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Prof. Dr Abhay Datarkar, MDS, DNB, FIBCOMS, Dr Shikha Tayal, MDS, Junior Resident, Mr Abhishek Thote, Research Scholar, Dr Manlio Galie, MD, DMD, FEBOMFS

PII: S1010-5182(18)30238-5

DOI: https://doi.org/10.1016/j.jcms.2018.11.004

Reference: YJCMS 3146

To appear in: *Journal of Cranio-Maxillo-Facial Surgery*

Received Date: 15 May 2018

Revised Date: 29 October 2018

Accepted Date: 5 November 2018

Please cite this article as: Datarkar A, Tayal S, Thote A, Galie M, An in-vitro evaluation of a novel design of miniplate for fixation of fracture segments in the transition zone of parasymphysis-body region of mandible using finite element analysis, *Journal of Cranio-Maxillofacial Surgery*, https://doi.org/10.1016/j.jcms.2018.11.004.

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An in-vitro evaluation of a novel design of miniplate for fixation of fracture segments in the transition zone of parasymphysis-body region of mandible using finite element analysis

Corresponding author

Prof. Dr Abhay Datarkar

MDS, DNB, FIBCOMS

Department of Oral and Maxillofacial Surgery

Government Dental College & Hospital,

Medical campus, Medical Square,

Nagpur, Maharashtra, India

Contact no: (+91) 9822698145, 0712 2283888

E-mail: abhaydatarkar@yahoo.com

2nd author

Dr Shikha Tayal

MDS (Junior Resident)

Department of Oral and Maxillofacial Surgery,

Government Dental College, Nagpur,

Maharashtra, India – 440003

Email: daringshikha@gmail.com

3rd author

Mr Abhishek Thote

Research Scholar,

Department Of Mechanical Engineering, VNIT, Nagpur,

Maharashtra, India

Email: abhi.thote8@gmail.com

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4th author

Dr Manlio Galie

MD, DMD, FEBOMFS

EACMF Education and Training Officer

Director and Chief, Unit of CranioMaxilloFacial Surgery

St Anna Hospital and University

Viale Aldo Moro, 8 44124

Ferrara – Cona, Italy

Manlio.galie@unife.it

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SUMMARY

The mandibular parasymphysis and body regions are highly dynamic areas. They are constantly subjected to both occlusal and muscular forces. Fractures at this transition zone of the parasymphysis and body region thus represent a special pattern that creates a dilemma for the surgeons — whether to use one miniplate fixation or two miniplates as per Champy's guidelines. Mental nerve paresthesia is a very common complication due to dissection and stretching of the mental nerve in this region. Hence, an in-vitro research study of a novel twin fork design of miniplate is performed, which evaluates the biomechanical behavior using computerized finite element analysis. A comparison is carried out with the conventional design. The results show that the twin fork miniplate produces the lowest stresses — 23.821 MPa — and the least total structural deformation after applying the maximum occlusal bite force. This study concludes that the newly designed miniplate is superior in terms of stability because it shows the least structural deformation, and produces the lowest equivalent stresses on application of maximal occlusal forces. An additional advantage is the preservation of the mental nerve during the plating procedure because the broad end of the Y shape allows atraumatic positioning of the miniplate and hence the fixation of fractured segments.

Keywords: finite element analysis; biomechanical evaluation; miniplate; internal fixation; mental nerve paresthesia

INTRODUCTION

Fractures through the mandible at the level of the parasymphysis, extending obliquely and traversing through the transitional zone to the body region, are relatively common and account for approximately 20% of mandibular fractures[1]. The mandibular parasymphysis and body regions are highly dynamic areas, constantly subjected to various types of occlusal and muscular force. It is well known that the mandible is normally subjected to tension forces on its superior border and compression forces on its inferior border[2–5]. Torsional forces are also created within the mandibular parasymphysis, which increases in strength towards the midline. However, there is disruption of the dynamics when a fracture occurs, causing the fracture segments to be subjected to various types of stress.

Anatomically, the transition zone is characterized by the presence of deeper roots, neurovascular bundle and associated mental foramen, and a change in density and orientation of the bony trabeculae due to the gradual change in the arch form of the mandible. These all contribute to a different clinical picture and, consequently, a different pattern of fractures in this zone, necessitating a different approach to management. Fractures in the transition zone of the parasymphysis and body region thus represent a special pattern that creates a dilemma for the surgeons — whether to use one miniplate fixation or two miniplates as per Champy's guidelines. Moreover, mental nerve paresthesia is a very common complication due to dissection and stretching of the mental nerve in this region[6]. Additionally, trauma itself may compromise the neurovascular function of the mental nerve.

