Head to Head Analysis of Closing-wedge versus Opening-wedge High Tibial Osteotomy on Tibia Deformity Using Computer Simulation

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Abstract

We aimed to clarify the difference in proximal tibia deformity between closing-wedge (CW) and opening-wedge (OW) high tibial osteotomy (HTO) in terms of difficulties in TKR conversion.

Surgical simulation of each CW-HTO and OW-HTO were performed on the same 3-D computer aided design (CAD) knee models reconstructed from 40 computed tomography (CT) datasets with medial osteoarthritis or osteonecrosis of mean 76.3 years old (range; 55 to 87), and the degree of proximal tibia deformity was analyzed in both groups.

The angle between anatomical axis and mechanical axis showed slight difference ($p < 0.001$), and the difference was 0.3° (-0.1 to 1.3), while the mechanical axis in CW-HTO group showed some lateral shift than OW-HTO group ($p < 0.001$), and the difference was 1.8mm (-0.2 to 5.1). The TKR tibial implant in CW-HTO group was substantially closer (5.6mm) to the inside wall of cortical bone than in OW-HTO group (7.3mm) ($p < 0.001$).

The risk of interference between TKR tibial implant and cortical bone was larger after CW-HTO than OW-HTO due to more lateral shift of the mechanical axis, while the differences in angular deformity of proximal tibia were relatively small and thought to be clinically negligible.

Introduction

High tibial osteotomy (HTO) is a useful treatment option for medial osteoarthritis of the knee with a varus deformity at the proximal tibia. The merits of HTO are that it can preserve the original articular surface of the patient and allow relatively high demanding activities.[1,2] Closing-wedge HTO (CW-HTO) has been mostly performed previously, and good results had been described in the mid- and long-term,[3-6] while this procedure requires a fibular osteotomy and can cause shortening of lower limb. Recently, opening-wedge HTO (OW-HTO) is becoming more popular, and several literatures have reported comparable results with CW-HTO.[7-10] OW-HTO offers benefits of less invasiveness and possibly less deformity in proximal tibia compared with CW-HTO.[11,12]

Despite initially successful realignment procedures, some HTO could be converted to total knee replacement (TKR) because of the progression of degenerative changes and subsequent pain.[13] A previous report regarding subsequent TKR after failed HTO suggested that there was no difference in functional outcomes or survivorship of the TKR between after CW-HTO and OW-HTO.[14] However, difficulties of surgical procedure in TKR conversion might be different between after these two HTO procedures due to the difference in the deformity of proximal tibia.[15] TKR conversion after failed HTO sometimes requires complicated procedures. Prosthesis with highly constrained surface and long stem extensions may be needed because of the ligament imbalance with potential medial collateral ligament (MCL) deficiency or increase in the amount of medical bone cutting especially for an excessive valgus deformity.[16,17] In such cases, change of mechanical axis and anatomical axis can affect the difficulties in introducing the long stem into the tibial shaft. Lateral shift of the proximal tibia from the anatomical axis can also make it difficult to use the long stem.[18] Difference in the deformity of proximal tibia between after CW-HTO and OW-HTO can result in the difference of these parameters and consequently, the difficulties of subsequent TKR would be different.[19,20] Difference in the difficulties in subsequent TKR conversion could be a reason in choosing the operative procedures of HTO.

The purpose of this study was to clarify the difference of deformity of proximal tibia between after CW-HTO and OW-HTO in the viewpoint of difficulties in TKR conversion. Surgical simulation of TKR conversion after CW-HTO and OW-HTO was performed on three-dimensional (3-D) bone models and the following parameters were investigated; 1) the angle between anatomic axis and mechanical axis, 2) the distance between the anatomical axis and the center of bone cut surface of proximal tibia, and 3) the distance between lateral cortex of tibia and stem of a tibial implant. We hypothesized that the effect of deformity was greater in CW-HTO due to the resection of proximal tibia.

Materials and Methods

A total of forty knees were extracted from the computed tomography (CT) data of preoperative patients who underwent TKR for medial osteoarthritis or osteonecrosis in our hospital. To select the patients with relatively mild bone deformity that could be treated with HTO, the following inclusion criteria were adopted; femorotibial angle (FTA) < 190 degrees, range of motion ≥ 120 degrees, and flexion contracture < 10 degrees, with no inflammatory disease, trauma nor surgical history.

