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Biomechanical Effects of Screw Fixation in Second Mandibular Reconstruction Plate

Ya-Wen Chang, Pao-Hsin Liu

Abstract— **The purpose of this study was to investigate biomechanical effects of second reconstruction plate with different combinations of fixed screws in patient with mandibular tumor resection by three-dimensional finite element analysis (FEA). The FEA models were consisted of defected mandible, reconstruction plate with different screw holes, and bone screws. The results indicated that application of the second reconstruction plate appeared to increase stability and decrease stress magnitude on the plates and screws accompanying with increasing screw number. For clinical cost consideration in usage of the second reconstruction plate, the conclusion showed that the second reconstruction plate could offer a better mechanical efficacy accompanying with increase of screw quantity, but single screw applied for the second plate fixation to defected mandible of tumor resection was enough to stabilize without increase of screw quantities.**

I. Introduction

Bone segment defects resulted from severe trauma or tumor resection is a great challenge in reconstructive surgery [1]. An ideal plate-screw system must be strong and rigid enough to withstand the functional loading and enable undisturbed to fracture healing [2]. Hence, double reconstruction plates were suggested to provide a better stability of defected mandibular surgery, but an influence in screw number of second reconstruction plate is unclear. Previous studies mentioned that the stability in the double plate was greater than that in the single plate [3-4]. Moreover, fracture of the plate and/or screw by stress-induced is still an essential factor for investigating [5]. The finite element analysis (FEA) have been demonstrated that a powerful tool was used in biomechanical evaluation of musculoskeletal system and/or prosthetic application in human body to provide numerical results for predicting or investigating of study [6-7]. Therefore, the purpose of this study is to build a 3D finite element mandibular corpus defect model to investigate the biomechanical effect in different combinations of reconstruction plates of screw-holes structures, in order to understand the contribution of second reconstruction plate which was located at the lower site of defected mandible.

Pao-Hsin Liu is with the Department of Biomechanical Engineering, I-Shou University, Kaohsiung City, Taiwan, ROC (corresponding author to provide phone: +88676151100-7473; e-mail: phliu@isu.edu.tw).

Ya-Wen Chang, is with the Department of Biomechanical Engineering, I-Shou University, Kaohsiung City, Taiwan, ROC (e-mail: isu10050003m@isu.edu.tw).

II. Material and Methods

The solid model of the defected mandible, including the structures and material properties of cortical and cancellous bone, was reconstructed from computerized tomography images of a 58-year male patient, a loss of mandibular continuity occurring as a result of tumor resection. The models of the reconstruction plates, which have one-, two-, three-screw-holes in each unilateral side, and screws (diameters 2.3mm) were created by the CAD software (SolidWorks 2010, SolidWorks Corporation, Concord, MA). Three FEA models, such as model A, B, and C with different screw-holes-fixed combinations of reconstruction plate, were investigated by 3-D FEA to understand biomechanical effects of screw number of the second reconstruction plate (fig. 1). The materials of all FEA models in this study were considered to be isotropic, homogeneous and linear elastic properties. The material properties of Young's modulus for the reconstruction plates, screws, cortical and cancellous bone were 14700, 1370, 110000, and 110000 MPa respectively (Table I), furthermore, Poisson ratio of 0.3 was assigned for all of the models [4]. A vertical force of 135 N was applied at the incisor region to simulate occlusal force (fig. 2) [8]. The components of intermediate articular disc and temporal bone were neglected in this study following previous studies [9-10]. Hence, two condylar processes were constrained to zero displacement as boundary condition. Furthermore, the interfaces between components of the FEA models were considered for bonding simulation. Total numbers of elements and nodes in the FEA model were 112943 and 191565 respectively. The simulations of the FEA models were executed by finite element analysis software (ANSYS V12.0, ANSYS Inc Swanson, Houston, USA). The converging test of 0.5% stop criteria has been performed in relationship between element size and peak von Mises stress in the FEA models of this study. Moreover, a numerical error evaluation of mesh density, such as element energy error and element stress deviation, were also performed, an acceptable criteria of percent error must be less than 10%. Therefore, the FEA results of this study could provide as a confident numerical reference for comparing with other previous study. The von Mises stresses of the reconstruction plate and screw and deformation of bone were calculated to evaluate for understanding the biomechanical effect of second reconstruction plate.

