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Deformation assessment of the manually pre-bent titanium miniplates in orthognathic surgery with finite element analysis

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INTRODUCTION

The aim of the present study was to analyze the biomechanical behaviors of manually pre-bent titanium miniplates including stress and displacement via FEA, and evaluate the extra deformation by comparing with the virtual pre-bent titanium miniplate models to enhance the accuracy of the pre-bent titanium miniplates in clinical practice.

MATERIAL AND METHODS

Modelling

3D models of titanium miniplates (4 holes I-shaped plate, 26.3 mm in length and 4.6 mm in width) with different thicknesses (1.0 mm, 0.8 mm, 0.6 mm) were constructed based on Synthes physical specimens (Synthes, Paoli, PA, USA) using COMSOL Multiphysics 5.2 (Comsol AB, Sweden) software. The three titanium miniplate models were saved as Stereolithography (STL) files for the following virtual bending simulation. Then the tetrahedral finite element meshes were generated on these titanium miniplate models, and we refined the mesh in the planned bending areas to achieve more accurate outcomes. The final mesh models consisted of 9026 elements (1.0mm- thickness), 7566 elements (0.8 mm-thickness), 5422 elements (0.6mm-thickness) respectively. The material of titanium miniplate models was assumed to be isotropic, homogenous, and linear elastic, the Young's modulus and Poisson ratio was 103 Gpa and 0.35 respectively.

Virtual bending simulation

The three saved titanium miniplate models were exported to the Freeform Modeling Plus software (Geomagic, Morrisville, NC, USA) to simulate the virtual bending of titanium plates in preoperative virtual surgical planning (Fig. 1). Each model was bent into five angles (15°, 30°, 45°, 60°, 80°) and the displacements of the bended titanium miniplate models at each angle in the 3D coordinate system (the right endpoint of the titanium miniplate model was defined as the origin of the 3D coordinate system in this study) were then recorded. These bent models were saved as STL files for the subsequent registration.

Manual bending simulation

COMSOL Multiphysics 5.2 software was used to simulate the manual bending of titanium miniplate by applying displacement loading. The left end of each mesh model was fixed to ensure the stabilization of this part, then the displacement loading was applied to the right end according to the displacement obtained in virtual bending simulation. The final displacement of the right end of titanium miniplate model and the stress distribution at each angle were computed and recorded at the steady state. These bent titanium miniplate models were saved as STL files for the following registration.

Registration and comparison

The two STL files of bent titanium miniplate models from Freeform Plus software and COMSOL Multiphysics 5.2 software were exported to the Geomagic Studio software (Raindrop, USA) respectively. The fixed left ends of the models were used to be the reference in registering the virtual bending simulation models and manual bending simulation models, and the deviation diagrams were then generated.

RESULTS

The maximum stresses observed in the bending areas increased with the thickness and bending angle of the miniplate models (Fig. 2). The displacements in the two simulations differed but they have the same trend. The maximum displacement of the right end in Z axis increased with the thickness and bending angle of the pre-bent titanium miniplate models (Fig. 3). The displacement deviations were mainly distributed at the right ends of the pre-bent miniplates, and the displacement deviations of the right end in Z axis increased with the thickness and bending angle of the pre-bent titanium miniplate models (Fig. 4, Fig. 5).

CONCLUSION

The biomechanical behavior analysis for manually pre-bent titanium miniplates demonstrated that the extra deformation increased with the thickness and bending angle of the pre-bent titanium miniplate models, providing instructions for the clinical practice of manual pre-bending of pre-bent titanium miniplates to achieve higher surgical accuracy.

