Effect of Distal Tibial Oblique Osteotomy on Joint Contact Pressure Distribution in Ankle Osteoarthritis: A Patient-Specific Finite Element Analysis Study

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INTRODUCTION: Distal tibial oblique osteotomy (DTOO) is a sophisticated surgical procedure designed to treat ankle osteoarthritis (OA) (Fig.1) [1]. However, the biomechanical consequences of DTOO have never been investigated, and its impact on joint contact pressure distribution remains to be elucidated. The purpose of this study was to establish a patient-specific finite element (FE) analysis approach to elucidate the effects of DTOO on joint contact pressure distribution in patients with ankle OA.

METHODS: This study included two patients diagnosed with ankle OA (Takakura grade IIIa) who underwent DTOO and one healthy control. Three-dimensional surface models of the distal tibia and talus were developed from pre- and postoperative CT DICOM data sets using Mechanical Finder version 10 (Computational Mechanics Research Center, Tokyo, Japan). The tibio-talar alignment in the weight-bearing position was reconstructed using a 2D-3D matching technique based on standing lower leg rediographs and supine ankle CT data (Fig.2). The elastic FE modulus was determined from bone mineral density values using the equation described by Keyak et al [2]; and the Poisson's ratio of bone, artificial bone and implant was set to 0.3. The Young's modulus and Poisson's ratio of the articular cartilage were set to 12 MPa and 0.42, respectively. The distal talus was fixed and the proximal tibia was constrained in the x and y axes only. The loading scenario was based on a single-leg stance, with the contact force of the distal tibia acting on the tibio-talar articular surface of the talus. The proximal tibia was simulated by applying a body weight equivalent load of 600N, in the z axis [3]. The joint contact area (CA) and maximum joint contact pressure (CP) at the articular surface of the talus before and after DTOO were calculated and compared with the control.

RESULTS: In the control subject (53-year-old male, right ankle), the CA was 584 mm^2 and the maximum CP was 2.6 MPa at the articular cartilage surface of the talus (Fig.3). In case 1 (73-year-old female, left ankle), the CA increased by 125% from 166 mm^2 preoperatively to 375 mm^2 postoperatively, while the maximum CP decreased by 36% from 9.8 MPa to 6.3 MPa (Fig.3). Similarly, in case 2 (65-year-old female, left ankle), the CA increased by 46% from 301 mm^2 to 439 mm^2, and the maximum CP decreased by 27% from 6.7 MPa to 4.9 MPa (Fig.3).

DISCUSSION: Our results suggest that DTOO manifests its efficacy in the redistribution of joint CP in patients with ankle OA. Our findings provide valuable insights for clinicians considering DTOO as a treatment option for patients with ankle OA, allowing for improved surgical planning and better patient outcomes. Limitations of this study include a limited sample cohort, the inability to assess joint stability using FE methods, and the limited loading condition of single-leg standing only, which warrants further investigation in the gait cycle and daily activities.

SIGNIFICANCE/CLINICAL RELEVANCE: This is the first study to demonstrate the biomechanical effects of DTOO using a patient-specific FE model with a tibio-talar joint alignment in the weight-bearing position. The results of this study highlight that improved tibio-talar joint biomechanics, manifested as increased CA and decreased maximum CP after DTOO, may correlate with pain relief in patients with ankle OA.

REFERENCES:

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2. Keyak JH, Rossi SA, Jones KA, et al. Prediction of femoral fracture load using automated finite element modeling. J Biomech. 31:125–33, 1998.
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IMAGES:

Fig.1: Weight-bearing radiographs of the ankle joint of case 1:
(A) Preoperative and (B) 6 months after distal tibial oblique osteotomy.

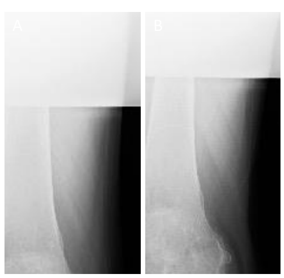


Fig.2: Finite element model of the tibio-talar joint in case 2:
(A) 3D surface model developed by 2D-3D matching of standing lower leg radiographs and supine ankle CT data.
(B) Finite element model with the loading conditions and boundary restrictions.

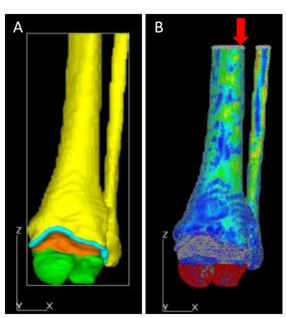
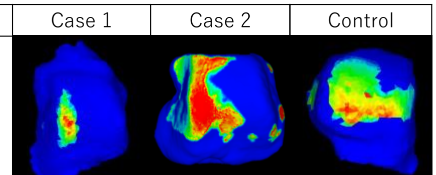
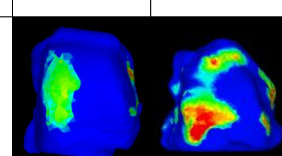


Fig. 3: Joint contact area (CA) and joint contact pressure (CP) on the talar cartilage before and after distal tibial oblique osteotomy (DTOO).

	Case 1	Case 2	Control
Before DTOO			
CA (mm^2)	166	301	584
Maximum CP (MPa)	9.8	6.7	2.6
After DTOO			
CA (mm^2)	375	439	
Maximum CP (MPa)	6.3	4.9