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Original Article

Three dimensional CT analysis of the change in rotational alignment in double level osteotomy after double level osteotomy performed for varus osteoarthritic knees

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ABSTRACT

Purpose: To analyze the change in rotational alignment caused by double level osteotomy (DLO) based on comparative three-dimensional image analysis of pre- and postoperative CT images.
Methods: Pre- and postoperative CT examination of the lower extremities were performed with informed consent for 39 consecutive knees undergoing DLO for varus knee deformity. The DLO procedure consisted of closed wedge distal femoral osteotomy (CWDFO) and open wedge high tibial osteotomy (OWHTO). Among those cases, 20 knees complicated with hinge fracture at the osteotomy site were excluded from the analysis to eliminate a confounding factor affecting the results. Consequently, data obtained from 19 knees were subjected to the study analysis while osteotomies with hinge fractures complications were excluded from the study. In the three-dimensional CT image analysis of axial plane images, femoral torsion (the angle between midline along the femoral neck axis and the tangent of the posterior edges of the medial/lateral femoral condyles) and tibial torsion (the angle between the tangent of the posterior edges of the medial/lateral tibial condyles and the transmalleolar axis) were measured. The torsion angle was measured in each of the femurs and the tibias on both pre- and postoperative CT axial images, and the change induced by the osteotomy was calculated and statistically(using Wilcoxon signed-rank test) compared.
Results: The mean pre- and postoperative femoral torsion (anteversion) angles were 29.3° and 31.4° with a significant postoperative increase in internal rotation of the bony segment distal to the osteotomy($P = 0.002$). On the tibial side, the mean pre- and postoperative torsion angles were 26.5° and 25.7°, indicating no significant postoperative change($P = 0.199$) (NS) .
Conclusions: This study showed that the DLO procedure (combining CWDFO and OWHTO) increased torsion (anteversion) of the femur by 2.1° on average while inducing no significant rotational change on the tibial side.

Introduction

Open wedge high tibial osteotomy (OWHTO) is an established surgical option for correction of varus knee deformity with osteoarthritis. In recent years, locking plate fixation and biplane cut osteotomy has been introduced to the procedure enabling early weight bearing after surgery due to improved stability of the osteotomy site.[1,2,3,4,5] Consequently, indication of osteotomy around the knee has been expanded and an increasing number of surgeries has been performed.

Among various osteotomy procedures, double level osteotomy (DLO) is a procedure combining distal femoral and proximal tibial osteotomies and is indicated for knees with severe varus deformity. In those knees, etiological factors of deformity are present both in the femur and the tibia. Correction of varus deformity by high tibial osteotomy alone in this situation would lead to non-physiological

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joint line obliquity, which induces unfavorable biomechanical consequences such as shear stress at the joint surface.[6,7] In addition, in severely deformed knees, etiological factors for deformity are present both in the femur and the tibia. A clinical study by Terauchi et al. has suggested that the varus inclination of the distal femur is responsible for the recurrence of varus deformity after high tibial osteotomy.[8] Therefore, corrections on both femoral and tibial sides by DLO has been become our surgical option for osteoarthritic knees with severe varus deformity.

In previous studies dealing with DLO, Babis et al. reported that the survival rate of the DLO at 100 months was 96% with physiologic joint line obliquity maintained after surgery.[9] The clinical follow-up study by Schröter et al. as well as our clinical experiences also has shown that DLO can achieve satisfactory clinical results by normalizing limb alignment and bony geometry while avoiding joint line obliquity.[10,11]

Key to success of corrective osteotomies depends on attainment of optimal knee alignment and resultant improvement of biomechanical environment in the knee. Since the alignment is three-dimensional in nature, the postoperative changes induced by osteotomy should be assessed on a three-dimensional basis; however, the analyses conducted in the majority of the previous relevant studies were limited to alignment on coronal plane.[9,10,11] In regards to high tibial osteotomy and distal femoral osteotomy, there have been some studies investigating rotational changes induced by the osteotomy,[12,13–15,16] while no study has investigated the change in rotational alignment after DLO.

The purpose of this study was to comparatively analyze the rotational alignment before and after DLO based on three-dimensional image analysis of pre- and postoperative CT images. We hypothesized that the femoral and tibial rotational alignment would change associated with the varus correction in DLO.

