Original Research

Effect of Wedge Insertion Angle on Posterior Tibial Slope in Medial Opening Wedge High Tibial Osteotomy

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Background: Medial opening wedge high tibial osteotomy (HTO) is a well-established surgery for medial compartment knee osteoarthritis (OA) wherein the lower extremity is realigned to shift the load distribution from the medial compartment of the knee to the lateral compartment. However, this surgery is known to affect the posterior tibial slope angle (PTSA), which could lead to abnormal knee kinematics and instability, and eventually to knee OA. Although PTSA control is as important as coronal realignment, few appropriate measurements for this parameter have been reported. The placement of a wedge spacer might have an effect on PTSA.

Purpose: To elucidate the relationship between the PTSA and the direction of insertion of a wedge spacer.

Study Design: Case series; Level of evidence, 4.

Methods: This study assessed 43 knees from 34 patients who underwent medial opening wedge HTO for knee OA. Pre- and postoperative lateral radiographs of the knee as well as postoperative computed tomography scans were performed to evaluate the relationship among PTSA, wedge insertion angle (WIA), and opening gap ratio (distance of the anterior opening gap/distance of the posterior opening gap at the osteotomy site).

Results: The PTSA significantly increased from 9.0° ± 2.8° preoperatively to 13.2° ± 4.1° postoperatively ($P < .001$), resulting in a mean ΔPTSA of 4.7° ± 4.5°. The mean opening gap ratio was 0.86 ± 0.11, and the mean WIA was 25.9° ± 8.4°. The WIA and opening gap ratio were both highly correlated with ΔPTSA ($r = 0.71$ and 0.72, respectively), implying that a smaller WIA or smaller gap ratio leads to less increase in posterior slope.

Conclusion: The direction of wedge insertion is highly correlated with PTSA increase, which suggests that the PTSA can be controlled for by adjusting the direction of wedge insertion during surgery.

Clinical Relevance: Study results suggest that it is possible to adjust the PTSA by controlling the WIA during surgery. Proper attention to WIA can avoid an iatrogenic increase in posterior tibial slope.

Keywords: high tibial osteotomy; posterior tibial slope; opening gap; wedge insertion angle

Medial opening wedge high tibial osteotomy (HTO) is a well-established surgery for patients with medial compartment knee osteoarthritis (OA); its most notable advantages include the precision of intraoperative angular correction, absence of the risk of peroneal nerve palsy in fibular osteotomy, absence of leg shortening, and preservation of bone stock.[10,14,15] The principle of this surgery involves the realignment of the lower extremity to shift the load distribution from the medial compartment into the lateral compartment, thus leading to a decrease in symptoms related to medial compartment knee OA. However, medial opening wedge HTO is also known to affect the posterior tibial slope angle (PTSA), and it is reported that PTSA increases after medial opening wedge HTO.[5,13,18,19] Satisfactory outcomes after surgery require optimal realignment[1] both in the sagittal and coronal planes; in fact, poor realignment could lead to unsatisfactory clinical outcomes.[6,11]

An unintentional increase in PTSA after medial opening wedge HTO may influence knee kinematics and stability in the sagittal plane,[8,14,22] which could lead to anterior

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

The Orthopaedic Journal of Sports Medicine, 4(2), 2325967116630748
DOI: 10.1177/2325967116630748

translation of the tibial plateau, anterior shift of the tibiofemoral contact area,[1] and subsequent redistribution of pressure into the posterior tibial plateau (particularly in knees with injured anterior cruciate ligaments). These conditions could result in articular cartilage degradation and further knee disability.[11,22]

Several theories have been proposed regarding the reason for PTSA increase due to medial opening wedge HTO. One well-discussed theory is that the triangular shape of the proximal tibia is responsible for the increase in PTSA. This geometric shape requires a smaller opening gap at the anterior part of the osteotomy site than the posteromedial part, as the former is closer to the hinge point of osteotomy if the PTSA remains unchanged.[4,10,19,23] A more anterior approach and subsequent anterior plate placement may worsen this problem.[10,21,22] According to Marti et al,[14] an incomplete posterior osteotomy and insufficient release of the posterior soft tissues may also lead to PTSA increase. Another factor affecting PTSA is location of the cortical hinge. The change of posterior tibial slope was larger in the posterolateral cortical hinge than in the lateral cortical hinge.[14] On the other hand, medial opening wedge HTO has the disadvantage of a large vacant space left in the proximal tibia after surgery.[3] Therefore, wedge-shaped spacers made from hydroxyapatite, β-tricalcium phosphate, and autologous or allogenic bone have been used to fill the vacant space.[9] It could be hypothesized that the shape and the direction of wedge spacer might affect PTSA. Insertion of a wedge spacer block from a more anterior starting point could result in an increased anterior gap opening and an increase in PTSA. Thus, the direction of the gap opening and wedge spacer insertion as well as the change in the PTSA may be related. Therefore, understanding the relationship among these factors may help develop a surgical technique for controlling PTSA in medial opening wedge HTO. The purpose of this study was to elucidate the relationship between the PTSA and the direction of the osteotomy wedge spacer insertion during the surgery.