Hence, a novel design of the conventional miniplate has been created with the aim of resolving this dilemma and additionally minimizing damage to the neurovascular bundle due to the plating technique. An in-vitro study is performed that evaluates the biomechanical behavior of the newly designed titanium miniplate using finite element analysis. This design promises to follow Champy's lines of osteosynthesis, as well as provide better stability and fixation properties compared with the conventional design.

Finite element analysis (FEA) is a computed technique originally developed by engineers to model the mechanical behavior of complex structures, ranging from buildings to human anatomical body parts. A numerical approach simplifies a complex shape with infinite degrees of freedom into a number of simpler, finite, interconnected shapes or elements. The accuracy of this approach is dependent on many variables, including the accuracy of geometric replication, and the number and complexity of the elements used in the model. As there are a limited (finite) number of elements in a given model, the analysis is termed finite element analysis. FEA has been used previously to evaluate the treatment of facial fractures[7, 8], and its use in evaluating plating techniques has been established[8].

The aim of this study is to evaluate the performance of the newly designed miniplate in terms of structural deformation and production of equivalent von Mises stresses, and to compare it with the conventional design using computerized FEA.

MATERIALS AND METHODS

This study analyzes the biomechanical behavior of a newly designed, twin-fork-shaped miniplate used for the internal fixation of fracture of the mandible at the transition zone of the parasymphysis and body region, and compares it with the conventional design. For this purpose, a three-dimensional finite element model of the mandible was developed. The type and positioning of the miniplates were determined in accordance with the clinical application.

1. Construction of the basic finite element model of mandible

The three-dimensional finite element computer model was generated on the basis of measurements from a human cadaveric model of the mandible using the software Creo version 2.0. The constructed model was equivalent to the real shape and size of the mandible, and an *xyz* coordinate system was assigned to the model such that the *x* direction was antero-posterior, the *y* direction was supero-inferior, and the *z* direction was medio-lateral.

The geometry data were imported into a generally accepted, and already commercially available, FEM program, ANSYS WORKBENCH 16. In our FE modeling, the anatomical specifications for the mandible were simplified by not considering the teeth. The properties of the bone were assumed to be isotropic, homogenous, and linearly elastic. The behavior of the bone was characterized by two constants (Young modulus and Poisson ratio). The average values already mentioned and approved in the literature[9] were attained. Young modulus was taken as 13 700 MPa, and Poisson ratio was 0.26.

2. Construction of finite element model of titanium plates with screws

The dimensions and specifications of the different designs of conventional titanium miniplate were entered into the software (Creo, version 2.0), and three-dimensional models of the miniplates along with the screws were created with exact geometry (Figure 1). Material properties for titanium were assigned as 110 000 MPa for Young modulus and 0.34 for Poisson ratio (strain limit-0.2%) [10]. The fracture site in the transition zone of the parasymphysis–body region was determined and different assemblies of miniplate were applied as per the clinical protocol defined by Champy. Perfect adaptation between miniplates/screws and the bone, with no slippage at their interfaces, was considered, along with the fixed contact of the miniplate with the bone, to evaluate the stresses transferred to the miniplate along the bone. The volume elements of ANSYS were meshed and elements obtained. The solid element type 10-node tetrahedron and 20-node hexahedron was chosen to model the bone segments, with three translations in the nodal *x*, *y*, and *z* directions per node (Figure 2).

3. **Occlusal loading**

A bite force of 570 N was applied over the occlusal surface of the generated model while keeping the condylar and coronoid processes fixed. Though the normal functional occlusal forces without any fracture of mandible, as well as in fractured mandible cases, are far less, the maximum occlusal force that can be possibly loaded in a mandible was taken in order to measure the biomechanical changes in the miniplates as well as the hosting bone.

With an adequate and simplified geometric finite element model and the appropriate material properties, along with the highest occlusal loading and support conditions (Figure 3), the finite element solver module of the ANSYS software carried out the mathematical procedure, and displacement and stress values for each node as well as element were obtained.