Materials and methods

Study design

A consecutive series of 39 knees in 30 patients who underwent DLO in our institute during the study period from September 2016 to July 2018 were initially enrolled in the study. Pre- and postoperative CT examinations of the operated limb for surgical planning and three-dimensional assessment were performed for all patients on informed consent. Among those subjects, knees complicated with hinge fractures were excluded from the analysis, because our previous study (unpublished data in our paper submitted to KSSTA) has shown that occurrence of hinge fracture is a factor inducing unpredictable change in rotational alignment in DLO. The study design was approved by the IRB of our institute (Approval number: 2477).

Surgical indication and procedure

DLO was indicated for severe varus osteoarthritic knees in active patient population who wished to retain high levels of activity after surgery. In the preoperative surgical simulation using the digital planning software (mediCAD®, Hectect, Germany), surgical planning was initiated with OWHTO alone. In the simulation, the intended mechanical tibiofemoral angle was set to 1°–2° (a slightly valgus position) corresponding to %weight bearing line of 55%.[10] If the predicted mMPTA in the surgical simulation was 95° or greater (or the wedge size was 15 mm or greater), DLO was considered as an option and surgical planning for DLO was conducted accordingly.

All surgeries were performed under general anesthesia by the second author (H.N.) following the procedure reported in our previous paper.[10] Briefly, the DLO procedure was performed using a minimally invasive biplanar osteotomy technique combined with locking compression plate fixation. The first procedure was lateral closed wedge distal femoral osteotomy (LCWDFO). The femoral osteotomies were composed of three cuts: two transverse cuts and one anterior ascending cut. The two transverse cuts were initiated from the lateral side of the femur proximal to the lateral epicondyle and intersect at the medial epicondyle on the medial side. The anterior ascending cut on the coronal plane was made from the anterior ends of the transverse cuts. The angle between the transverse and anterior ascending cuts on the lateral side of the femur was set at about 100° (Fig. 1). Fixation of the osteotomy was accomplished with the minimally invasive plate osteosynthesis (MIPO) technique. Subsequent to the LCWDFO, the surgery was completed with OWHTO. The OWHTO was performed via a technique which was previously described by Lobenhoffer and Staubli[3,4,5] using biplanar osteotomy technique with medial open wedge correction.

CT examination

CT examination was performed on all knees (from hip to ankle), both preoperatively and at one week after surgery with the consent of each patient. CT images were acquired using a 256-slice multidetector CT scanner (SOMATOM Definition Edge, Siemens Healthineers, Erlangen, Germany), and sequential images from the hip joint to the ankle joint were obtained with a 0.7-mm slice thickness, 40-cm field of view, and 512 × 512 matrix (pixel size: 0.78 mm).

Analysis of CT images of femoral/tibial torsional angles

After extracting the Digital Imaging and Communications in Medicine (DICOM) data from the picture archiving and communication system (PACS) software, the image data were imported into ZioCube® imaging software (Ziosoft Inc, Japan). The geometrical assessment was performed using this image analyzing software.

In order to measure the pre- and postoperative femoral and tibial torsion angles on the reliable and consistent basis, a longitudinal axis of the shaft was established on CT images of the femur and tibia for matching of the pre- and postoperative images. The

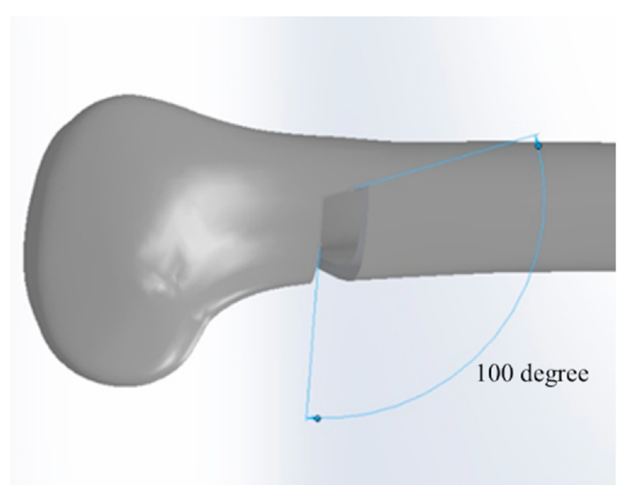

Fig. 1. Configuration of the femoral bony cuts in the lateral view
The anterior ascending cut on the coronal plane was made from the anterior ends of the transverse cuts. The angle between the transverse and anterior ascending cuts on the lateral side of the femur was set at about 100°.

