, 17], and others report that knee kinematics and stability in the sagittal

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plane may have influenced these unintended increases in PTS after medial open-wedge HTO [19–22, 24, 26].

Many studies have proposed methods for preventing unintentional increases in PTS after medial open-wedge HTO. Noyes et al. [20–22] report that the anterior osteotomy gap at the tibial tubercle should be approximately one half of the posteromedial gap in order to maintain normal sagittal tibial slope. Lee et al. [15] report that normal tibial slope can be maintained if the anterior opening gap is 67% of the posterior opening gap. Marti et al. [18] suggest that an undesirable increase in PTS can be avoided by a complete posterior cut.

A previous study focusing on the effect of cortical hinge position on PTS found that posterolateral positioning of the cortical hinge increased PTS [26], called the "hinge effect". In addition, previous studies identified a safe zone in open-wedge HTO in which hinge position location could significantly reduce tibial lateral cortex hinge fracture. However, there have been few studies on changes in PTS and medial proximal tibial angle (MPTA) in relation to the hinge position within the safe zone. Therefore, how different hinge positions affect PTS, changes in PTS and MPTA in medial open-wedge osteotomy in accordance with hinge position was analysed through a cadaveric study.

The purpose of this study was to evaluate how a lower hinge position would affect PTS in medial open-wedge HTO. It is hypothesized that a low osteotomy position would result in a greater increase in PTS compared to the standard position, and that lateral tibial cortex hinge

fracture would be expected to impact knee joint stability following medial open-wedge HTO.

Materials and methods

The Gyeongsang National University Hospital Institutional Review Board of the institution approved the study (IRB approval number: GNUH IRB 2016-08-002). Sixteen cadaveric knees (8 matched pairs) without a history of surgery, gross limb deformity, anterior cruciate ligament (ACL) injury, posterior cruciate ligament (PCL) injury, or notch stenosis were used. Matched pairs were used to minimize anatomical difference between specimens. The subjects included six males and two females. The demographic characteristics available for each specimen included subject age, sex, side, weight, height, body mass index (BMI), and tibial length. The median donor age was 61.5 years (43–80 years), median weight and height were 73.6 kg (46.3–83.5 kg) and 167.7 cm (150.0–180.0 cm), respectively, and median BMI was 26.2 kg/m^2 (19.5–32.3 kg/m^2). Detailed demographic characteristics are indicated in Table 1. Furthermore, the measured mean and standard deviation of PTS and MPTA are indicated in Table 2.

During the experimental HTO procedure, the proximal femur was clamped in a vice-grip construct. In order to confirm accurate hinge position and osteotomy entry site when performing HTO, we used cadaveric knee models with dissected soft tissue. The standard hinge position was determined according to the most commonly described

Table 1 Demographic characteristics

	Age (year)	Sex (n)	Length of tibia (mm)	Weight (kg)	Height (cm)	BMI (kg/m^2)
1	71	Male	43.3	79.6	174.2	26.2
2	58	Male	47.6	83.5	180.0	25.8
3	43	Male	53.5	76.2	175.3	24.3
4	56	Male	48.7	84.5	165.5	29.9
5	80	Male	35.2	72.6	150.0	32.3
6	64	Male	52.4	83.7	173.2	27.9
7	71	Female	48.8	62.6	161.4	24.0
8	67	Female	50.5	46.3	158.4	19.5
Mean	63.8		47.5	73.6	167.3	26.2

BMI body mass index

Table 2 Measured parameters

	Standard hinge position		Low hinge position		*p* value
	Pre	Post	Pre	Post	
PTS, °	8.0 ± 2.2°	13.6 ± 2.4°	8.3 ± 2.3°	19.5 ± 3.2°	<0.001
MPTA, °	83.7 ± 1.5°	88.0 ± 3.5°	84.4 ± 1.1°	95.4 ± 3.5°	<0.001
Gap ratio, %	–	62.4 ± 7.2	–	63.5 ± 7.4	

PTS posterior tibial slope; *MPTA* medial proximal tibial angle

method reported by several previous studies [19, 25, 26]: a line was placed towards the fibular head 3 cm inferior to the medial tibial plateau and made to cross with a longitudinal line 1 cm medial to the fibular shaft. Low hinge position was defined as 1 cm inferior to the standard position (Fig. 1). Open-wedge biplanar osteotomy was performed in all patients using the Lobenhoffer surgical technique [16]. The tibial osteotomy was performed from the medial to the lateral side, with the most lateral 10% of the tibia left intact. With great care taken not to break through the lateral side, the osteotomy site was opened slowly medially, with the proximal fragment elevated evenly in both the front and the back.