4. Finite element analysis

On application of the highest occlusal forces, the total structural deformation of the miniplates and screws, along with the bone and von Mises (VM) stresses generated, were obtained and recorded for each configuration of miniplate and screws using the computerized software. By analyzing the VM stresses predicted by the model for each configuration, and the total structural deformation of the miniplates in each configuration, we could analyze which configuration of miniplate and screws provided the greatest stability. VM stress is a value used to determine whether a given material will yield or fracture under a given load. If the VM stress is greater, the material is expected to yield or fracture. Hence, configurations with the lowest relative VM stress and the least structural deformation were likely to be the most stable.

RESULTS

1. Total structural deformation

Results indicated that the total structural deformation for the newly designed twin fork miniplate after applying maximum occlusal bite force was lowest, at 0.058 mm. This compared with 0.0684 mm for the single miniplate and a maximum static structural deformation of 0.0686 mm for the two-miniplate configuration (Figure 4).

2. Equivalent von-Mises stresses

The equivalent VM stresses generated for the various configurations are depicted in Figure 5. These were calculated to predict yielding in the fixation units (plates and screws). The results showed that the twin-fork miniplate produced the lowest stress — 23.821MPa — on occlusal loading, and had the least chance of yielding when compared with the other two miniplate configurations. The maximum stress was generated by the two-miniplate design (76.92 MPa). The VM stress value for the single miniplate was 76.23 MPa. This showed that our newly designed twin-fork miniplate, even on application of maximum forces, can provide the best stability.

DISCUSSION

As a result of dynamic biomechanics, the behavior of various patterns of stresses, and the forces generated in the transition zone of the body and parasymphysis of the mandible, there is always a dilemma for the surgeons as to whether to fix the mandibular segments with one or two miniplates. The presence of the mental nerve in this region makes it more challenging for the surgeons to fix the fracture segments without dissecting and damaging the nerve. This new miniplate is therefore designed to overcome these issues.

Evaluation of the biomechanical behavior of this new miniplate using finite element analysis revealed that this newly designed miniplate is superior in terms of stability. The structural deformation for this design of miniplate was the lowest of those studied and, further, produced the lowest equivalent VM stresses on application of maximum occlusal forces. Thus, it reduces the yielding of the fixation units under stresses, and restricts any micromovements in the fracture segments as well as in the miniplate/screws and associated bone. This more rigid fixation should lead to faster healing.

Additional advantages include preservation of the mental nerve during the plating procedure and, as a result of the broad end of the Y-shaped miniplate, atraumatic positioning of the miniplate and hence fixation of fractured segments. Although improper handling of the soft tissues may cause neurosensory disturbances, only gentle reflection of the periosteum is required in order to insert the twin-fork-shaped miniplate in the inframental foramen region.

Another mechanical advantage of this specific design is the equal distribution of the vector forces and stresses along the three arms. As a result, forces along the inner zone of the broad end of the Y shape are neutralized, with the neutral zone overlying the anatomical location of the

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mental nerve. The miniplate can also be adapted according to the exact location of the fracture line in order to achieve similar results (Figure 6).

There are two limitations of this study:

1. There are inherent limitations in the finite element model because of its geometrical simplification/idealization, material characteristic properties, and boundary conditions[11].
2. Further anatomical variations of the mandible and fracture cannot be considered in the analysis.

The interim results of this finite element analysis study are very encouraging, leading to the conclusion that the new miniplate is better in terms of stability. Further in vivo, long-term studies continue in the department, where clinical utility and outcome are being evaluated in terms of occlusion, stability of miniplate and fractured fragments, operating time, ease of use, surgical access, and, most importantly, mental nerve paresthesia.

An interesting characteristic of this miniplate is its novel design, and fixation of the fracture segments using a minimum of four screws (two on each side of the fracture segment) up to a maximum of nine screws, in a single twin-fork-shaped miniplate. The stability of this configuration is being assessed clinically. These results are not in the scope of this article, and further publications will be submitted when the clinical study is completed.

The authors recommend the use of twin-fork miniplates for fixation of transitional zone fractures of the mandible because these plates, according to FE models, produce the lowest stress values and therefore the most stable fixation.

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FURTHER STUDIES

This was a purely computerized, in-vitro study to evaluate the biomechanical behavior of a newly designed miniplate, using finite element analysis, and compare it with conventional designs. A further in-vivo study regarding its clinical use is underway, and outside the scope of this article. Hence, part two of this study will be purely on a clinical basis, and will soon be submitted after practical and clinical evaluation of this novel twin-fork-shaped miniplate.

