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ORIGINAL ARTICLE

An In Vitro Evaluation of a Novel Design *Z* Plate for Fixation of Mandibular Symphysis and Parasymphysis Fractures—A Finite Element Analysis

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Abstract

Aim Surgical management of mandibular symphysis and parasymphysis fractures has evolved from rigid fixation to semi-rigid fixation with miniplate osteosynthesis. Various miniplate systems have been developed in recent years including three-dimensional miniplate, microplates and bioresorbable plate, and their advantages and disadvantages have been compared and studied. To overcome the shortcomings of 3D plating system such as difficulty in adaptation and fixation in fractures involving the mental nerve, a novel *Z* plate has been designed by our institute.
Material and Methodology An in vitro study was performed to evaluate the biomechanical behaviour of the newly designed *Z* plate with 3D plate and two-miniplate system using finite element analysis.
Results Our study showed total structural deformation of 0.17 mm and 0.31 mm of newly designed *Z* plate after canine loading and molar loading, respectively. The equivalent von Mises force for plate after canine loading had shown the following results—*Z* plate showed values of 121.3 MPa and 58.40 MPa after molar loading.
Conclusion Our study concluded that the *Z* plate produces lowest stresses, lesser total structural deformation, superior stability and support in comparison with the 3D plate and two-miniplate system

Keywords Semi-rigid fixation · Finite element analysis · Mental nerve paresthesia · 3D plate · *Z* plate · Miniplate

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Introduction

Maxillofacial region is the most exposed part of the body and by far more susceptible to trauma. Worldwide, the causes are attributed to traffic accidents, interpersonal violence, falls and sports injuries [1]. Out of all the maxillofacial fractures, 42% are mandibular fractures which constitute fracture of the angle (30%) followed by parasymphysis (27%), condyle (27%), body (9%), symphyseal (4%), ramus (3%) and then the coronoid ($\leq$ 1%) [2]. Over the years due to improved understanding of biomechanics, biomaterials and scientifically based treatment outcomes, management of mandibular fractures has been subjected to various advances. Miniplates are the preferred method in the fixation of maxillofacial fractures due to their better stability and support [3]. However, due to higher complication rates and better understanding of mandibular biomechanics newer concepts and modifications have taken an impact on present treatment protocol.

The concept of three-dimensional (3D) plates was developed by Farmand and Dupoirieux [4] which was based on the principle that a quadrangular shape has a more geometrically stable configuration providing better support and stable fixation. Various studies in the literature suggest that 3D miniplate system is difficult to adapt, difficult to use in the fractures involving the mental nerve and has to be bent in three dimensions. Finite element analysis (FEA) is an in vitro, accurate and valid system used to simulate the biomechanical properties of an intact mandible and to compare it with a fractured mandible. To overcome the shortcomings of the two-miniplate system and 3D plate, a novel design of *Z* plate was designed. An in vitro study was performed to evaluate the biomechanical behaviour of the newly designed *Z* plate with 3D plate and two-miniplate system using FEA.

Materials and Methods

The analysis and effect of stress and strain on an intact mandible, fractured mandible and after fracture fixation with plates were assessed using FEA. FEA is software used to analyse any physical and structural properties of a material with the help of numerical data. The topographic and anatomical details were collected by 3D scanning of the cadaver mandible using 3D scanners. 3D models were obtained using 3D Computer-Aided Design (CAD) software. Each segment of the scanned images was saved in separate volumes, and an assembly was finally exported to Analysis System (ANSYS) product version 19.2 software. Volumes were imported from SolidWorks, the material was assigned, and boundary conditions were selected which focused on the origin of forces and the location of the body that will be fixed. Thus, a 3D model with these geometrical entities was obtained. The 3D model of the mandible was assigned XYZ coordinate system, where the *X* plane was directed in mediolateral position, *Y* plane in superoinferior position and *Z* plane in the anteroposterior position.

To prevent rigid body translation and rotation, the mandible was fixed at coronoids. Two material constants were considered, i.e. Young's modulus and Poisson's ratio, for determining linear elastic behaviour [5]. The Young's modulus in our study for human mandible was considered as 14,000 megapascal (MPa), for human tooth as 50000 MPa and for titanium as 1138000 MPa, whereas Poisson's ratio for mandible was taken as 0.3, for human tooth 0.33 and for titanium 0.31.

A single linear fracture distal to canine in transition zone on right side was made on 3D model of mandible. The 3D modelling of the miniplate, 3D plate, *Z* plate of 1 mm thickness each and monocortical screws was done by using the 3D CAD software and imported to the ANSYS software. Two loading points (canine and molar) on fractured side were considered to study the stresses and biomechanical behaviour of the mandible along with the plate. In our study, 110 Newtons bite force was applied as a point load on the canine and 600 Newtons bite on the molars [6].

In the ANSYS program, the mathematical analysis was carried out and strain and stress values were obtained. Design patent was granted for Z plate with Controller General of Patents, Designs, and Trademarks, Government of India, with design no. 327731-001, class 24-01, dated on 2 March 2020.

