Original Article

Role of 1.5 mm microplates in treatment of symphyseal fracture of mandible: A stress analysis based comparative study

Syed S. Ahmed^{a,*}, Siddharth Bhardwaj^b, Md. Kalim Ansari^c, Omar Farooq^d, Abid Ali Khan^e^a Department of Oral and Maxillofacial Surgery and Diagnostic Medicines, College of Dentistry, Majmaah University, Al Zulfi, Saudi Arabia^b Division of Ergonomics, Department of Mechanical Engineering, ZH College of Engineering and Technology, Aligarh Muslim University, Aligarh, India^c Department of Oral and Maxillofacial Surgery, Dr. Z. Z. A. Dental College, Aligarh Muslim University, Aligarh, India^d Department of Electronics Engineering, ZH College of Engineering and Technology, Aligarh Muslim University, Aligarh, India^e Division of Ergonomics, Department of Mechanical Engineering, ZH College of Engineering, Aligarh Muslim University, Aligarh, India

ARTICLE INFO

Article history:

Received 6 February 2017

Accepted 9 March 2017

Available online 14 April 2017

Keywords:

Finite element model

Stress strain analysis

Rigid internal fixation

Mandibular fractures

von Mises stress

ABSTRACT

Aims and objectives: To perform comparative finite element analysis (FEA) for 2.0 mm standard miniplate and 1.5 mm microplate in isolated symphyseal mandibular fractures.**Material and method:** Two FE models of mandible were developed and symphyseal fracture was created in both of them. Each fractured model was reduced and fixed using two mini plates and two microplates, respectively according to Champ's principle. Stresses thus developed in the plates after application of masticatory load were observed in the models.**Results:** Results of the study indicated there was no significant difference in the stresses developed in either of the bone plating systems.**Conclusion:** 1.5 mm Microplates can be used in place of 2.0 mm miniplates in isolated symphyseal fractures of the mandible.

© 2017 Craniofacial Research Foundation. All rights reserved.

1. Introduction

While road traffic accidents are the commonest cause of maxillofacial injuries, mandibular fractures are the second most common fractures in this region. Its incidence accounts for about 38% with symphysis being a frequently fractured site.^{1,2} Open reduction with rigid internal fixation using 2.0 mm standard miniplate and screws is a routine method of treatment for such symphyseal fractures. There are few studies that have shown the efficacy of microplate in similar fracture condition where miniplates are currently being used.^{3–5} The use of microplate may be considered as a meaningful shift from current practice as it is less traumatic to soft tissues, causes less periosteal tissue reflection and also makes use of less implant material. Thus, it is necessary to study the efficacy of such fixture plates for mandibular fractures which has less implant material (foreign body), provides optimum rigidity, and is strong

enough to bear the masticatory load with uncompromised bone healing.

The following study compares two finite element (FE) models for 4 hole 2.0 mm mini and 4 hole 1.5 mm micro plates in case of isolated symphyseal fracture following Champy's principle. The models were compared for the induced stresses, inter-fragmentary displacements and factor of safety (FOS).

2. Material and method

2.1. Material

A point cloud of the mandible was created by scanning a stereolithographic model of a healthy human mandible by a 3D scanner (3D scanner: Roland Picza LPX60 available at IIT Roorkee). Each point cloud was later imported to SolidWorks for surfacing and generating solid 3D model for the mandible. The solid model was exported to STEP file format for working in Unigraphics NX 9.0 FEM environment for linear stress analysis. All materials are modelled as elastic and isotropic with $E = 13,700 \text{ MPa}$ and $\nu = 0.3$ for the cortical bone, and $E = 7930 \text{ MPa}$ and $\nu = 0.3$ for the cancellous bone. For simplification of the CAE model, the teeth possessed the same property of the bone and are integral part of

* Corresponding author.

E-mail addresses: drssahmed@msn.com (S.S. Ahmed), siddharth.bhardwaj@live.com (S. Bhardwaj), drmdkalimansari@gmail.com (M. K. Ansari), omarfarooq70@gmail.com (O. Farooq), abidak71@yahoo.com (A.A. Khan).

Fig. 1. Dimensions for mini (A) and micro plate (B) used in the study.

the mandible and the fracture site was straight and non-interdigitating.⁹ Two plates viz. mini and micro plate compared in the present study were modeled in SolidWorks. Fig. 1 shows the dimension for the plates.

