Prediction of surgical stability in relation to plate position in high tibial osteotomy: A finite element analysis

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INTRODUCTION: High tibial osteotomy (HTO) is a surgical treatment that changes the mechanical axis by using a plate and screws after osteotomy to relieve unilateral osteoarthritis of the knee joint [1]. However, complications such as loss of correction, fracture of the implant or removal of the fractured implant during revision after HTO may cause infection and cause additional symptoms [2]. It has been reported that the plate position is a variable that affects fixation force, but biomechanical studies on this are insufficient [3]. In this study, the surgical stability in relation to the insertion position of the plate during the HTO procedure is predicted through a finite element analysis.

METHODS: A 3D bone model was used (Mimics software v25.0, Materialize inc., Belgium) based on the right Tibia and Fibula CT images (1mm) of a normal male (70kg), cortical bone (E=17000MPa, v=0.36) thickness was set to 1 mm to be separated it from Cancellous bone (E = 300 MPa, v = 0.3) [4,5]. The 3D model was validated through comparison of stiffness with reference to the 4-point bending test of a previous study [6]. For the osteotomy method, the biplanar osteotomy, which has been frequently performed recently among the HTO surgical methods was applied [7]. In the anterior view, the 1st osteotomy line was set from 40mm distal medially to 15mm lateral. In the medial view, the osteotomy was performed by forming a 10mm wedge by setting the 2nd osteotomy line at a 110 º between the 1st osteotomy line and the point 10mm posterior to the tibial tuberosity [8]. The plate (TomoFix^{TM}, Standard, DePuy Synthes, USA, Ti6Al4V, E=113000, v=0.33) was used to reproduce the post-operative models. The distal of the plate was aligned with the center axis of the shaft in medial view. The proximal of the plate was placed 10 mm anteroposteriorly to the center (anterior 10mm, anterior; center; posterior 10mm, posterior) and inferiorly at 4 mm intervals parallel to the tibial posterior slope line (4 mm, proximal; 8 mm, middle; 12 mm, distal). The 9 types of finite element models were reproduced. And a total of 8 screws (TomoFix^{TM}, Standard, DePuy Synthes, Ti6Al4V, E=113,000, v=0.33) were inserted to fit the plate hole. The plate and screw are assumed rigidly bond "Tie contact" and a friction coefficient of 0.3 was assigned between the bone and screw [9]. The distal of the tibia was fixed in all directions [Figure 1]. Assuming a one-legged stance as a load condition, a load of twice the body weight (1400N) was applied to the tibia plateau in the medial (60%) and lateral (40%). And for the compressive load generated during opening, 200 N was applied at the osteotomy proximal site [8]. To analyze the biomechanical effect of the position of the plate, axial and shear interfragmentary micromotion between osteotomy site and mean stress generated at the bone and implants constructs were compared.

RESULTS SECTION: The interfragmentary micromotion and mean stress of 9 finite element models showed the lowest results in plate position of proximal and posterior. As the plate was positioned distal to proximal and anterior to posterior, micromotion and mean stress were decreased. The axial interfragmentary micromotion in group of center and posterior position decreased by 0.17mm, 30% and 0.27mm, 47% compared to anterior position (0.57mm), respectively [Figure 2(A)]. In case of the shear direction showed the same trend as the axial direction. In additionally in group of middle and distal position increased by up to 0.5mm, 5% and up to 0.9mm, 8% compared to proximal position (1.01~1.09mm) [Figure 2(B)]. The mean stress generated at the bone decreased by up to 21% when the plate was placed posteriorly and in the case of implant constructs, by up to 25%. Likewise, as the plate was placed proximally, the mean stress generated in the bone decreased by up to 13% and in the case of implant constructs, by up to 11% [Figure 2(C, D)].

CONCLUSION: This study suggests that the proximal and posterior position of the plate in medial view improves biomechanical stability by reducing the interfragmentary micromotion and the stress at bone and implant in HTO.

SIGNIFICANCE/CLINICAL RELEVANCE: This is the first study to demonstrate that plate positioned proximally and posteriorly in the medial view for high tibial osteotomy increase the surgical stability.

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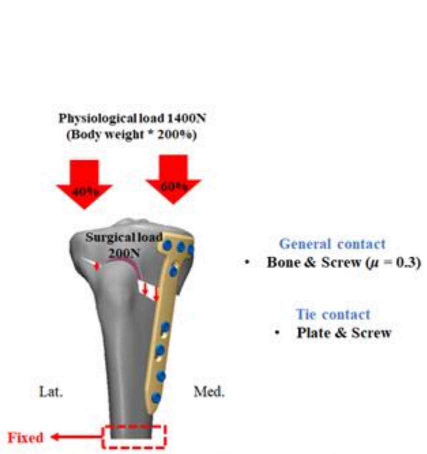

Figure 1. Loading and boundary conditions

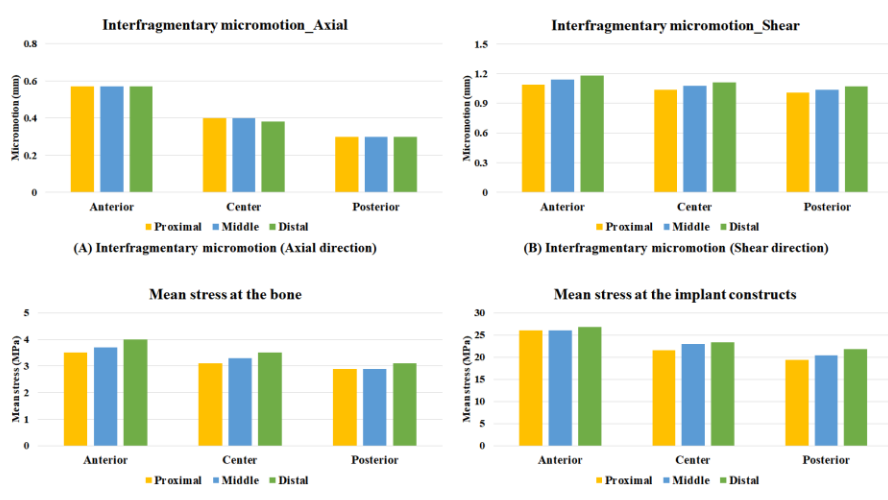

Figure 2. Graph results. (A) Axial & (B) Shear interfragmentary micromotion, Mean stress at (C) the bone & (D) implant constructs