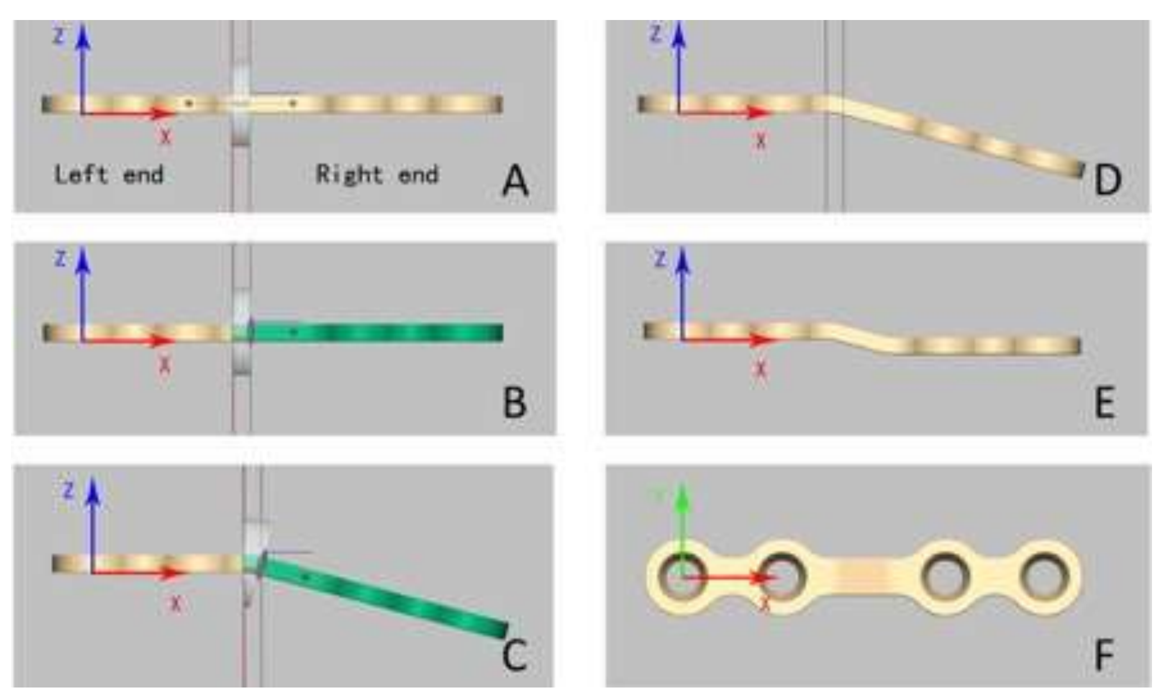

Figure 1 The virtual bending simulation. The simulation of virtual bending process of titanium miniplate in preoperative virtual surgical.