First, the two hinge positions were made and then two 1.6 guide wires were inserted. One wire was inserted along the line towards the fibular head from 3 cm inferior to the medial tibial plateau. The other wire was positioned 1 cm below the intersection between the first wire and tibial medial border. Guide wire position was observed through the incision site. Next, the guide wires were located for the two hinge positions. Then, a saw was passed over the
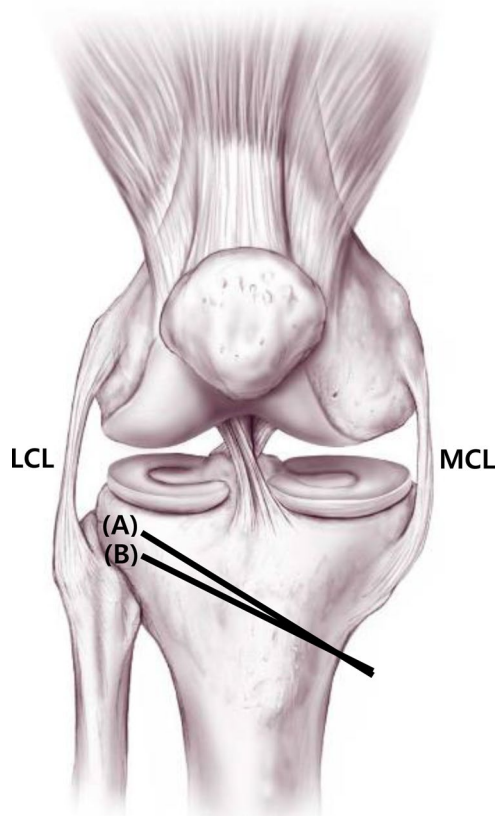

Fig. 1 Anatomical placement of osteotomy *A* standard hinge position: the line was drawn towards the fibular head 3 cm inferior to the medial tibial plateau and made to cross with a longitudinal line 1 cm medial to the fibular shaft, *B* lower hinge position: 1 cm lower than standard hinge position. LCL, lateral collateral ligament; MCL, medial collateral ligament

guide wires. Following this, all knees underwent biplane medial open-wedge tibial tuberosity osteotomy with a lateral cortical hinge, as described in a previous study focused on preventing an unintended increase in PTS [15, 19]. The superficial medial collateral ligament was located at the osteotomy site and was cut along the planned osteotomy line. All knees were corrected by 10 mm at the medial tibial side. Eight cases had osteotomies through the standard hinge position, and the other eight cases had osteotomies through the low hinge position by a senior author. Osteotomies were performed with careful attention in order to avoid iatrogenic damage to the adjacent soft tissues.

After the osteotomies, computed tomography (CT) scans of each knee were performed. From the CT images, bone morphology landmarks were measured to determine the PTS, MPTA, and gap ratio for each cadaveric knee. In addition, using axial sections from the CT scans, the lateral tibial cortex was identified as compromised. A 3D model of each knee was reconstructed using MIMICS® software (Mimics 12.3, Materialise, Leuven, Belgium) to identify the tibial hinge position orientation. Geomagic® software (Research Triangle Park, North Carolina) was used to create the virtual hinge position and perform 3D measurements. The 3D model was rotated sagittally until the best-fit plane was aligned on the 2-dimensional (2D) projected plane. This created the true anteroposterior (AP) view. After the true AP view was captured, the 3D model was rotated 90° axially. The true lateral view was then completed. The PTS was measured as the angle formed at the intersection of a line parallel to the posterior tibial inclination and a line that bisects the diaphysis of the tibia in the captured true lateral view (Fig. 2). MPTA was measured in the true AP view, and the gap ratio was calculated in the true lateral view (Figs. 3, 4). Two experienced orthopaedic surgeons independently evaluated all measurements. Parameters were measured twice, with an interval of 2 weeks between measurements by each surgeon. The inter- and intraobserver reliabilities were satisfactory with mean values of 0.97 and 0.94, respectively.