femoral and tibial torsion angles were measured using the method proposed by Waidelich et al., which has been proven to provide high reliability in previous studies.[17,18]

The femoral torsion angle (femoral anteversion angle) was determined by measuring the angle formed between a midline through the femoral neck and a tangent line to the posterior contour of the femoral condyles (Fig. 2A). The axial center was identified on the axial images at two levels of the proximal femoral shaft (Fig. 2B), and the longitudinal axis of the femur was determined by connecting the axial center points at the two levels on coronal and sagittal planes (Fig. 2C). In order to match the three-dimensional orientation of the pre- and postoperative images, each of the images at both time periods were rotated around the center of the femoral head on coronal and sagittal planes until matching of the longitudinal axis was achieved (Fig. 2D).

The tibial torsion angle was determined by measuring the angle formed between a tangent line to the posterior contour of the tibial plateau and the intermalleolar axis at the ankle. The intermalleolar axis was defined as a line through the most prominent points of the medial and lateral malleolar surfaces (Fig. 3A). The axial center was identified at two levels of the distal tibial shaft (Fig. 3B), and the longitudinal axis of the tibia was determined as performed for the femur (Fig. 3C). In order to match the three-dimensional orientation of the pre- and postoperative images, each of the images at both time periods were rotated around the midpoint of the line connecting the medial/lateral malleoli (intermalleolar point) on coronal and sagittal planes until matching of the longitudinal axis was achieved (Fig. 3D).

Surgical information including the closed wedge size in CWDFO and the open wedge size in OWHTO was obtained from the surgical record.

Reliability and statistical analysis

Reliability of the CT measurement was assessed via intraclass correlation coefficients (ICC). The images of 10 randomly selected subjects were used in the analysis. Repeated measurements by a rater with one-week time interval as well as independent measurements by 2 raters were conducted on the same images to determine the intra- and interobserver reliabilities. As shown in Table 2, high ICC values of more than 0.9 were demonstrated for both intra- and interobserver analyses. Based on the high reliability confirmed by the reliability analysis, measurement results derived from a single investigator's assessment (by S.K.) were adopted and analyzed in the study.

In the statistical analysis, the results obtained from pre- and postoperative CT measurements were compared using Wilcoxon signed-rank test. The correlation between the wedge size and postoperative torsional change was analyzed using Pearson product-moment correlation coefficient. The statistical analysis was performed using IBM SPSS Statistics version 19 software (IBM, Armonk, New York, USA). Significance level was set at less than 5%.