The 3-D bone models were reconstructed from the series of 2 mm slices two-dimensional contours using the 3-D reconstruction algorithm. The 3-D imaging software (Mimics, materialize NV, Leuven, Belgium) was applied and simulation of surgical procedure for each CW-HTO and OW-HTO were performed on the same computer aided design (CAD) knee models. The correction angle was determined so that the postoperative FTA would be 170 degrees after either CW- or OW-HTO for each knee. In CW-HTO, resection level was set at 2cm below the medial joint line, and the lateral bone wedge was removed depending on the correction angle. Then, distal bone CAD model was rotated with respect to the medial tibial cortex (**Fig.1a-b**). While in OW-HTO, the proximal tibia cut was set at 3.5cm below the medial joint line and passed obliquely towards the tip of the fibular head (**Fig.2a**). After that, distal bone CAD model was rotated valgus referring to the correction angle, which was same as that in CW-HTO. The opening gap was filled with bone CAD model made by using the simulation software (**Fig.2b**).

Secondly, a simulated TKR conversion was operated on the each tibial bone models after HTO. The anterior-posterior (AP) axis was defined as a line from the medial edge of tibial tuberosity to the center of posterior cruciate ligament footprint.[21] Resection level of the proximal tibia in TKR was set 2mm below the lateral joint line and it was aligned perpendicular to the mechanical axis. The mechanical axis was defined as a line connecting the center of cutting surface and the center of ankle joint.[22] The anatomical axis was defined as a line connecting the midpoint of diaphysis at the level of 1/3 and 2/3 of the tibia. The posterior slope of the cut surface was adjusted parallel to the lateral tibial plateau. Then, tibial implant was placed on the cutting surface so that it passed through the center of the resected tibial plateau and to be parallel to the AP axis for rotational alignment. CAD models of tibial implant from NexGen (Zimmer, Warsaw, IN, USA) were used for this simulation (**Fig.3**).

In order to assess the deformity in the proximal tibia, 1) the angle between anatomical axis and mechanical axis after the HTO simulation (**Fig.4**) and 2) the distance between the centers of resection surface (mechanical axis) and anatomical axis after the TKR conversion were measured in each CAD model (**Fig.5**). In addition, 3) the distance between the nearest points of tibial implant and inside wall of cortical bone was assessed as the index of the bone-implant interference (**Fig.6**).

As there are several TKR cases following HTO with progression of the lateral osteoarthritis due to the overcorrection in clinical practice, the over-correction models (the correction angle were set to 20 degrees) were made in either CW- or OW-HTO and 1), 2) were measured as described above. The distance between the nearest points of tibial implant and inside wall of cortical bone was not measured because of the protrusion of the CAD model of the implant in some models.

This study protocol was reviewed and approved by the institutional review board at our university, and all patients gave their informed consent before they were included. Statistical analysis was assessed by using JMP software version 9.0.2 (SAS, Cray, NC). A $p<0.05$ was considered statistically significant. Each measurement was compared by using a paired *t* - test. The numerical data is expressed as average and range.

Results

The included patients consist of 9 men and 31 women with age of 76.3 years old (55 to 87). The FTA was 181.2° (176.0 to 187.0). The results of the measurements from the computer simulation using the 3D CAD models were presented in **Table 1**. The angle between anatomical axis and mechanical axis showed slight difference ($p < 0.001$), and the difference was 0.3° (-0.1 to 1.3). The distance of the center of resection surface (mechanical axis) from the anatomical axis also showed some difference ($p < 0.001$), and the difference was 1.8mm (-0.2 to 5.1). Finally, the distance between the nearest point of tibial implant and inside wall of cortical bone was 5.6mm (1.8 to 8.8) in CW-HTO group and 7.3mm (3.0 to 10.4) in OW-HTO group. It was significantly closer in CW-HTO group than in OW-HTO group ($p < 0.001$).

Regard to the over-correction models, the differences of angle between anatomical axis and mechanical axis was 0.5° (0.1 to 1.0). The anatomical axis in CW-HTO group shifted more laterally and the distance from the anatomical axis to the center of resection surface was 2.2mm (-0.6 to 5.4) (Table 2).