METHODS

All patients provided informed consent for the use of their medical records for this retrospective study. In addition, the study was approved by the institutional review board of our university.

This retrospective study included a consecutive series of patients who underwent medial opening wedge HTO for OA of the knee in our institution between July 2012 and July 2015. Forty-three knees from 34 patients treated with this surgical procedure were examined in this study, including 23 women and 11 men with a mean age of 63.0 ± 6.4 years (range, 48-72 years) at the time of surgery. The operative side was the right side in 21 knees. All surgeries were performed by 1 of 2 surgeons (H.O., K.M.). The inclusion criterion for medial opening wedge HTO included the presence of medial compartment knee OA with varus malalignment of the lower extremity. The exclusion criteria were severe OA of the patellofemoral joint, femorotibial angle of >190°, and a flexion contracture of >15°.

Surgical Procedures

During conventional preoperative planning, using the method by Miniaci et al,[16] the valgus correction angle and the distance between the upper and lower edges of the opened posteromedial osteotomy site were measured on the radiograph used for prediction. The aim was to obtain a mechanical axis of the lower extremity (Mikulicz line) that passes through Fujisawa point (a point at 62.5% of the tibial plateau from the medial edge).[7] Prior to medial opening wedge HTO, knee arthroscopy was performed to evaluate the extent of cartilage degradation, and microfracture was performed for degraded cartilage lesions to trigger cartilage regeneration. Thereafter, a longitudinal skin incision approximately 6 cm in length was made over the pes anserinus insertion at the anteromedial aspect of the tibia. The medial aspect of the proximal tibia was exposed by elevating the insertion of the pes anserinus, gracilis tendon, semitendinosus muscle tendon, and the superficial layer of the medial collateral ligament. The neurovascular structures underlying the knee joint were protected by retracting them with a blunt retractor. Two Kirschner wires, 2.0 mm in diameter, were inserted into the tibia as an osteotomy guide under an image intensifier, and biplane osteotomy was performed. First, an osteotomy was performed in the frontal plane, from 5 mm proximal to the insertion of the patellar tendon to the second osteotomy plane, maintaining a tibial tubercle thickness of approximately 10 mm. The osteotomy in the second plane was initiated approximately 5 cm distal from the tibial plateau, in a medial to lateral direction, and stopped at a distance of approximately 5 mm from the lateral cortical margin and approximately 20 mm below the joint line. With the help of an image intensifier, the osteotomy line was gradually opened to the axis on the lateral cortex by the stepwise insertion of a set of 5 chisels. The posteromedial gap distance was measured to confirm the predicted opening width while the gap was temporarily fixed using a bone spreader, which was inserted with the patella face upright. The posteromedial gap distance was measured to confirm the predicted opening width using a bone spreader, which was inserted into the tibia as close to the coronal plane as possible with the patella face upright. Two β-tricalcium phosphate wedges (OSferion60; Olympus Terumo Biomaterials) were trimmed to the size of the opening gap during surgery. The wedges were then inserted into the osteotomy gap horizontally, after which the elevated hamstrings were repaired. These β-tricalcium phosphate wedges have been shown to be nearly completely resorbed within 3.5 years.[20] The medial osteotomy site was then rigidly fixed using a TOMOFIX Osteotomy system (DePuy Synthes) over the osteotomy site.