Statistical analysis

Power analysis indicated that a sample size of eight subjects per group would provide 80% statistical power to detect effect size ($d = 0.66$) between the groups ($\alpha = 0.05$, $\beta = 0.20$). SAS software (version 9.3; SAS Institute, Cary, NC) was used for statistical analyses. A p value <0.05 was considered statistically significant. First, a paired t test was used to compare the PTS and MPTA between the standard hinge position and the low hinge position. The reliability of the measurements was assessed by examining the intraclass correlation coefficient. The Mann–Whitney test was used
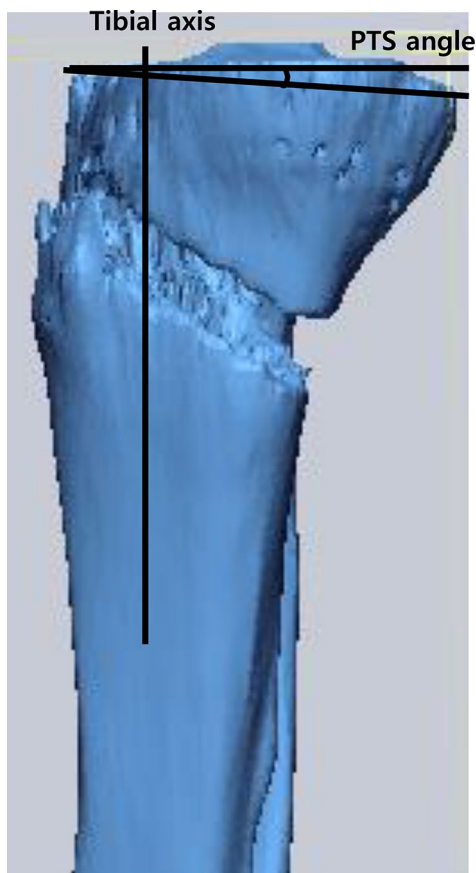
Fig. 2 Posterior tibial slope (PTS) from 3-dimensional (3D) computed tomography images

Fig. 3 Medial proximal tibial angle (MPTA) from 3-dimensional (3D) computed tomography images

for comparison of the bone morphometry of the cadaveric knees. The groups with and without lateral tibial cortex hinge fractures were analysed using a Chi-square test.

Results

In this study, demographic characteristics available for each specimen included subject age, sex, side, weight, height, BMI, and tibial length. There were no significant differences in demographic data between the two groups. Furthermore, there were no significant differences in PTS or MPTA between subjects before osteotomy. The intraobserver and interobserver reliability of the measurements was 0.953 and 0.921, respectively. The reliability of measurements was relatively high in this study.