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III. RESULTS AND DISCUSSION

The peak von-Mises stress of the reconstruction plate on the model A, B, and C were 356.5, 342.77, and 318.29 MPa respectively. The result showed that the model A, was one screw fixation each side in the second plate, revealed the tendency of a lower resistant strength than the others under loading applied (fig. 3). An inverse proportion was detected between stress magnitude and insertion of screw number in each side (fig.4). The result indicated that the screw number increase could truly reduce the stress intensity in the reconstruction plate and screw. The least deformation on the model C was discovered (fig. 5), this result indicated that increasing screw insertions in the defected mandible could provide a better stability.

The largest stress concentration of the reconstruction plates in whole combinations were detected at the connected structure around a screw hole near left surgery cutting plane. According to above result, this study suggested that the reconstruction plate should be reinforced at the bilateral sides near to bone-plate connected region. Furthermore, the role of second reconstruction plates in three FEA models have been evidenced, it could increase stability and decrease stress magnitude accompanied to large number of screw insertions. In fact, the influence of the second reconstruction plate with plenty screws, such as three-screw fixation in each side, was not significantly increase mechanical benefit in the defected mandibular bone plate repair. The results of the present study verify the consequences of clinical observations and previously published biomechanical studies [11-12]. Therefore, for mandibular reconstruction surgery, one screw insertion in each side of second reconstruction plate can provide enough for mechanical function. The limitations of this FEA study were to lack of muscle forces applied, effect of temporomandibular joint (TMJ) structure especially in TMJ disc, and verification of experimental mechanical examination. However, further investigations of this study are required according to above limitations to provide more detail biomechanical effects about defected mandible fixation and reconstruction.

IV. CONCLUSIONS

Double reconstruction plates, particular second reconstruction plate, can increase stability and decrease stress magnitude on the plates and screws of the defected mandible. Moreover, single screw fixation at each side of the second reconstruction plate was also evidenced a positive mechanical contribution. For clinical consideration of the second reconstruction plate, the conclusion was that single screw fixation to the second plate for defected mandible of tumor resection was enough to stabilize, not necessary wasted screw insertions.

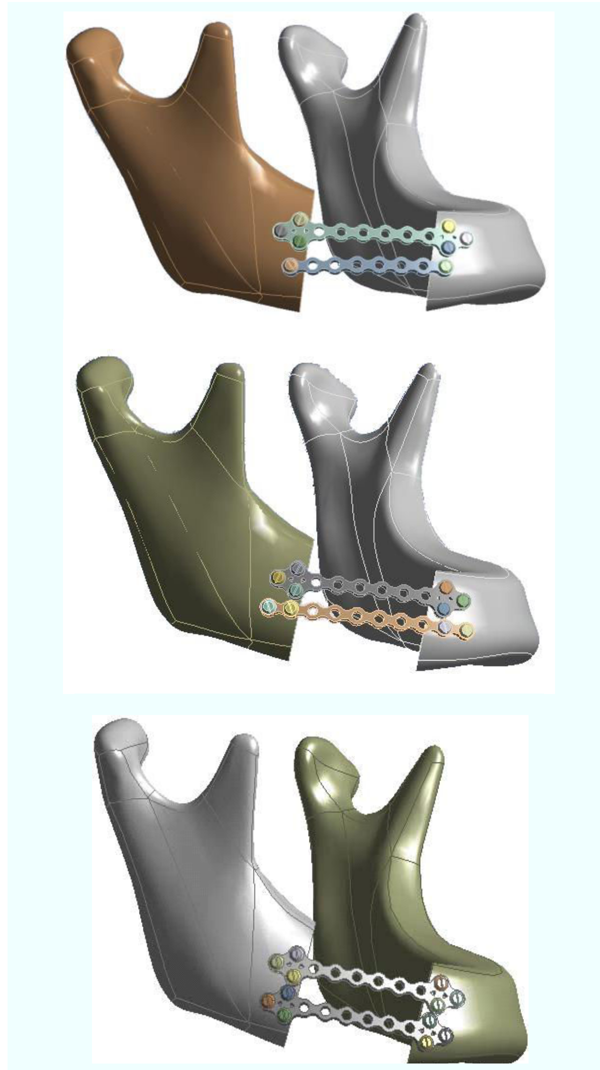

Figure 1. Three fixed combinations of the reconstruction plates, which have different screw-holes structures, were evaluated to investigate the mechanical effect of defected mandible.