ACKNOWLEDGEMENTS

Mechanical Engineering Department, Visvesvaraya National Institute of Technology, Nagpur, for conducting the analysis.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

FUNDING SOURCE

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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REFERENCES

1. Boole JR, Holtel M, Amoroso P, Yore M. 5196 mandible fractures among 4381 active duty army soldiers, 1980 to 1998. The Laryngoscope 2001 Oct 1;111(10):1691-6.

2. Madsen MJ, McDaniel CA, Haug RH. A biomechanical evaluation of plating techniques used for reconstructing mandibular symphysis/parasymphysis fractures. Journal of Oral and Maxillofacial Surgery. 2008 Oct 31;66(10):2012–9.

3. Wong RC, Tideman H, Kin L, Merkx MA. Biomechanics of mandibular reconstruction: a review. International Journal of Oral and Maxillofacial Surgery. 2010 Apr 30;39(4):313–9.

4. Ji B, Wang C, Liu L, Long J, Tian W, Wang H. A biomechanical analysis of titanium miniplates used for treatment of mandibular symphyseal fractures with the finite element method. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2010 Mar 31;109(3):e21–7.

5. Champy M, Lodde JP, Schmitt R, Jaeger JH, Muster D. Mandibular osteosynthesis by miniature screwed plates via a buccal approach. Journal of Maxillofacial Surgery. 1978 Dec 31;6:14–21.

6. Cawood JI. Small plate osteosynthesis of mandibular fractures. British Journal of Oral and Maxillofacial Surgery. 1985 Apr 1;23(2):77–91.

7. Wagner A, Krach W, Schicho K, Undt G, Ploder O, Ewers R. A 3-dimensional finite-element analysis investigating the biomechanical behavior of the mandible and plate osteosynthesis in cases of fractures of the condylar process. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2002 Dec 31;94(6):678–86.

ACCEPTED MANUSCRIPT

8. Lovald ST, Khraishi T, Wagner J, Baack B, Kelly J, Wood J. Comparison of plate–screw systems used in mandibular fracture reduction: finite element analysis. Journal of Biomechanical Engineering. 2006 Oct 1;128(5):654–62

9. Tanne K, Miyasaka J, Yamagata Y, Sachdeva R, Tsutsumi S, Sakuda M. Three-dimensional model of the human craniofacial skeleton: method and preliminary results using finite element analysis. Journal of Biomedical Engineering. 1988 May 1;10(3):246–52.

10. Korkmaz HH. Evaluation of different miniplates in fixation of fractured human mandible with the finite element method. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2007 Jun 30;103(6):e1–3.

11. Cook RD. Concepts and applications of finite element analysis. John Wiley & Sons; 2007.

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Figure 1: Finite element models for different configurations of titanium miniplates and screws.

Figure 2: Meshing of the generated models for various configurations.

Figure 3: General assembly of the three configurations of titanium miniplate with the host bone. The blue markings show the fixed condylar support when the occlusal forces (red area) are applied.

Figure 4: Color grid diagram showing total structural deformation for the three configurations.

Figure 5: Equivalent von Mises stress distributions along the three miniplate configurations.

Figure 6 Equalization of stress vectors along the arms of the twin-fork miniplate.