Assessment and Statistics

Standing full-length anteroposterior radiographs of the lower extremity and lateral radiographs of the knee were obtained preoperatively and 1 month postoperatively after full range of motion of the knee was recovered. The following parameters were measured on these radiographs:

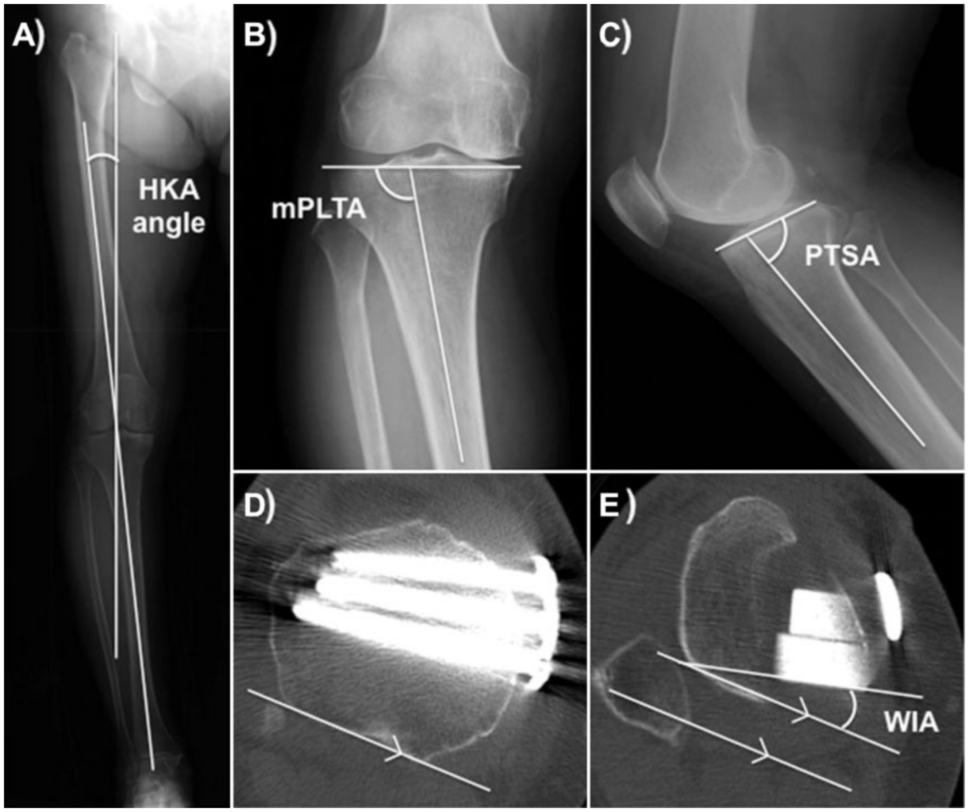

Figure 1. Radiographic assessments. (A) Hip-knee-ankle (HKA) angle: the angle between the femoral and tibial mechanical axes in the anteroposterior view; varus, negative; valgus, positive. (B) Mechanical proximal lateral tibial angle (mPLTA): the angle between the tibial margin tangent and the tibial mechanical axis in the anteroposterior view of the knee. (C) Posterior tibial slope angle (PTSA): the angle between the proximal tibial anatomic axis and the line tangent to the joint line in the lateral view of the knee. (D) Tangential line to the tibial posterior condyles at the level of the fibular head apex in the axial view. (E) Wedge insertion angle (WIA): the angle between the direction of wedge insertion and the tangential line to the tibial posterior condyles at the level of the fibular head apex in the axial view.

hip-knee-ankle (HKA) angle (defined as the angle between the femoral and tibial mechanical axes; negative = varus; positive = valgus) (Figure 1A), mechanical lateral proximal tibial angle (mPLTA) (defined as the angle between the tibial margin tangent and the tibial mechanical axis) (Figure 1B), and posterior tibial slope angle (PTSA) (defined as the angle between the proximal tibial anatomic axis and the line tangent to the joint line in the lateral view of the knee) (Figure 1C). The overall realignment was evaluated by HKA angle. The realignment as a result of bony correction was evaluated using the degree of change in the mPLTA (defined as bony correction or ΔmPLTA: preoperative mPLTA – postoperative mPLTA). Multislice computed tomography was performed 1 week after surgery to assess the β-tricalcium phosphate wedges and opening gap at the osteotomy site. The wedge insertion angle was defined as the angle between a line drawn along the posterior aspect of the more posterior wedge and a line tangential to the tibial posterior condyles at the level of the fibular head apex (Figure 1, D and E). The distance of the anterior and posterior opening gaps[23] (defined as gaps at the medial edge of the frontal plane osteotomy and the posteromedial edge of the tibia, respectively) were measured in the sagittal reconstruction view (Figure 2). The opening gap ratio was defined as the anterior opening gap divided by the posterior opening gap.