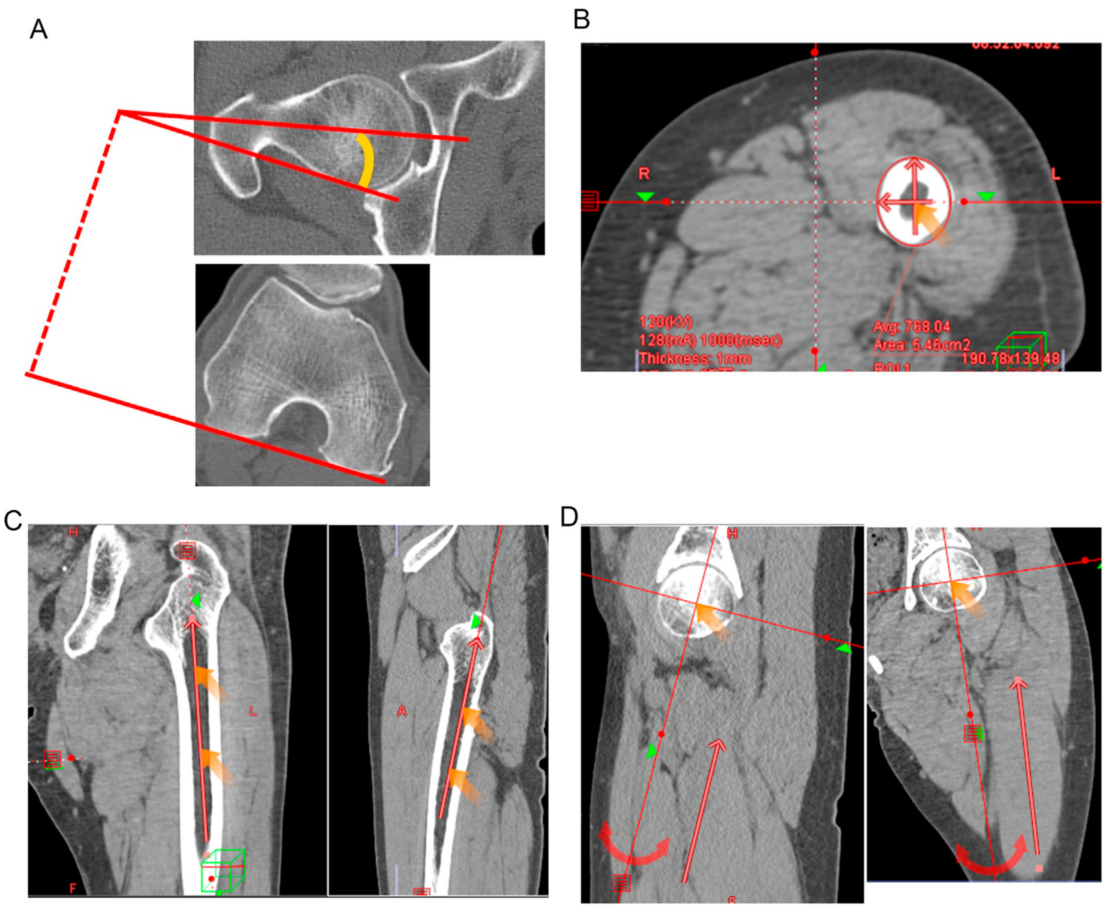

Fig. 2. AThe femoral torsion angle (angle formed between a midline through the femoral neck and a tangent line to the posterior contour of the femoral condyles).
Fig. 2B The axial center was identified on the axial images at two levels of the proximal femoral shaft
Fig. 2C The longitudinal axis of the femur was established by connecting the axial center points at the two levels on coronal and sagittal planes.
Fig. 2D In order to match the three-dimensional orientation of the pre- and postoperative images, each of the images at both time periods were rotated around the center of the femoral head on coronal and sagittal planes until matching of the longitudinal axis was achieved.