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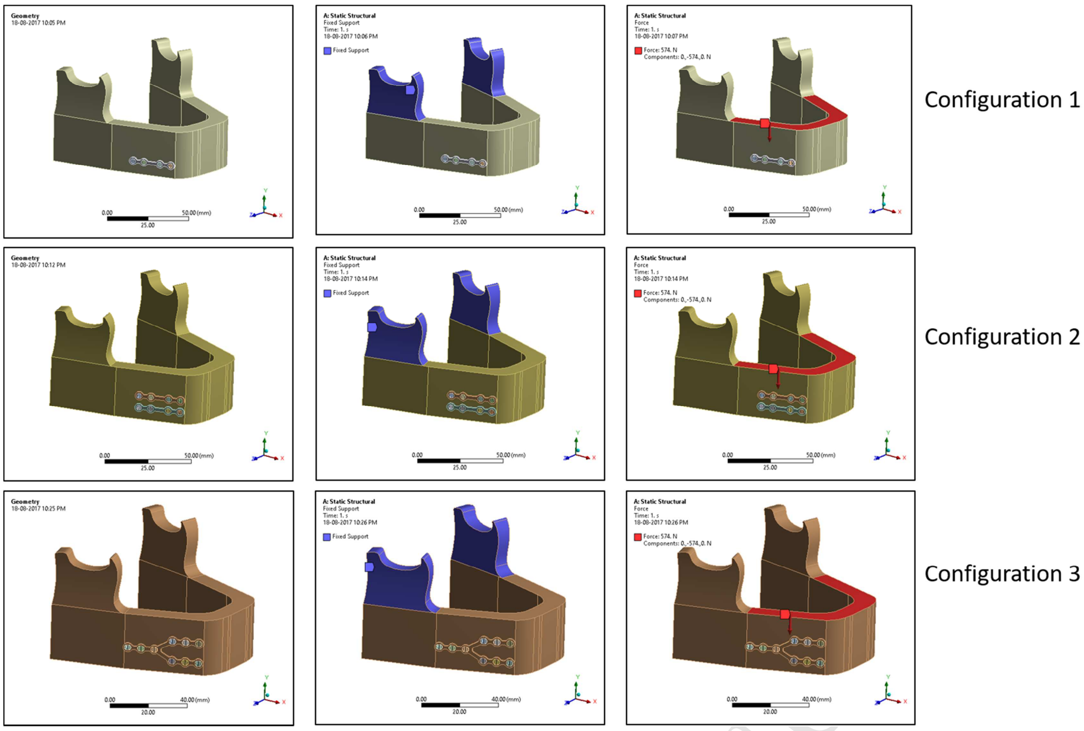

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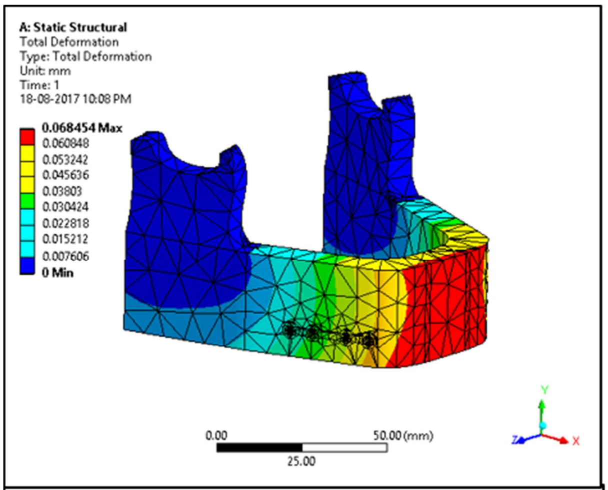

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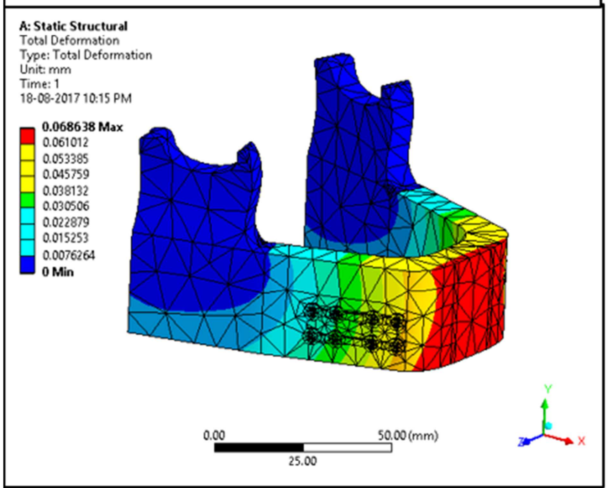

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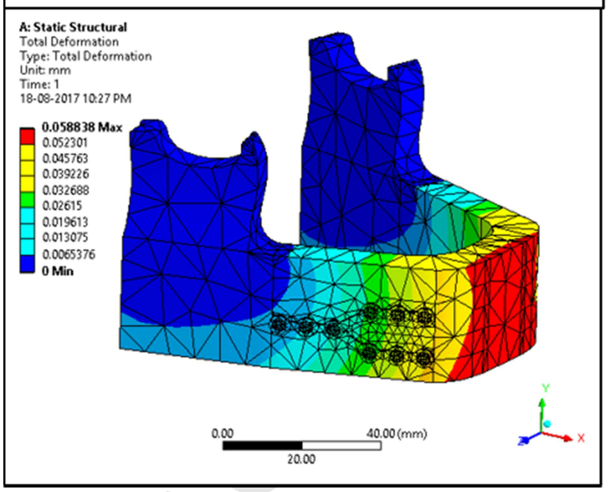