All radiographic measurements were performed by 2 independent observers, including 1 of the authors (H.O.) and an orthopaedic surgeon not involved in the surgeries, in a blinded manner. The intra- and interrater reliability were expressed as intraclass correlation coefficients (ICCs), which varied from 0 (no agreement at all) to 1 (total agreement).

Statistical comparisons of the clinical results were performed using SPSS software (version 13.0; IBM Corp). A paired *t* test was used to evaluate the differences in all of the measured preoperative and postoperative parameters. The correlation between ΔPTSA, wedge insertion angle, and opening gap ratio was evaluated by simple linear regression analysis. *P* values <.05 were considered significant.

RESULTS

The results of the radiographic measurement are summarized in Table 1. The mean HKA angle significantly

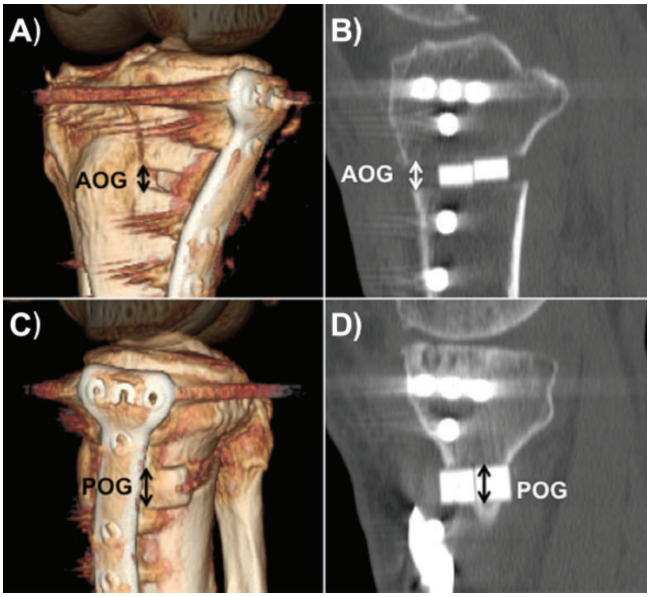

Figure 2. Length of the anterior and posterior opening gaps. (A) Anterior opening gap (AOG) on 3-dimensional computed tomography: a gap at the medial edge of the frontal plane osteotomy site. (B) AOG in the sagittal reconstruction view. (C) Posterior opening gap (POG) on 3-dimensional computed tomography: a gap at the posteromedial edge of the tibia. (D) POG in the sagittal reconstruction view.

TABLE 1
Radiographic Measurements[a]

Parameter	Mean ± SD
Preoperative HKA angle, deg	–9.4 ± 4.0
Postoperative HKA angle, deg	3.3 ± 2.5
Bony correction (ΔmPLTA), deg	9.5 ± 3.3
Opening gap ratio	0.86 ± 0.11
Wedge insertion angle, deg	25.9 ± 8.4
ΔPTSA, deg	4.7 ± 4.5

[a]HKA, hip-knee-ankle; mPLTA, mechanical lateral proximal tibial angle; PTSA, posterior tibial slope angle.

improved from –9.4° ± 4.0° preoperatively to 3.3° ± 2.5° postoperatively ($P < .01$). The mean mPLTA also significantly changed from 95.2° ± 3.2° preoperatively to 85.7° ± 3.3° postoperatively ($P < .01$), which resulted in a mean bony correction (ΔmPLTA) of 9.5° ± 3.3°. The PTSA significantly changed from 9.0° ± 2.8° preoperatively to 13.2° ± 4.1° postoperatively ($P < .01$), resulting in a mean PTSA increase of 4.7° ± 4.5°. The mean anterior and posterior opening gaps were 11.1 ± 2.7 mm and 12.9 ± 2.9 mm, respectively, resulting in a mean opening gap ratio of 0.86 ± 0.11. The average wedge insertion angle was 25.9° ± 8.4°. The wedge insertion angle and gap ratio were both highly correlated with an increase in ΔPTSA ($r = 0.71$ and 0.72, respectively; both $P < .001$) (Figures 3 and 4). The wedge insertion angle and the opening gap ratio were also moderately correlated with each other ($r = 0.62$, $P < 0.001$)