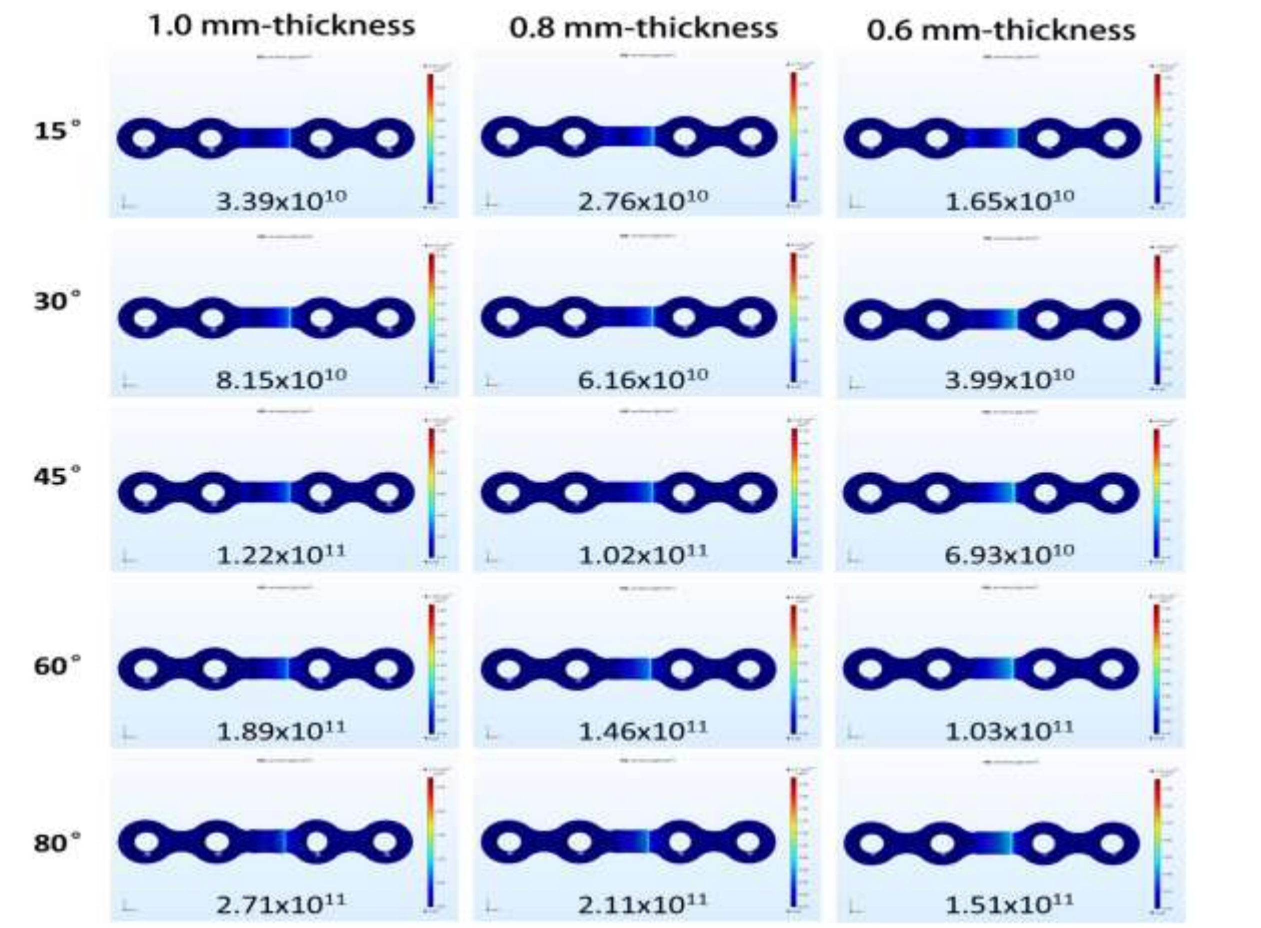

Figure 2 The stress distribution of the pre-bent titanium miniplate models and the value of maximum stress in the manual bending simulation.

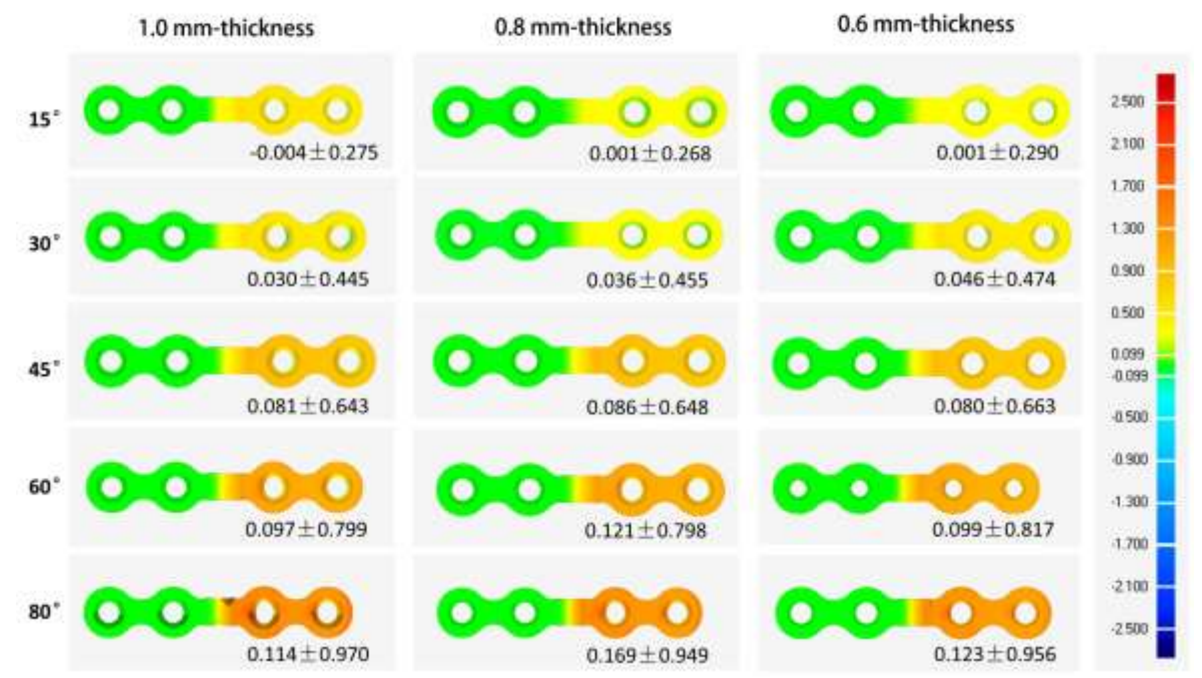

Figure 3 The registration colored map and the mean (± virtual deviation) values of displacement deviations of the point cloud.