Increase in PTS in the low hinge position group was significantly greater than in the standard hinge position (standard: $5.6 \pm 2.5°$ vs. low: $11.2 \pm 3.0°$) ($p < 0.001$). The low hinge position group's mean MPTA was significantly increased compared to the standard position (standard: $4.3 \pm 1.2°$ vs. low: $11.7 \pm 1.6°$) ($p < 0.001$). However,
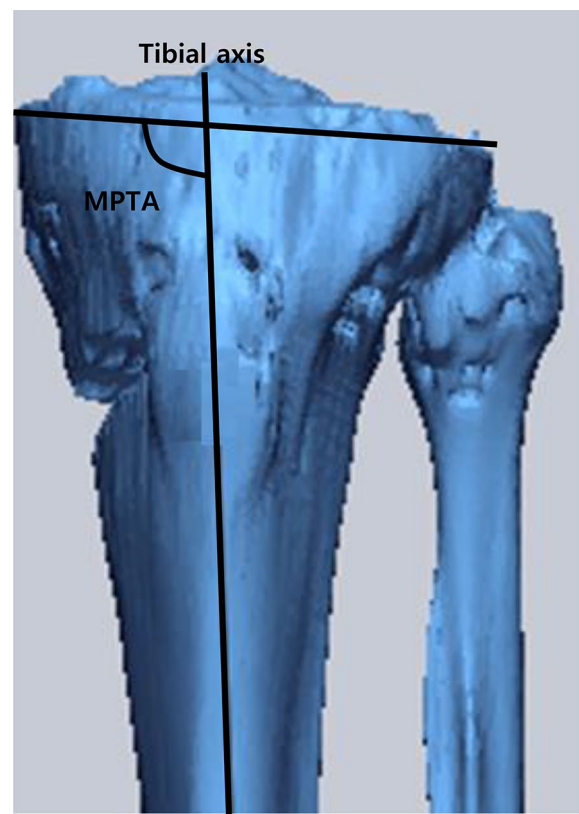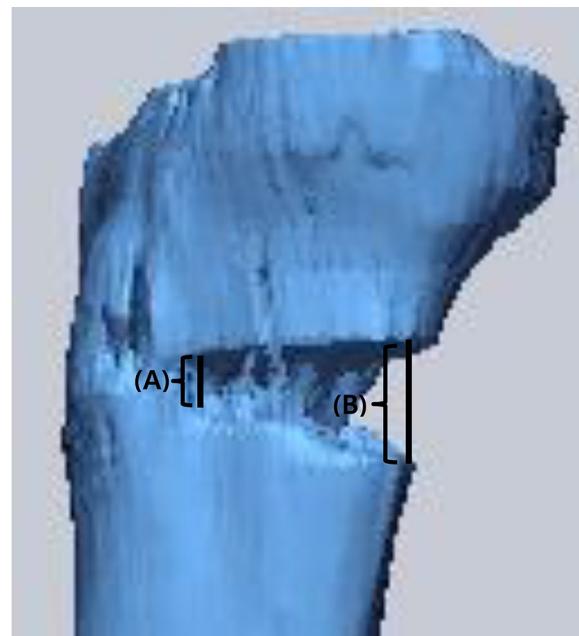

Fig. 4 Gap ratio from 3-dimensional (3D) computed tomography images. *A* Distance of the anterior opening gap, *B* distance of the posterior opening gap (gap ratio: A/B)

Table 3 The characteristics of hinge position orientation

Specimen	Increased PTS (°)	Increased MPTA (°)	Gap ratio (%)
Standard	5.6 ± 2.5	4.3 ± 1.2	64.6 ± 7.2
Low*	11.2 ± 3.0	11.7 ± 1.6	63.5 ± 7.4

PTS posterior tibial slope; *MPTA* medial proximal tibial angle; standard, standard hinge position; low, low hinge position

Low*: 2 cases in that lateral tibial cortex hinge fracture occurred

there was no significant difference between the mean gap ratios for the two groups (n.s.) (Tables 2, 3, and Fig. 6). Lateral tibial cortex hinge fracture occurred in 2 of the 16 cases, both in the low hinge position group (Fig. 5). Thus, despite the use of a safe zone, lateral tibial cortex hinge fracture may be associated with the low hinge position technique (n.s.).

Discussion

The most important finding of this study was that, compared to the standard hinge position, a low hinge position during medial open-wedge HTO resulted in a significantly greater increase in the PTS. Our hypothesis was that tibial osteotomy in a low hinge position would cause abnormal osteotomy angles, and that the low hinge position would be associated with greater PTS and increased risk of lateral tibial cortex hinge fracture. The results of this study support the hypothesis that the low hinge position during medial open-wedge HTO is significantly associated with malalignment, which may contribute to the subsequent development of mechanical failure after medial open-wedge HTO.

