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Three-dimensional relationships between secondary changes and selective osteotomy parameters for biplane medial open-wedge high tibial osteotomy

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ABSTRACT

Background: To assess the axial rotational change of distal tibia and posterior tibial slope (PTS) change after OWHTO in 3-D planes and to identify the causal relationship on the effect of variation in the posterior slope angle and rotational errors.
Methods: A total of 21 patients (23 knees) underwent OWHTO and were evaluated with 3D-CT before and after surgery. Medial proximal tibial angle in the coronal plane, PTS in the sagittal plane, and rotational axis in axial plane were evaluated and compared between pre- and post-operative 3D models constructed by applying reverse-engineering software. As a selective osteotomy parameter, hinge axis and gap ratio were measured in the postoperative 3D models
Results: The increasing tendency of internal rotation of the distal tibia after OWHTO was positively related to hinge axis ($\beta = 0.730$, $p = 0.001$, $R^2 = 0.546$) and gap ratio ($\beta = -0.283$, $p = 0.001$, $R^2 = 0.520$), which also showed statistically significant linear correlations to PTS changes after multivariate regression analysis that controlled for the rotational change of the distal tibia (hinge axis: $\beta = 0.443$, $p = 0.006$; gap ratio: $\beta = 0.144$, $p = 0.017$).
Conclusion: Hinge axis more posterolaterally was related to a greater increase in internal rotation after biplane medial open-wedge HTO, and hinge axis and gap ratio were significant predictors of PTS change after rotational change was controlled for. Hinge axis has to be considered an important independent variable for limiting unintended axial rotation change as well as PTS change as secondary.
Clinical relevance: The relationship of the hinge axis with the rotational change and its influence to PTS change, acknowledged from by-product of the statistical analysis, might provide a deeper understanding of HTO, and should have constitutional effects on the development of HTO procedures and implants.

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1. Introduction

Medial open-wedge high tibial osteotomy (OWHTO) is a generally accepted surgical method for medial unicompartmental osteoarthritis with varus malalignment of the lower extremity [1–6]. However, a number of authors have suggested the possibility of unintentional secondary changes during OWHTO, which include posterior tibial slope (PTS) angle change [7–10], tibial rotation change [11], and medial-lateral slope change of the knee joint line [12].

Inadvertent secondary changes likely arise from a triangular-shaped osteotomy performed in the proximal tibia [13,14]. The operations are performed in three-dimensional (3-D) (coronal, sagittal and axial) planes, whereas pre-operative planning and evaluation are based only on the coronal plane. These conflicts might lead to unpredictable and unreliable changes in PTS (sagittal plane) and rotation (axial plane) during coronal alignment correction.

Many authors have already demonstrated that alterations in the posterior tibial slope occur with OWHTO [1,15]. Numerous recommendations have been suggested for preventing unintentional increases in PTS after medial OWHTO: Lee et al. [16] and Noyes et al. [14] suggested using a 50% or 67% anterior-to-posterior gap ratio, respectively, to maintain normal tibial slope. However, there is no reliable consensus on the appropriate gap ratio to maintain normal posterior tibial slope, due to the highly variable results for gap ratios [14,16]. Recently, a few studies have addressed axial tibial rotation after OWHTO; [15,17] however, there has been almost no research into which factors contribute to rotational change [15], and several assumptions just have been used to explain the mechanism of postoperative axial tibial rotation change and to predict the direction and amount of change [11,17,18].

For understanding the alignment changes in each 3-D plane, it is obvious that direct comparison of pre-operative and postoperative 3-D models would provide a clear explanation, and inadvertent secondary changes might be avoided if the independent variables could be controlled to affect the changes. This study was performed with particular interest in the hinge axis as a selective osteotomy parameter, which was evaluated to determine the influence of the change in PTS in previous studies [16,19].

The purpose of the current study was to assess the axial rotational change of distal tibia and posterior tibial slope change after OWHTO in 3-D planes, and to identify the causal relationship on the effect of variation in the posterior slope angle and rotational errors. It was hypothesized that the orientation/direction of hinge axis would affect the unintended axial rotational changes in the distal tibiae, which would be a significant factor in ensuring constant unchanged PTS in biplane medial OWHTOs.

2. Materials and methods

The current study obtained Institutional Review Board approval, and informed consent was obtained from all participants. A retrospective review was conducted of 23 consecutive patients (25 knees) who underwent navigation-assisted medial OWHTO between 2011 and 2012. The primary inclusion criterion was that patients were scheduled to undergo OWHTO to treat medial tibiofemoral osteoarthritis with varus malalignment >5°. All participants agreed to undergo computed tomography (CT) scanning before and after surgery. There were two cases with intraoperatively identifiable lateral hinge breaches, and three cases with simultaneous ACL reconstruction due to associated injury. Two cases were excluded that had a hinge axis not within the 3-D model of proximal tibia. A total of 23 knees (both knees of two participants) were enrolled in the study. The participants' demographic information is summarized in Table 1.

One surgeon (J.H.W.) performed all operations using an OrthoPilot navigation system (HTO version 1.3, OrthoPilot, Aesculap, Tuttlingen, Germany). All knees underwent biplane medial open-wedge tibial tuberosity osteotomy with a lateral cortical hinge, as was mentioned in a previous study, to prevent unintentional increases in PTS [20]. The superficial medial collateral ligament, located at the osteotomy sites, was cut using electrocautery along the planed osteotomy line. Then, the osteotomy procedure was continued using the prescribed method, taking care to complete osteotomy of the posterior cortex. After the mechanical axis was corrected with monitoring by the navigation system, stabilization was achieved by fixing a Tomofix plate with locking screws (Synthes, Bettlach, Switzerland) [21].

All CT data were obtained using the same CT scanner (Light Speed VCT; GE Medical System, Milwaukee, WI, USA). The collimation was 16 × 0.625 mm, slice thickness was 0.625 mm, and the acquisition matrix was 512 × 512 pixels. After the data were extracted via a picture-archiving communication system, they were exported to Mimics (Materialise, Leuven, Belgium), and the 3-D

Table 1
Participants' demographics and baseline characteristics.[a]

Characteristic	Mean (range) or N
Age, years	45 (19–59)
Sex, n	Male, 9; female, 12
Side, n	Right, 11; left, 12
Height, cm	165.5 (149.7–183.3)
Weight, kg	70.2 (50.8–90.9)
BMI, kg/m^2	26.2 (19.6–33.7)
K–L grade	3 ± 0.8 (1–4)

BMI, body mass index; K–L, Kellgren–Lawrence osteoarthritis.
[a] Mean values with range in parentheses.

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