Indigenously made miniplates, microplates and screws were in the study and were supplied by Loyal Surgicals, Mumbai and were composed of Titanium alloy (CP-Ti UNS R50400), $E = 105,000$ MPa and $\nu = 0.37$). The monocortical mini and micro screws were simulated as solid cylinders with 2 mm and 1.5 mm diameter respectively.

2.2. FE Modeling

Fracture was created at the symphysis using line splitting tool in SolidWorks. Two FE models (Model A and Model B) were developed for the comparative FEM stress analysis. Model A used two 2.0 mm mini plates at the fracture site, while Model B used two 1.5 mm micro plates (Fig. 2). In both the models the four holes plates were fixed by four 1.5 mm and 2 mm screws respectively.

During mastication process the upper denture restricts the movement of the mandible, hence mandible denture was provided fixed constrain in the model. Pin joint was provided at the mandible condyle for allowing hinging action thus simulating the mastication process. Surface contact set was provided between fractured parts of mandible, between plates and mandible, between plate and screws, and between mandible and screws.

Uniformly distributed normal loads of 167.1 N and 510.9 N were provided at the incisor and molar regions, respectively, acting from the lower side of mandible for the analysis. Tetrahedral meshing was done with maximum elemental length of 5 mm and tolerance 0.005 mm. Fig. 3 shows the model constraints and loads for Model A.

3. Observation

The displacement results from Model A and Model B are shown in Fig. 4. None of the model showed any displacement greater than safe limit of $150 \mu\text{m}$ and in no case displacement reached to maximum inter-mandibular gap. In Model A the displacement induced in the mandible was 0.0104 mm, while for Model B the displacement was 0.0128 mm.

Fig. 2. Symphyseal fracture-fixture 3D model. Model A with 2.0 mm mini plate (a) and Model B with 1.5 mm micro plates (b).

Fig. 3. FE model constraints for Model B.

For miniplates and microplates von Mises stresses have been shown in Fig. 5. In both the models, the stresses developed for the masticatory loads in mandible and plates were far below the materials' yield stress. With the use of mini plates maximum von Mises stress of 22.60 MPa was induced, while for micro plate arrangement it was 22.68 MPa. The stresses within the microplates were slightly more than the miniplate, however, they were within the safe limit. For Model A and Model B, a minimum FOS 5.36 and 3.48 were obtained respectively (Fig. 6).

4. Discussion

There is a lack of consensus on the maximum bite force in a healthy individuals, but it is in common agreement that bite forces are reduced just after trauma and progressively improve in subsequent weeks of reduction and fixation.^{6,7} Bite forces have been estimated to be different in different races and varies with body structure, food habits, and genetic background. Finite element analysis has been extensively used in past researches to perform numerical simulations and study biomechanical behavior of mandible.^{7–10} Fernandez et al. used FE modeling to study the biomechanical loads and stress distribution of a symphyseal fracture in mandible treated with miniplates using two different techniques.¹¹

Cox et al.,¹² and Tams et al.¹³ assessed the efficacy of rigid fixation using bio-resorbable bone plates and screws by FE models in treatment of mandibular fracture and evaluated if the fixture system provided adequate stiffness and strength. However, being limited to the model assumptions, these mathematical models can't be compared absolutely to clinical situation, so difference is possible. Even then the findings can be used in clinical situations. The advantages of miniplate osteosynthesis are well understood. The complications, if occur, are basically due to faulty technique i.e. incorrect internal fixation or inadequate rigidity of the osteosynthesis system.¹⁴

For proper application of fixture plates it is always necessary to determine the ideal position as well as selection of fixture plates for the placement of osteosynthesis system. In the present study the placement was done as per Champy's lines of osteosynthesis,

Fig. 4. Displacement results for mini plate Model A (a) and micro plate Model B (b).

Fig. 5. von Mises stress results for mini plate Model A (a) and micro plate Model B (b).

Fig. 6. FOS results for mini plate Model A (a) and micro plate Model B (b).

From the FEA conducted in present study, the working stresses generated in the mandible and fixture plates during mastication process were far below the materials' yield strength.