Based on a systematic review of medial open-wedge HTO studies, the definition of medial open-wedge HTO is not clearly established. Among various surgical technical factors of medial open-wedge HTO, the most important factor is a hinge position. In general, the standard hinge position for medial open-wedge HTO is set along a line towards the fibular head 3 cm inferior to the medial tibial plateau and crossing with a longitudinal line 1 cm medial to the fibular shaft. However, despite the importance of hinge position, previous studies have not focused on accurate hinge position; thus, the purpose of this study was to evaluate the effects of tibial hinge position by comparing different hinge positions (standard and low hinge) to determine the effects of hinge position on outcomes for medial open-wedge HTO. In addition, not only the hinge point location, but also the collateral ligament is a crucial factor when considering HTO, because both are expected to influence the orientation angles of the two hinge positions. In accordance with this theoretical evidence, many authors also stated that the remaining collateral ligament is
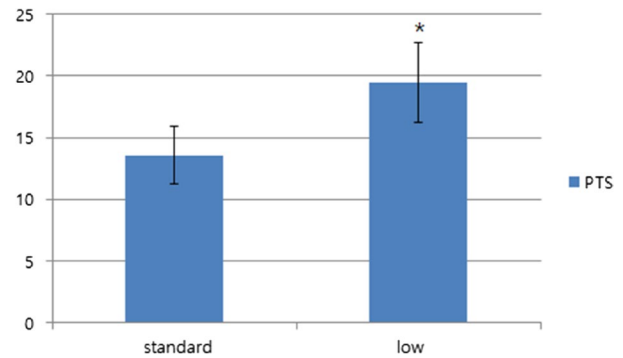
Asterisk(*) means significant value.
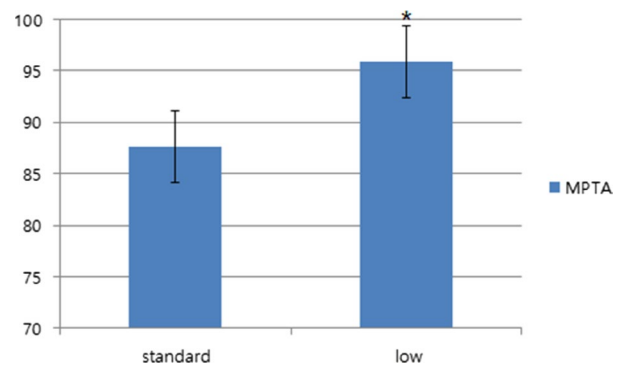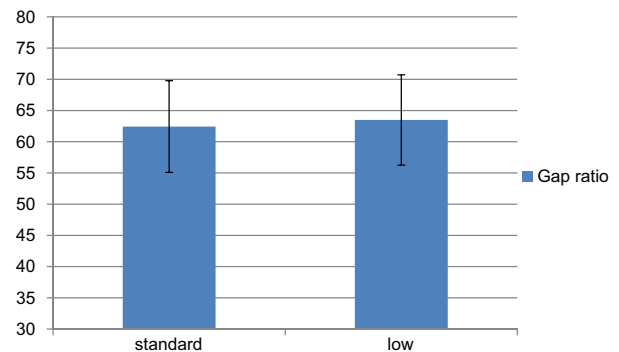

Asterisk(*) means significant value.

Fig. 5 Posterior tibial slope (PTS), medial proximal tibial angle (MPTA), and gap ratio **a** PTS, **b** MPTA, **c** gap ratio. *Asterisk* (*) means significant value

an important consideration when performing an osteotomy through the hinge position used in their study [21, 26]. For these reasons, to duplicate real clinical situations in this study, we conserved collateral ligament of cadavers, and then the standard hinge position more closely restored in posterior tibial slope of normal knee compared to the low hinge position.
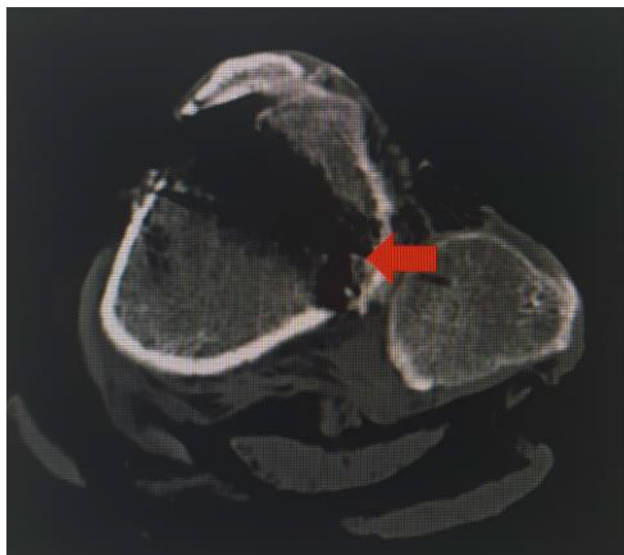
Fig. 6 Computed tomography (CT) scans of the cases with lateral tibial cortex hinge fracture (*red arrow*)