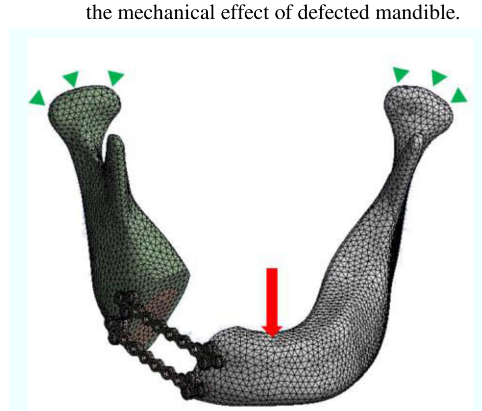

Figure 2. Finite element meshed model of the mandibular defect with reconstruction plate repair, a biting force of 135 N and constrain at the bilateral condylar head was applied

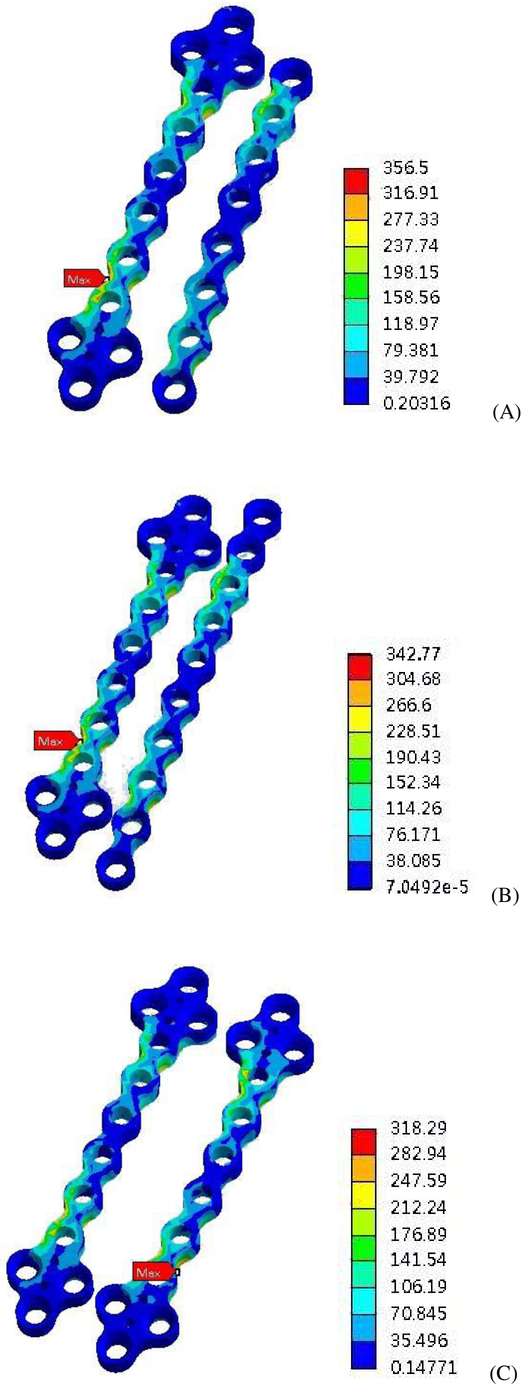

Figure 3. Distribution of von-Mises stress of the reconstruction plates on the model A, B, and C (from left to right).