Discussion

The most important finding of this study was that the change of mechanical axis and anatomical axis after HTO, which can be related to the difficulties in subsequent TKR conversion, was greater after CW-HTO than after OW-HTO. The difference in distance of the center of cut surface (mechanical axis) from the anatomical axis was about 2 mm, while the difference of the angle between mechanical axis and anatomical axis was only 0.3°, which was clinically small. These results suggest that, with regard to the interference of implant, CW-HTO was closer to the cortical bone than OW-HTO and we recommend surgeons to note the shape of tibial implant when TKR conversion after HTO, especially CW-HTO. Relating to the proximal tibial angular deformity, there is no clinical difference in difficulties for TKR between after CW-HTO and OW-HTO. Furthermore, these tendencies were similar even if the excessive correction was needed.

In TKR conversion after HTO, it is considered that the procedure of HTO may affect the difficulties of TKR.[19,20] The two most common approaches to valgus-producing osteotomy are CW-THO and OW-HTO. Several studies have reported outcomes of TKR in patients who previously underwent HTO.[23-25] Meanwhile, TKR following HTO often could be possible to use the implant for the revision and long stem. Then, the problems of TKR conversion after HTO are the change of mechanical axis and anatomical axis. Because it was difficult to compare the two surgical techniques in identical cases in-vivo, we used the computer simulation in this study.

Filho et al[15] reported that more medial releases needed to be performed following OW-HTO, while more significant lateral releases needed to be performed following CW-HTO, however there was no increase in operative time or complications in the two surgical techniques. Robertsson and W-Dahl[26] reported that patients undergoing TKR after HTO were more likely to undergo revision surgery than patients undergoing primary TKR. However, the risk of revision after TKR conversion of both CW-HTO and OW-HTO was not significantly different. We hypothesized that the effect of deformity was greater in CW-HTO due to the resection of proximal tibia. Given the finding of this study, the angular change of mechanical axis and anatomical axis was similar between CW-HTO and OW-HTO and the effect of deformities on the difficulties of TKR conversion was clinically small, but it needs attention to select the implant, because lateral shift of mechanical axis did happen and thus bone-implant distance was closer in CW-HTO.

The present study had some limitations. First, tibial bone models immediately after HTO were used when TKR conversion were simulated, and progression of osteoarthritis after HTO were not considered. Furthermore, axial rotation of distal bone CAD model was not considered. These could affect to the change of mechanical and anatomical axis in HTO. However, we compared the two surgical procedures as the same situation. Therefore, influence of rotation would be small. Second, we simulated in

HTO so that postoperative FTA would be only 170 degrees. The best correction angle in HTO is controversial. However, the overcorrection models were simulated in this study, and the difference between two procedures was clinically small. Third, this study did not evaluate ligaments and any other soft tissue. Finally, this study utilized only one implant when determining the interference between implant and cortical bone. Tibial implant for minimally invasive surgery would less interfere in lateral cortical bone. Surgeons should consider selecting the implant for TKR following HTO.

The risk of interference between TKR tibial implant and cortical bone was larger after CW-HTO than OW-HTO due to more lateral shift of the mechanical axis, while the differences in angular deformity of proximal tibia were relatively small and thought to be clinically negligible.