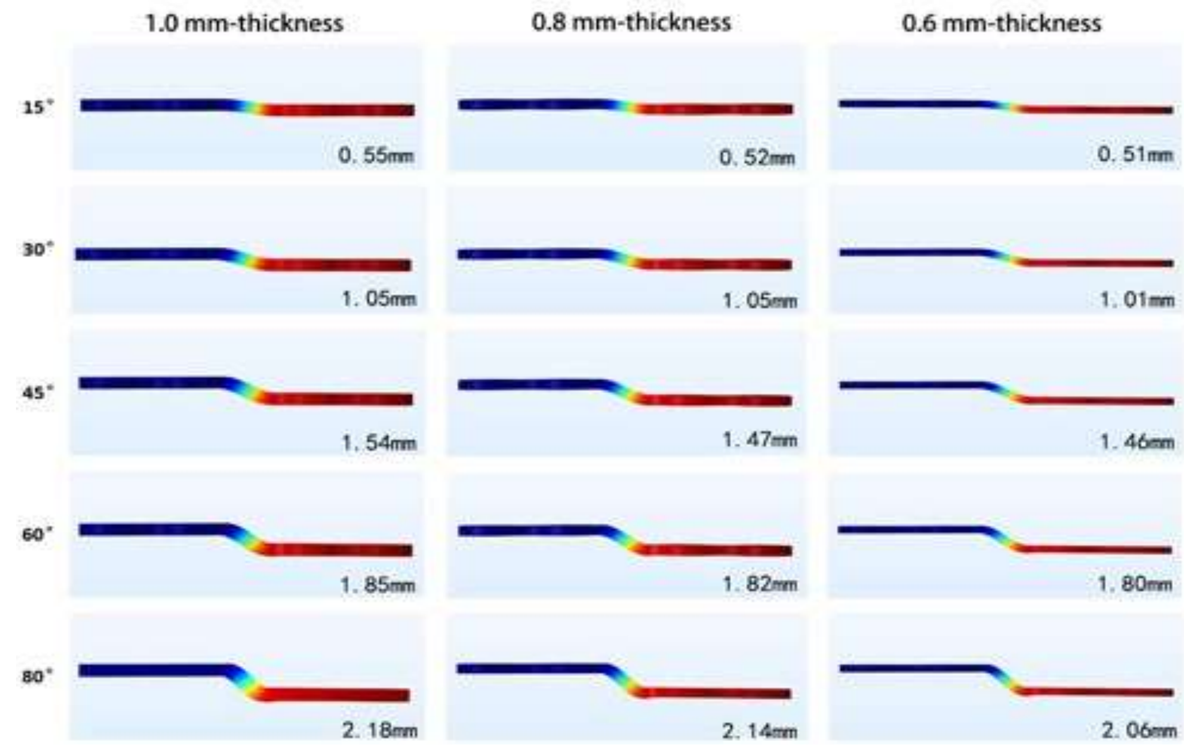

Figure 4 The lateral views of pre-bent titanium miniplate models and the final displacements of the right end in Z axis in the manual bending simulation.

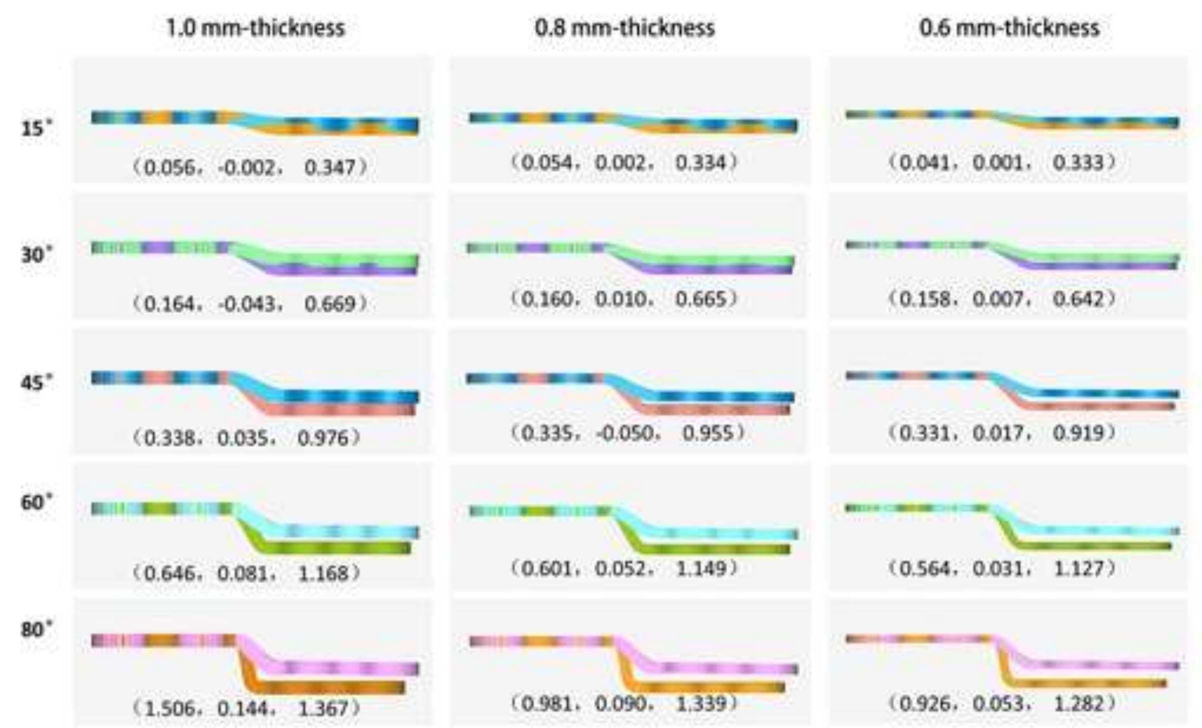

Figure 5 The lateral views of the registered models and the values of displacement deviations of the right end in the 3-dimensional coordinate system (x, y, z).