An important finding in this study was that PTS increased when osteotomy was performed through the low hinge position. Eight standard tibial osteotomy hinge positions were compared with eight low hinge positions. The mean orientation angle for the PTS in the low hinge position group was $10.4 \pm 3.0°$. This angle represents a greater increase in the PTS compared to the mean for the standard hinge position group, and it contributed to the finding of a greater MPTA. In addition, when osteotomy was performed through the low hinge position, two of eight cases had lateral tibial cortex hinge fractures. This also suggests that in the low position, the improperly oriented angle shortens the tibial osteotomy length and thereby may contribute to surgical complications such as lateral tibial cortex hinge fracture.

Previous studies have made several recommendations to avoid an increase in the PTS after medial open-wedge HTO, including making a complete posterior osteotomy and maintaining an optimal gap ratio [19–22, 25]. Most of these previous studies evaluated two-dimensional (2D) preoperative and postoperative radiographs. However, these studies had limitations in their evaluation of significant factors influencing the PTS change. Therefore, in this study, 3D imaging was applied to characterize more fully the effects of varying hinge position during medial open-wedge HTO.

Many studies report that a complete posterior osteotomy and maintenance of the optimal gap ratio are independent factors that can be applied to maintain the PTS [2, 13, 19, 26]. However, hinge position was considered a link between the complete posterior osteotomy and the optimal gap ratio. Wang et al. [26] have shown that a posterolateral

position leads to an increase in PTS, but their study was a retrospective study of patients who had undergone medial open-wedge HTO. They only considered standard positions of hinge (posterior or posterolateral), so they did not evaluate the effects of different hinge positions (standard or low) like our study. Therefore, this study was undertaken in order to determine whether different hinge position affects on PTS. In this prospectively designed cadaver study, it was found that a low hinge position is significantly associated with greater PTS compared to the standard hinge position.

In this study's results, unlike the change in PTS and the change in MPTA according to hinge position, there was no significant difference in gap ratio between two groups. The results regarding the change in PTS and MPTA are the same as those previously reported by Lustig et al. [17] and Ozalay et al. [23]. In particular, Lustig et al. [17] suggested that the average change in PTS was also significantly greater in the medial compartment compared with the lateral compartment. In addition, although our study did not investigate regarding a correlation between the change in PTS and the coronal correction (the change in MPTA), they reported the change in MPTA was not significantly associated with change in PTS. In terms of gap ratio, the previous studies found that normal tibial slope could be maintained at gap ratios of approximately 50 and 67%, respectively [9]. Although these figures are similar to our results, in contrast, our findings regarding the gap ratio are somewhat different from those previously reported by Lee et al. [15] and Noyes et al. [20–22]. Aforementioned, Lee et al. [15] suggested that the gap ratio should be kept the anterior opening gap approximately 67% of the posterior opening gap. And Noyes et al. [21] reported the anterior osteotomy gap at the tibial tubercle was generally one half of the posterior gap to maintain the normal sagittal tibial slope. In other words, whereas they suggested that gap ratio is critical to determine PTS, our results revealed there was no significant difference in gap ratio between two groups. Those differences in gap ratio might be caused by different experimental protocols and different measuring methods. For solving these problems, well-controlled large-scaled studies are encouraged.