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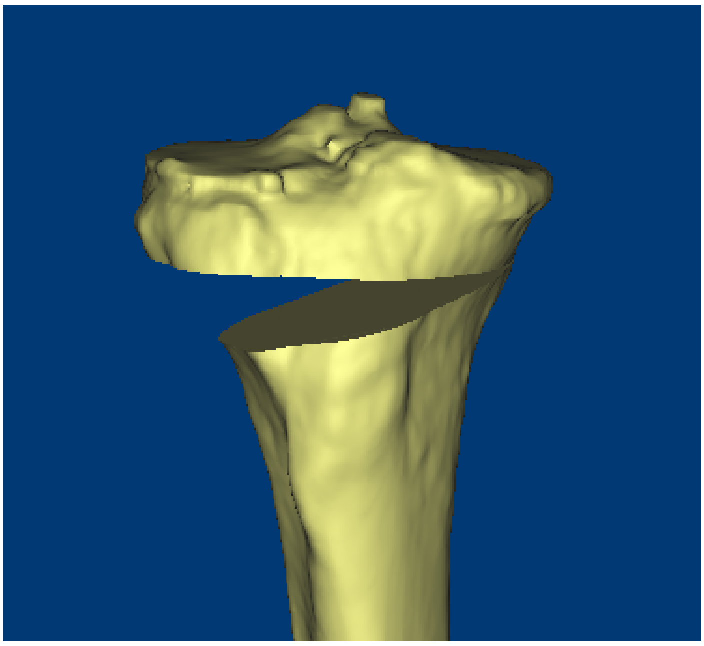
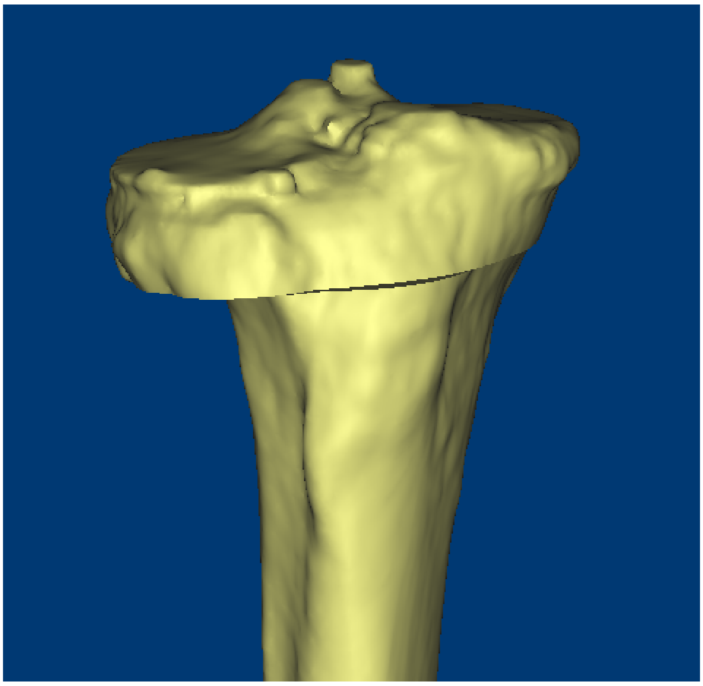
Figures and Legends



a)

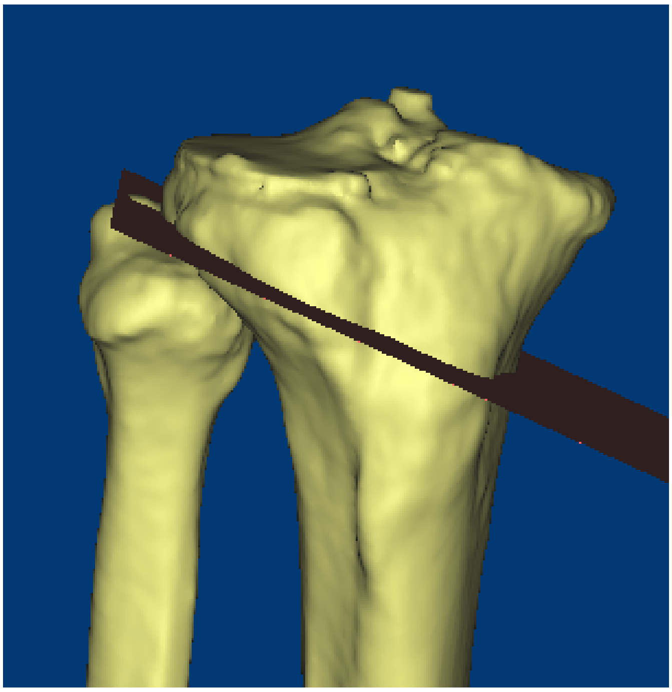


b)

Fig. 1. The simulation of CW-HTO using 3D-CAD models is shown.

a) The lateral bone wedge was removed depending on the correction angle.

b) The distal part of the CAD model was rotated with respect to the medial tibial cortex to correct the varus deformity.