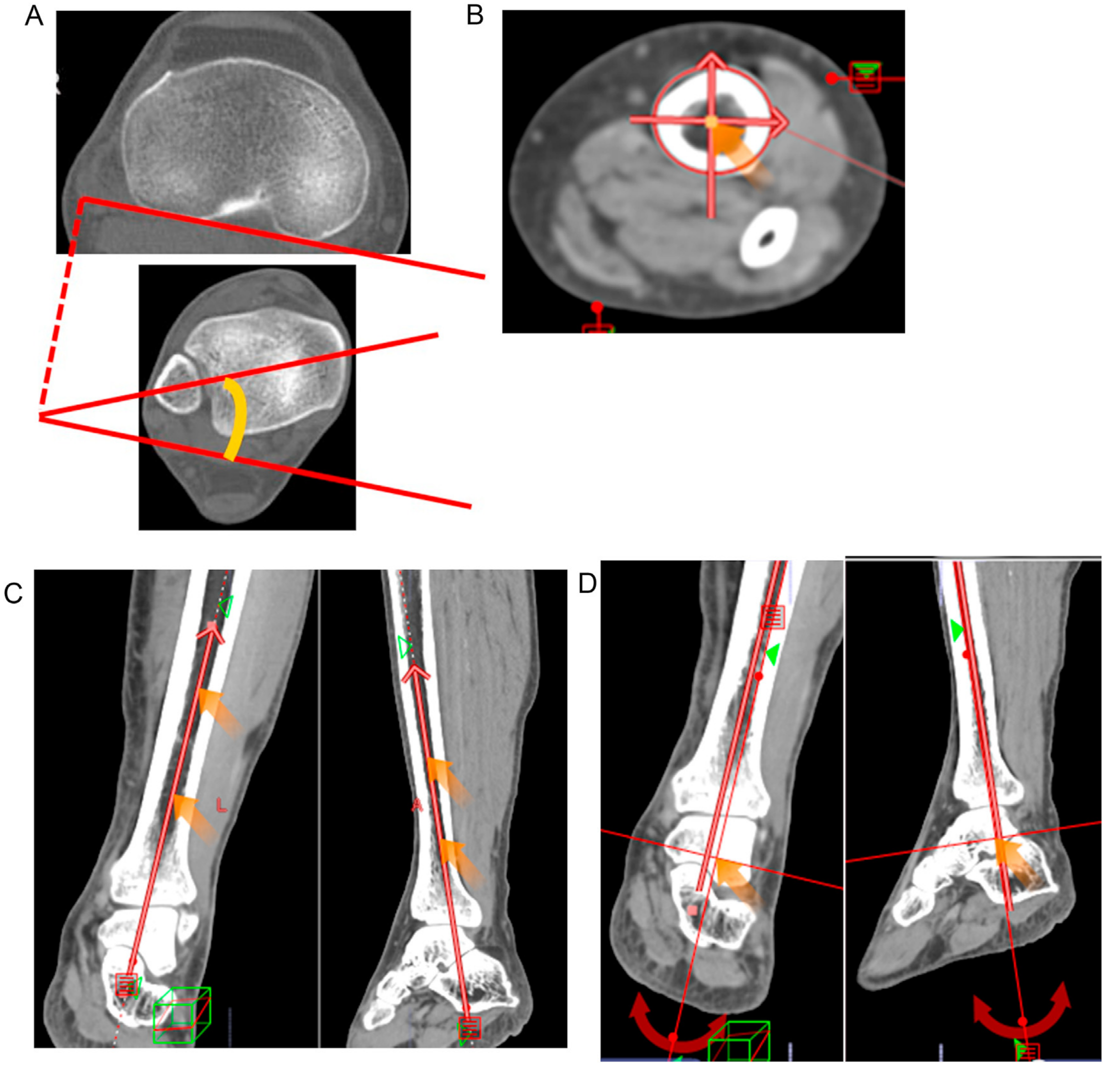

Fig. 3. AThe tibial torsion angle (angle formed between a tangent line to the posterior contour of the tibial plateau and the intermalleolar axis).
Fig. 3B The axial center was identified on the axial images at two levels of the distal tibial shaft
Fig. 3C The longitudinal axis of the tibia was determined by connecting the axial center points at the two levels on coronal and sagittal planes.
Fig. 3D In order to match the three-dimensional orientation of the pre- and postoperative images, each of the images at both time periods were rotated around the midpoint of the line connecting the distal edges of the medial/lateral malleoli (intermallelar point) on coronal and sagittal planes until matching of the longitudinal axis was achieved.

In order to assess the adequacy of the sample size, a post-hoc power calculation was performed for the analyses of postoperative torsional change. In the calculation, the standard deviation values of 2.79° and 2.99° were adopted for the torsional change in the femur and the tibia respectively based on the results of this study, and difference of 2° was determined as a difference to be detected. Consequently, the power calculation showed that the number of the subjects in this study (19 knees) could provide adequate statistical power (>90%) with an α of 0.05.

Results

Among the 39 knees enrolled in the study, hinge fractures either on the femoral or tibial side were identified in 20 knees (14 femoral hinge fractures and 10 tibial hinge fractures), and those knees were excluded from the study analysis considering a confounding effect of hinge fracture on rotational alignment. Consequently, 19 knees constituted the study population and were subjected to the study analysis. The patient group consisted of 12 females (63%) and 7 males (37%) with the mean age at surgery of 60.3 ± 6.9 years (range 45–75 years).

The mean pre- and postoperative femoral torsion angles were 29.3° ± 10.8° and 31.4° ± 11.1° with a significant postoperative increase of 2.1° (P = 0.002) in femoral anteversion (internal rotation of the distal bony segment). The postoperative change in the femoral torsion angle ranged from 3.6° external rotation to 4.5° internal rotation. When the change in each subject was analyzed, almost all cases exhibited consistent pattern of internal rotation (Fig. 4). On the tibial side, the mean pre- and postoperative torsion angles were 26.5° ± 9.1° and 25.7° ± 9.0° with a small and no significant postoperative change in tibial torsion (P = 0.119) (Table 1). When the change in each subject was analyzed on the tibial side, mixed pattern including both internal and external rotations was observed across the cases (Fig. 5).