There is a "safe zone" through which medial open-wedge HTO can be performed with minimal risk of lateral cortex hinge fracture. Nah et al. [8] define this "safe zone" as applying no more than 20 mm of distraction at the osteotomy site. They only evaluated risk of lateral cortex hinge fracture which is one of complications of medial open-wedge HTO within and outside this "safe zone", but they did not evaluate the PTS, MPTA, or the gap ratio. Compared to other studies, this study investigated various surgical parameters such as PTS, MPTA, or gap ratio, and those parameters were associated with clinical outcomes, and thus, this study can strengthen the importance of the hinge

position. The low hinge position was defined as 10 mm distal to the standard hinge position, but performed all procedures within the "safe zone". Interestingly, although all the low hinge position in this study was within the "safe zone", the change in PTS and MPTA was found to be significantly greater in the low position compared to the standard hinge position. Therefore, selection of accurate hinge position is critical for medial open-wedge HTO.

Previous studies used only 2D modelling using radiologic data or relied on dissected cadaveric knee models. The dissected cadaveric knee models did not consider the effects of soft tissues around the knee, such as the collateral ligaments, and all of these studies investigated only the most commonly used hinge position in their experiments. Because these limitations in the existing literature do not reflect real clinical situations, we accounted for soft tissue effects around the knee using an intact cadaver knee model. In this study, hinge positions were reconstructed and analysed using 3D simulations, which enabled more accurate measurements. The 3D images further revealed the occurrence of abnormal angles resulting from incorrectly oriented hinge positions. These malalignments may contribute to many of the complications reported in previous studies of medial open-wedge HTO, suggesting that surgeons should carefully consider hinge position. Surgeons must overcome these technical challenges in order to successfully perform medial open-wedge HTO.

There are several limitations in this study. First, because this is a cadaveric study, there were only a limited number of subjects. Therefore, other factors such as the corrective angle or the choice of fixation plate were not considered. However, study limitations were minimized by selecting the optimal corrective angle and surgical protocols based on previously studied outcomes for medial open-wedge HTO. Second, evaluation of varus/valgus using long-leg radiograph was impossible, because this study is a cadaver study. Taking radiographs in a standing position was not plausible in a cadaveric study, and a preoperative long-leg view was not attainable as it involved joint contracture. The most important purpose of this study was to observe changes in the PTS in medial open-wedge HTO for different hinge positions and to determine whether changes in valgus/varus deformity were crucial in HTO. Therefore, when selecting subjects, normal knees without history of operation, knee pathology, or gross deformity were included for precise observation. Third, subjects involved in this study were old-aged cadaveric knees, and factors such as bone mineral density (BMD) and bone morphometric changes may differ from those who actually are indicated for HTO, which may suggest our findings are not applicable to actual patients. However, this study observed changes following osteotomy and intraoperative complications related to BMD, such as metal failure or subsidence,

did not occur. Furthermore, match-paired cadaveric knees were used to minimize the effects of other independent factors. Therefore, it was assumed that BMD did not affect our results. Bone morphometrics did not differ between the two groups, but we could not compare morphometrics for those ages in which HTO is generally indicated. Fourth, this study is a cadaveric study, and the number of subjects was insufficient to take into consideration factors such as hinge position or fixation device. Thus, additional high-quality research needs to be conducted using well-established protocols. Finally, because this study was a cadaveric study, this study included only time-zero effects on knee alignment. It could not consider the effects on the knee at postoperative points.

Some clinical studies including a retrospective analysis of patients following medial open-wedge HTO with CT report that although scrupulous preoperative planning for ideal hinge position preceded HTO, the post-operative hinge position varies from the originally planned position. Compared to such reports, this study has an advantage because the random hinge positions were adopted so that the changes in MPTA and PTS can be precisely analysed using cadaveric knees. The clinical significance of the changes in PTS and MPTA has been widely reported, and long-term prognosis partially may depend on hinge position. Regarding clinical relevance, a surgeon must establish an accurate hinge position in order to avoid inappropriate post-operative change in PTS and MPTA when performing medial open-wedge HTO.

Conclusion

High tibial osteotomy using a low hinge position should be avoided because this position results in increased PTS, increased MPTA, and greater risk of lateral tibial cortex hinge fracture. With regard to clinical relevance, avoiding low hinge position may be considered critical when performing medial open-wedge HTO for post-operative stability of knee joint.

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