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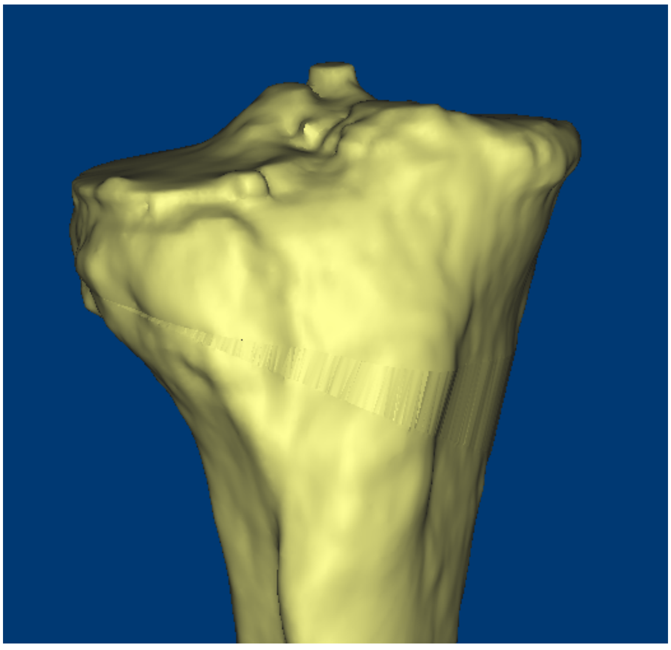
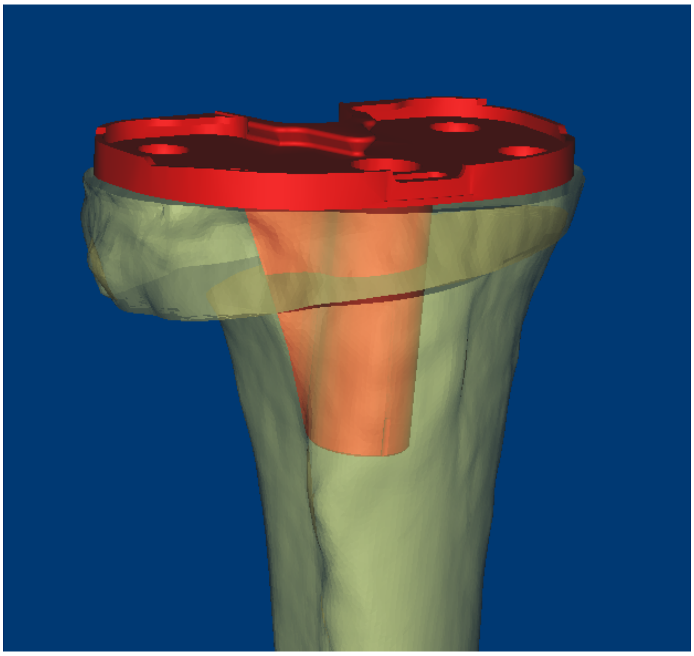


b)

Fig. 2. The simulation of OW-HTO using 3D- CAD models is shown.

a) The proximal tibia cut was set at 3.5cm below the medial joint line and passed obliquely towards the tip of the fibular head.

b) Distal bone CAD model was rotated valgus referring to the correction angle and the opening gap was filled with bone CAD model using the simulation software.



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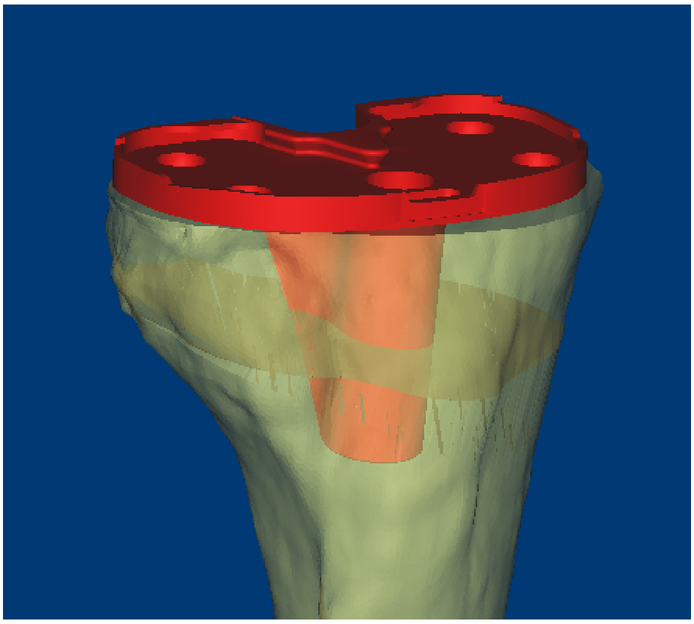

b)

Fig. 3. a) The simulation of TKR conversion on to the tibia CAD model after CW-HTO is shown.

b) The simulation of TKR conversion on to the tibia CAD model after OW-HTO is shown