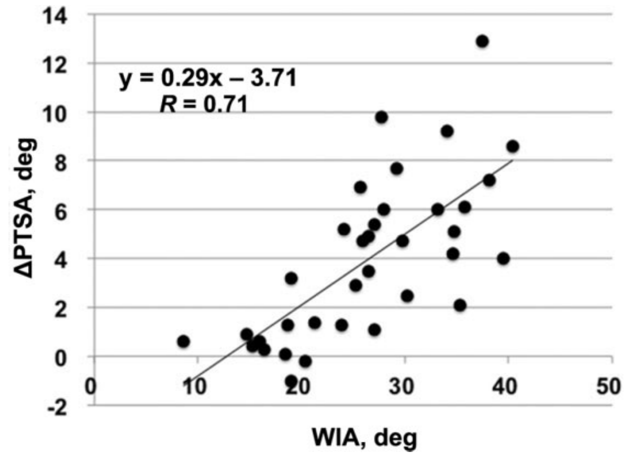

Figure 3. Relationship between the wedge insertion angle (WIA) and change in the posterior tibial slope angle (ΔPTSA). The scatter plot shows a high correlation between WIA and ΔPTSA ($r = 0.71$, $P < .001$).

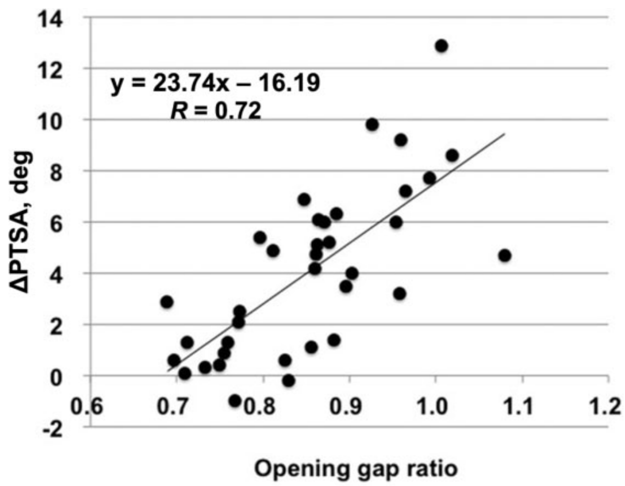

Figure 4. Relationship between the opening gap ratio and change in posterior tibial slope angle (ΔPTSA). The scatter plot shows a high correlation between the opening gap ratio and ΔPTSA ($r = 0.72$, $P < .001$).

(Figure 5). The ICCs of the radiographic parameters are shown in Table 2. The ICCs were reasonable in all measurements, and intra- and interrater agreement were similar for all assessments.

DISCUSSION

The most important finding of the present study is that the direction of wedge insertion and the gap ratio were highly correlated with PTSA. Although the importance of PTSA in knee function is well recognized,[1,5,6,10] there are currently few effective surgical techniques to adjust PTSA during surgery. This study suggests that controlling the wedge insertion angle could be an effective means of controlling

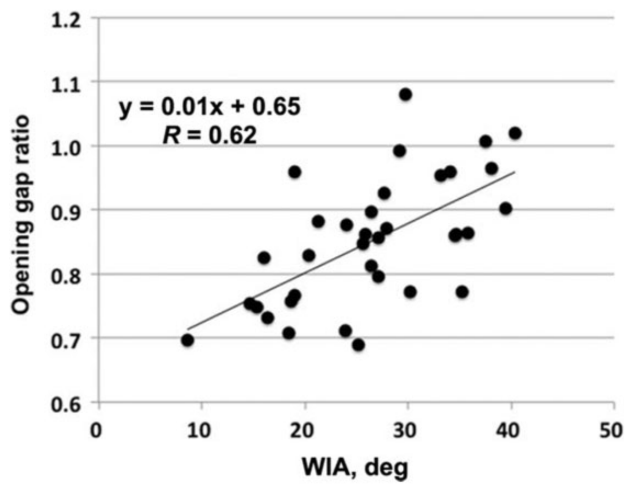

Figure 5. Relationship between the wedge insertion angle (WIA) and the opening gap ratio. The scatter plot shows a moderate correlation between the WIA and the opening gap ratio ($r = 0.62$, $P < .001$).

TABLE 2
Intraclass Correlation Coefficient
of Preoperative Radiographic Parameters[a]

	Intrarater Agreement	Interrater Agreement
mLPTA	0.99	0.78
HKA angle	0.98	0.97
PTSA	0.92	0.92
WIA	0.95	0.95
AOG	0.99	0.96
POG	0.99	0.97

[a]AOG, anterior opening gap; HKA, hip-knee-ankle; mLPTA, mechanical lateral proximal tibial angle; POG, posterior opening gap; PTSA, posterior tibial slope angle; WIA, wedge insertion angle.