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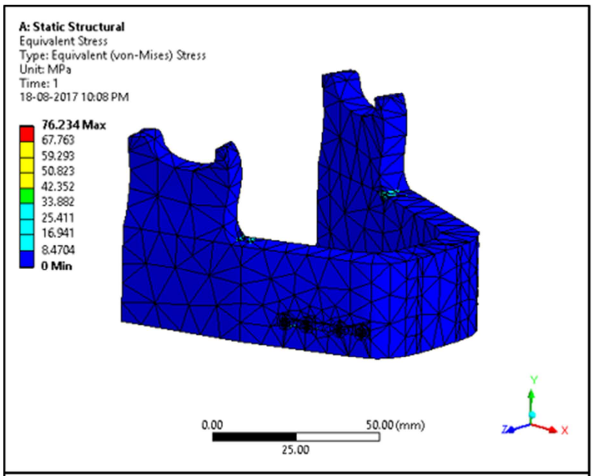

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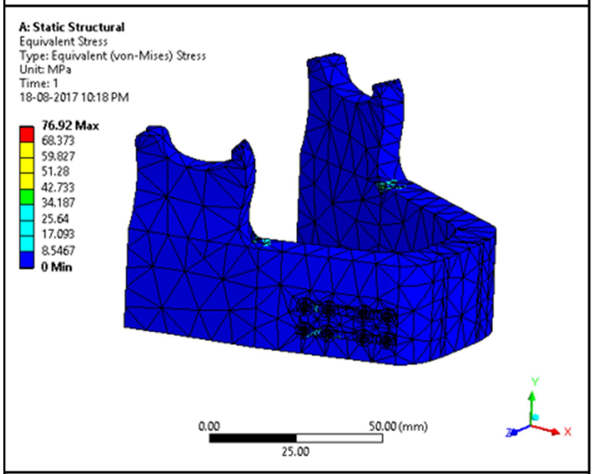

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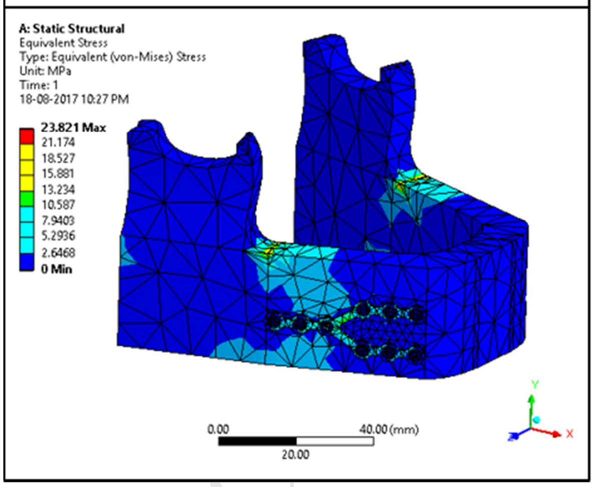

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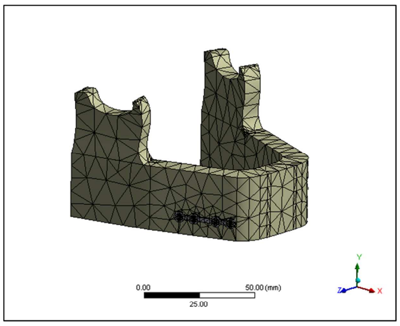

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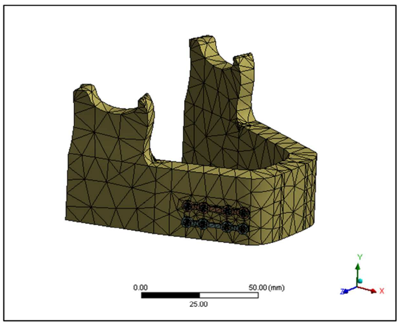