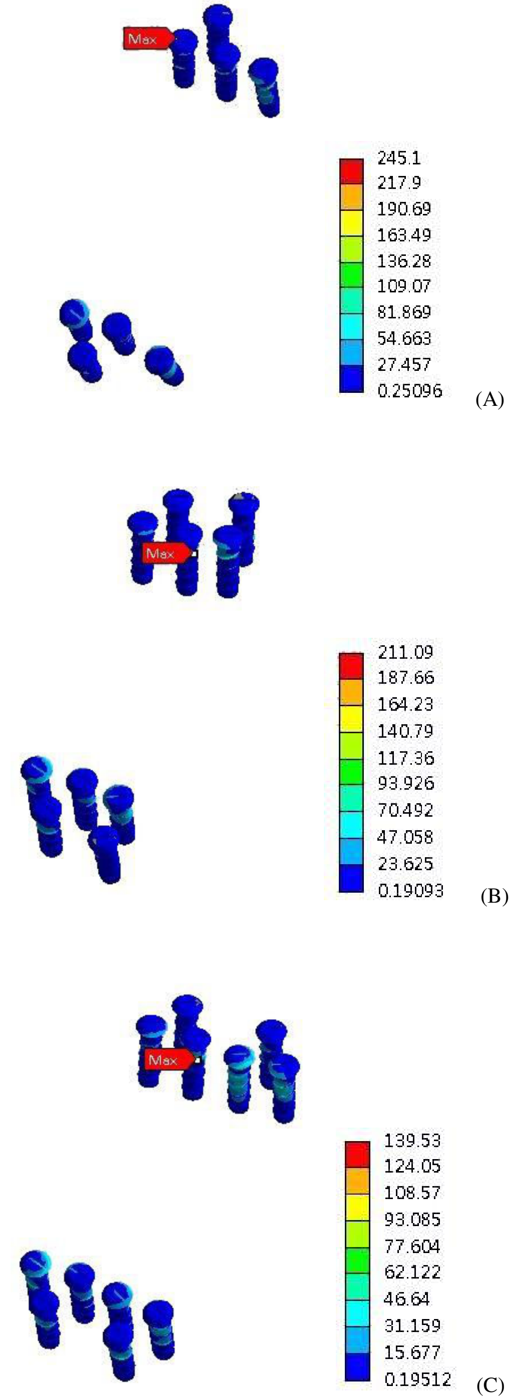

Figure 4. Distribution of von-Mises stress of the screws on the model A, B, and C (from left to right)

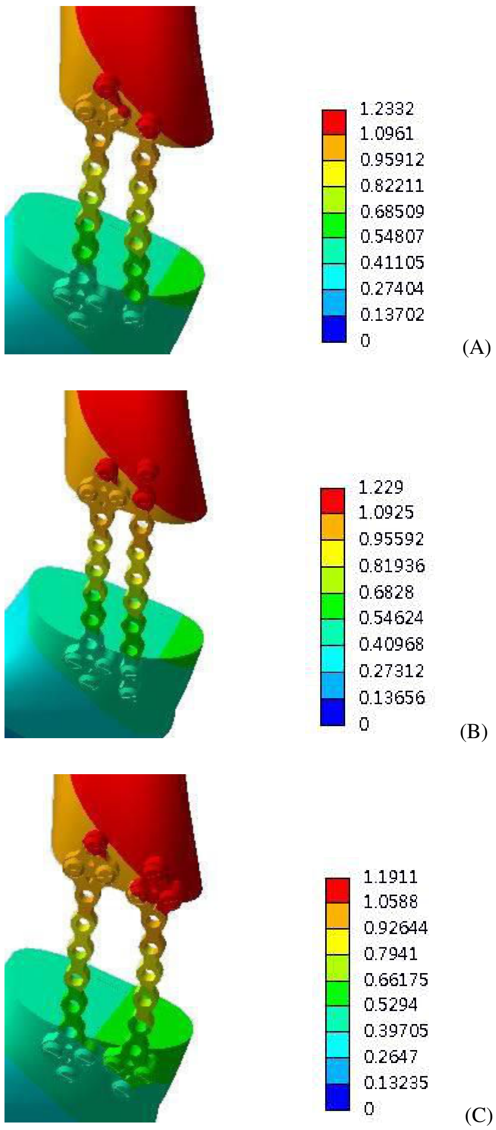

Figure 5. Distribution of total deformation on the model A, B, and C (from left to right).

TABLE I. The material properties of FEA model

	Young's Modulus(MPa)	**Poisson's Ratio**
Reconstruction Plate (Ti)	110000	0.3
Screw (Ti)	110000	0.3
Cortical Bone	14700	0.3
Cancellous Bone	1370	0.3

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