PTSA. During surgical planning with the method by Miniaci et al,[16] the bony correction angle is generally decided using full leg–length radiographs in the anteroposterior view; hence, both gap opening and wedge insertion should be performed from the posteromedial gap point on the frontal plane during surgery to accurately achieve planed correction, as the medial edge of the proximal tibia on anteroposterior radiographs corresponds with the posteromedial opening gap point of the tibia during surgery. Thus, theoretically, the horizontal insertion of the wedge spacer with the knee in the anatomic position can help maintain the PTSA in any patient. Otherwise, PTSA increases if the wedge is inserted from more anterior to posterior, and PTSA decreases if the wedge is inserted from more posterior to anterior.

Previous studies have reported several factors related to PTSA in medial opening wedge HTO, including the triangular shape of the proximal tibia,[4,10,19] insufficient posterior osteotomy or release of posterior soft tissue,[14,24] anterior plate placement,[2,10,21,22,24] and posterior hinge point.[17,24] However, the most important cause of increased PTSA is the presence of an asymmetrical gap opening in the sagittal plane, which may be affected by the direction of wedge insertion. Song et al[23] reported that the normal tibial posterior slope can be maintained if the anterior opening gap is approximately 67% of the posterior opening gap in navigation-assisted HTO; this is consistent with our result wherein the opening gap ratio (anterior opening gap/posterior opening gap) was 0.86 ± 0.11, with a mean increase in PTSA of 4°. This discrepancy in the opening gap ratio may be partially due to a difference in the osteotomy technique. The other authors performed monoplane osteotomy, whereas we performed biplane osteotomy while leaving the tibial tuberosity unosteotomized; this biplane osteotomy shifts the anterior opening gap point posteromedially as compared with the anterior part of the tibia in monoplane osteotomy. Consequently, the distance between the anterior opening gap point and the hinge point may be larger, which would lead to a larger opening gap ratio even with the same wedge angle.

In the present study, PTSA increase was highly correlated with the direction of wedge insertion similar to the opening gap ratio as PTSA increased if the wedge was inserted from more anterior to posterior (see Figure 3). With regard to the clinical application of the opening gap ratio and the direction of wedge insertion for the purpose of PTSA control, we believe that the opening gap ratio may not be suitable as it varies depending on the surgical technique and bone shape, whereas control of wedge insertion direction may not be influenced by bone shape or osteotomy technique. Moreover, even if the opening gap ratio is inappropriate in opening osteotomy, wedge insertion in the frontal plane can adequately compensate and maintain the PTSA as the opening gap is forced to close via soft tissue contraction until the gap fits the wedge spacers. An advantage of the wedges is that 2 inserted wedges can maintain the stability of the opening gap ratio and not restrict placement of the fixation plate. However, it should be noted that PTSA increased even with lower wedge insertion angles, as shown in Figure 3, suggesting that additional techniques to control wedge insertion angles need to be developed. Surgeons who do not use wedges should continue to rely on the opening gap ratio to avoid large increases in PTSA.

Although some factors affecting the PTSA have been reported, there is no simple technique to control this parameter during surgery. In this context, control of the wedge insertion angle can be a simple and common technique for the adjustment of PTSA during surgery. In addition, it may be possible to increase the PTSA and reduce stress on the posterior cruciate ligament in patients with injured posterior cruciate ligaments by inserting the wedges in a more anterior to posterior direction.[25] Similarly, it may also be possible to decrease the PTSA in patients with injured anterior cruciate ligaments by inserting the wedges from a posterior to anterior direction.[12] These could lead to expansion of the surgical indications for knee OA patients with cruciate ligament insufficiency.

There are some limitations of this study. First, this is a retrospective study. A prospective study is needed to examine whether spacer wedge insertion in the frontal plane actually does not change the PTSA in medial opening wedge HTO. Second, a common technique to accurately insert the wedge spacer in the frontal plane should be developed. At present, we perform wedge insertion in the frontal plane under an image intensifier without any specific device. The appropriateness of this technique should be evaluated or a specific device should be developed to confirm the direction of wedge insertion during surgery. Last, it is unclear how PTSA change after medial opening wedge HTO influences knee function, stability, range of motion, and mechanical strain on the cruciate ligaments. Clarifying these questions can help determine how to adjust PTSA during surgery to achieve better clinical outcomes.

CONCLUSION

The direction of wedge insertion is highly correlated with PTSA increase, which suggests that the PTSA can be controlled by adjusting the direction of wedge insertion in the surgery.

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