The mean wedge size of the femur was 4.7 mm in CWDFO, and the mean wedge size of the tibia in OWHTO was 8.4 mm. In the analysis of correlation between the wedge size and torsional change, mild correlation was present between the wedge size and the femoral torsion change (r = 0.396 and P = 0.093), and no correlation was present between the wedge size and the tibial torsion change (r = −0.076 and P = 0.757).

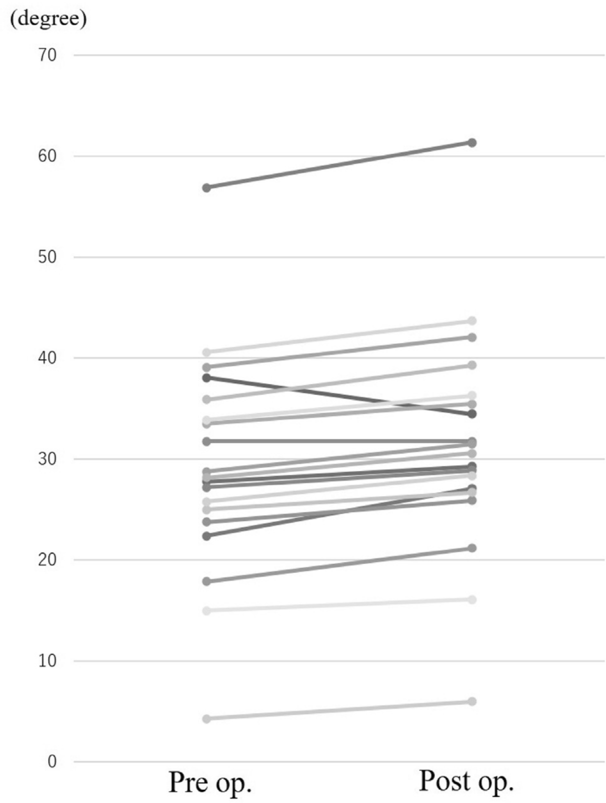

Fig. 4. Comparison of pre- and postoperative femoral torsion angles.

Table 2
Results of intraclass correlation coefficient(ICC) value of each measurment.

Time points	Intra-observer(95%CI)	Inter-observer(95%CI)
Femoral torsion°		
Preoperative	0.994(0.977–0.998)	0.992(0.962–0.998)
Postoperative	0.988(0.954–0.997)	0.995(0.979–0.999)
Tibial torison°		
Preoperative	0.982(0.935–0.996)	0.977(0.799–0.995)
Postoperative	0.974(0.905–0.993)	0.960(0.734–0.991)

Note. A measurment was considered reliable if the ICC was higher than 0.80.

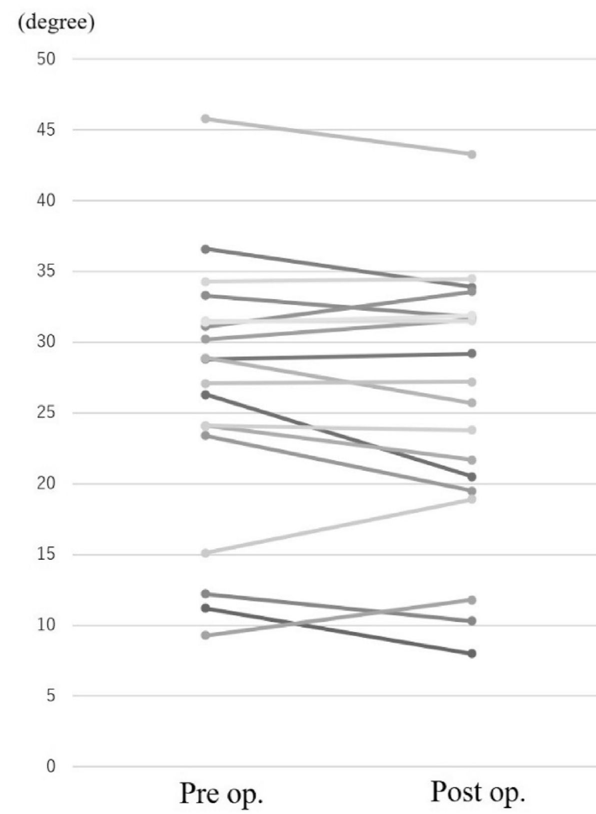

Fig. 5. Comparison of pre- and postoperative tibial torsion angles.