Proper stabilization and tolerance of fixation device to masticatory stresses are mandatory for proper healing. The study found the strength of microplates to have adequate strength to bear the stresses and strains developed in functional state of symphysis fractured mandible during healing phase. It has been established that bite forces are significantly reduced in early 6 weeks of post-operative week of treatment. The result from the present study has given a positive direction with the use of micro plate for symphyseal fracture, as the maximum displacement at fracture site was found less than the recommended inter-mandibular gap of 150 mm. Also, the loads transmitted through the plates didn't exceed the limit of yield strength (minimum FOS

was 35) of the material which is primary need for success of osteosynthesis system

Although the distribution of the stress may improve the rigidity of the osteosynthesis but combination of microplates was in no way jeopardizing. The results from present study are in accordance with the findings presented by Arabag et al. (2008), that length and shape of the miniplate doesn't bear any significant effect on the stability of fractured segments, however location of the plate was most important parameter for the success of fracture treatment.¹⁵

Acknowledgements

The authors are highly t o Dr. BP Singh, Sr. Scientist and Dr Sanjay Dhakate, Principal Scientist, Department of Materials Physics and Engineering, CSIR- National Physical Laboratory,

New Delhi. for performing testing the mechanical properties of micro and miniplates.

The authors are also thankful to M/S Loyal Surgicals, Mumbai for supplying microplates, miniplates, and the screws used in this study.

References

1. Krishnaraj S, Chinnasamy R. A 4-year retrospective study of mandibular fractures in a South Indian city. *J Craniofac Surg.* 2007;18:776–780.
2. Subhashraj K, Nandakumar N, Ravindran C. Review of maxillofacial injuries in Chennai, India: a study of 2748 cases. *Br J Oral Maxillofac Surg.* 2007;22:298–302.
3. Burn JS, Hansen JE. The use of microplates for internal fixation of mandibular fractures. *Plast Reconstr Surg.* 2010;125(5):1485–1492.
4. Song SW, Burn JS, Yang WY, Kang SY. Microplate fixation without maxillomandibular fixation in double mandibular fractures. *Arch Craniofac Surg.* 2014;15(2):53–58. [10.7181/acfs.2014.15.2.53](https://doi.org/10.7181/acfs.2014.15.2.53).
5. Ji B, Wang C, Liu L, Long J, Wang Tian W. A biomechanical analysis of titanium miniplates used for treatment of mandibular symphyseal fractures with the finite element method. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2010;109(3):21–27.
6. Tate GS, Ellis 3rd E3rd, Throckmorton G. Bite forces in patients treated for mandibular angle fractures: implications for fixation recommendations. *J Oral Maxillofac Surg.* 1994;52:734–736.
7. Dal Santo F, Ellis 3rd E3rd, Throckmorton GS. The effects of zygomatic complex fracture on masseteric muscle force. *J Oral Maxillofac Surg.* 1992;50:791–799.
8. Hart RT, Hennebel VV, Thongpreda N, et al. Modeling the biomechanics of the mandible: A three-dimensional finite element study. *J Biomech.* 1992;25:261.
9. Koriath TW, Versluis A. Modeling the mechanical behavior of the jaws and their related structures by finite element (FE) analysis. *Crit Rev Oral Biol Med.* 1997;8:90.
10. Voo K, Kumaresan S, Pintar FA, et al. Finite-element models of the human head. *Med Biol Eng Comput.* 1996;34:375.
11. Fernandez JR, Gallas M, Burguera M, et al. A three-dimensional numerical simulation of mandible fracture reduction with screwed miniplates. *J Biomech.* 2003;36:329.
12. Cox T, Kohn MW, Impelluso T. Computerized analysis of resorbable polymer plates and screws for the rigid fixation of mandibular angle fractures. *J Oral Maxillofac Surg.* 2003;61:481.
13. Tams J, Otten B, van Loon JP, et al. A computer study of fracture mobility and strain on biodegradable plates used for fixation of mandibular fractures. *J Oral Maxillofac Surg.* 1999;57:973.
14. Mathog RH, Toma V, Clayman Letal. Nonunion of the mandible: An analysis of contributing factors. *J Oral Maxillofac Surg.* 2000;58(746).
15. Arbag H, Korkmaz HH, Ozturk K, Uyar Y. Comparative Evaluation of Different Miniplates for Internal Fixation of Mandible Fractures Using Finite Element Analysis. *J Oral Maxillofac Surg.* 2008;66:1225–1232.