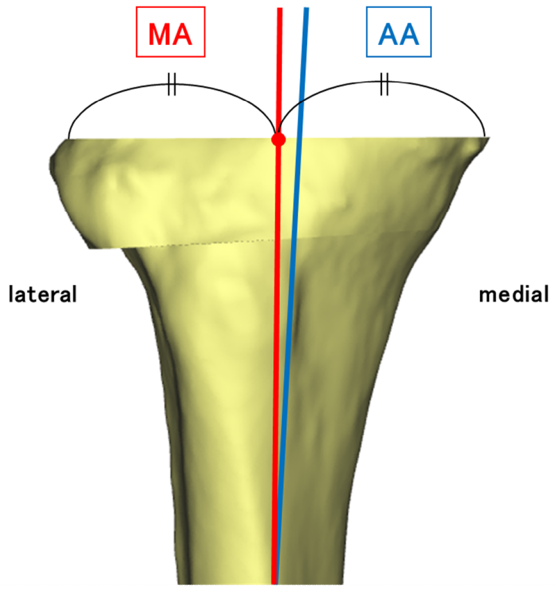

Fig. 4. The angle between anatomical axis (AA) and mechanical axis (MA) after the HTO simulation was measured. A positive angle represents varus alignment.

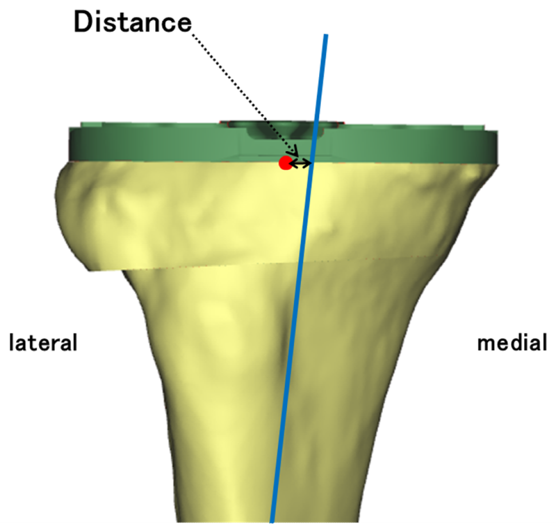

Fig. 5. The distance between the center of resection surface and anatomical axis (AA) was measured. A positive distance represents the center of resection surface is lateral from the anatomical axis.

Fig. 6. The distance between the nearest point of tibial implant and inside wall of cortical bone was measured on the 3D software. In this model, the red area means the distance is under 5mm and the green area means the distance is over 8 mm.

Table 1. Measurements values from the computer simulation of HTO and following TKR when the postoperative FTA was set at 170°.

	CW-HTO	OW-HTO	Difference
Angle (°)	+0.7* (-1.6 to 2.5)	+0.3 (-1.8 to 2.1)	0.3 (-0.1 to 1.3)
Shift of mechanical axis (mm)	+0.9* (-7.1 to 9.0)	-0.9 (-10.7 to 6.7)	1.8 (-0.2 to 5.1)
Bone-implant interference (mm)	5.6* (1.8 to 8.8)	7.3 (3.0 to 10.4)	1.7 (-0.2 to 6.1)

TKR: total knee replacement.

HTO: High tibial osteotomy. CW: Closing wedge. OW: Opening wedge.

Angle: the angle between anatomical and mechanical axis after the HTO simulation.

Shift of mechanical axis: the distance between the center of resection surface in TKR conversion and anatomical axis. The plus sign indicates the lateral shift.

Bone-implant interference: the distance between TKR tibial implant and the cortical bone.

*: $P < 0.001$ compared with OW-HTO.

Table 2. Measurements values from the computer simulation of HTO and following TKR when the correction angle were set at 20°.

	CW-HTO	OW-HTO	Difference
Angle (°)	+1.2* (-1.1 to 2.7)	+0.7 (-1.4 to 2.3)	0.5 (0.1 to 1.0)
Shift of mechanical axis (mm)	+3.4* (-5.9 to 9.8)	+1.2 (-8.9 to 7.6)	2.2 (-0.6 to 5.4)

TKR: total knee replacement.

HTO: High tibial osteotomy. CW: Closing wedge. OW: Opening wedge.

Angle: the angle between anatomical and mechanical axis after the HTO simulation.

Shift of mechanical axis: the distance between the center of resection surface in TKR conversion and anatomical axis. The plus sign indicates the lateral shift.

*: $P < 0.001$ compared with OW-HTO.