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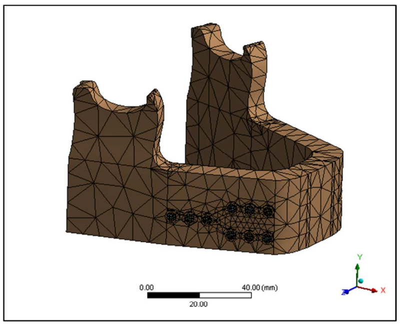

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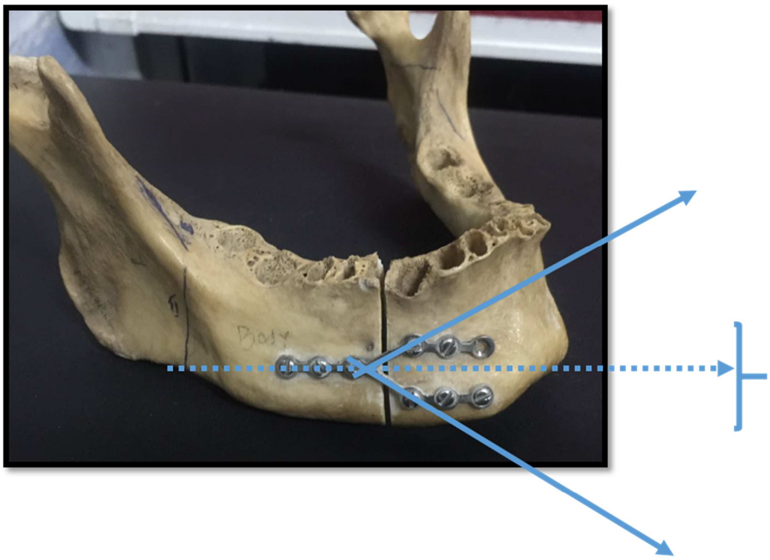

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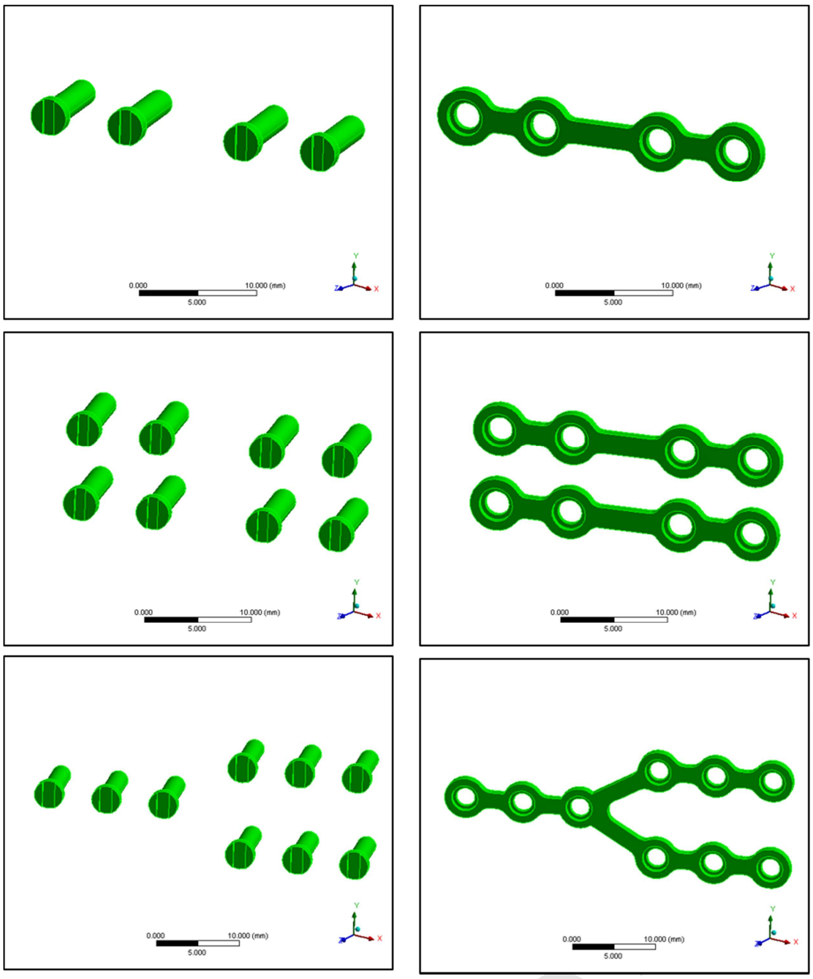

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