Discussion

The present study was undertaken to assess the torsional changes induced by DLO procedure combining CWDFO and OWHTO in our patient population. Consequently, it was shown that the DLO procedure in our patient population increased torsion (anteversion) of the femur by 2.1° while no significant torsional change was induced on the tibial side.

As regards three-dimensional alignment change in a femoral osteotomy, a cadaveric study by Imhoff et al. showed coupled rotational and coronal plane (varus/valgus) alignment changes occurring in corrective femoral osteotomy[14] Several clinical studies have examined the postoperative change in rotational alignment after OWHTO; however, the reported results are somewhat discordant. An increased internal rotation of the distal bony fragment (decreased tibial torsion) was shown in some studies,[13,15] while no significant postoperative change was noted in another study.[19] Two cadaveric studies using motion capture system and CT image analysis showed postoperative increases in external rotation.[12,16] To date, no relevant clinical results have been reported for DFO or DLO. The femoral torsional change is thought to be caused by the difference in lengths of proximal and distal bony cuts due to the obtuse angle (about 100°) between the transverse and ascending bony cuts in the lateral view (Fig. 1). As a geometrical consequence, internal rotation of the distal bony segment is inevitably induced during approximation of the bony cuts at wedge closing.

Although the effect of torsional change on postoperative mechanical environment in the knee has not been clarified, the influences of malrotation after femoral/tibial fractures on tibiofemoral contact force and patellofemoral alignment were investigated in previous biomechanical studies. Cadaveric studies reported significant alterations in medial compartment contact pressure of the knee in the presence of femoral or tibial rotational deformity.[20,21] Other biomechanical studies showed that internal rotation of the distal femur resulted in increased patellofemoral

Table 1
Pre- and postoperative femoral/tibial torsion angles measured by CT assessment.

Variable	Preoperative	Postoperative	Difference between preoperative and postoperative values	P value
Femoral torsion°	29.3 ± 10.8(4.3–56.9)	31.4 ± 11.1(6.0–61.4)	2.1 ± 1.73(-3.6-4.5)	0.002
Tibial torsion°	26.5 ± 9.1(9.3–45.8)	25.7 ± 9.0(8.0–43.3)	−0.8 ± 2.4(-5.8-3.8)	0.119(NS)

Data are mean ± SD.

contact stress.[22,23,24] Although the magnitude of rotational changes detected in this present study was low (less than 5° in the majority of the cases) compared to the experimental conditions adopted in those cadaveric studies (10° or 15° increments). The present study has shown that changes in rotational alignment are present after DLO and these issues should be taken into consideration in assessment of the surgical outcomes. In our clinical experience to date, the change in rotational alignment in the present patient population does not affect the short-term clinical outcomes; however, its effect on the long-term results is still to be observed. Another potential problem caused by the rotational change is an increased risk of intraoperative hinge fracture. Therefore, gentle manipulation during wedge closing is necessary to avoid this complication.

There are some limitations included in the design and contents of this study. First, there are potential sources of errors included in the CT image analysis. There may have been differences in limb alignment and positioning between the pre- and postoperative CT examinations. In addition, the level and orientation of the pre-and postoperative images subjected to the comparative analysis were not exactly the same, though careful process of image matching was followed. Second, the torsion angle assessment was performed on each of the femur and tibia, and the effects of the postoperative rotational change of each bone on the overall limb alignment and knee kinematics/kinetics are not known. Finally, the effect of the torsion changes detected in this study on postoperative clinical outcomes were not examined. Further clinical follow-up of this patient population is required.

Conclusion

This study showed that the DLO procedure (combining CWDFO and OWHTO) increased torsion (anteversion) of the femur by 2.1° on average while inducing no significant rotational change on the tibial side.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2021.03.002.

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