Results

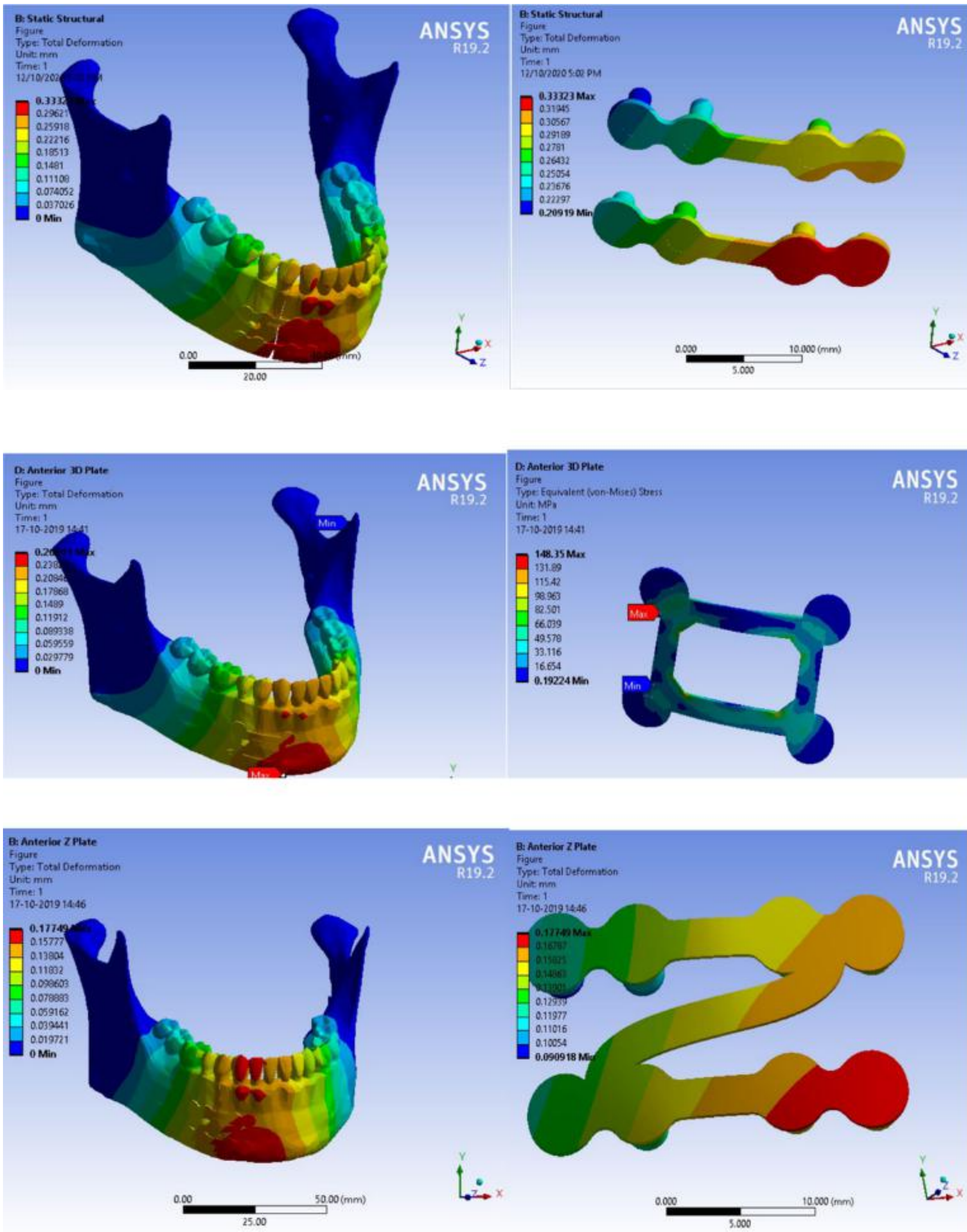
Distribution of forces when stress was applied was analysed using ANSYS software by considering the influence of masticatory forces and muscular forces. Equivalent von Mises force is a value used to determine whether a given material will yield or fracture under a given loading. Figures 1 and 2 show total deformation of mandible with plates and with three different types of plates after canine and molar loading, respectively. Figure 3 of the FEA model shows von Mises stress of three different plates after canine and molar loading. The structural deformation and equivalent stress on the left and right sides of mandible and on plates were analysed separately. Canine and molar stresses were loaded on mandible without fracture, after fracture fixation with *Z* plate, and compared with 3D plate and two-miniplate system.

Equivalent stress of 24.4 MPa and 0.17 mm total deformation was seen on mandible after canine loading (Table 1), whereas equivalent stress of 61.85 MPa and 0.27 mm total deformation was observed on mandible after molar loading (Table 2).

The total structural deformation of our newly designed *Z* plate seen after canine loading was 0.17 mm (Table 1) and 0.31 mm after molar loading (Table 2). The equivalent von Mises force for Z plate after canine loading was 121.3 MPa (Table 1) and after molar loading 58.40 MPa (Table 2).

Discussion

There has been a massive change in the protocol used in the management of mandibular fractures with many different fixation techniques in open reduction introduced in recent times. Sequentially, bone plates such as compression plates, dynamic compression plates, eccentric dynamic compression plates, miniplates, microplates and bioresorbable plates have been used. FEA is a method used for predicting the mechanical strength of materials. It is especially useful in carrying out studies on human jaws and dental implants with the results showing great compatibility with clinical situations. Gallas torrerira and



configuration 1

configuration 2

configuration 3

Fig. 1 Total deformation after canine loading in three different types of plates and their effect on fractured mandible

Fernandez [7] reported FEA to be a non-invasive and valid method for studying traumatic human mandibles as the results are comparable with actual clinical cases and provide an accurate prediction of their complex biomechanical behaviour. The risks of bone fracture and that of plates were studied based on total deformation and von Mises stress.

The concept of three-dimensional plate was developed by Farmand and Dupoirieux [4] which was based on geometrically stable configuration. Various studies are documented comparing miniplate with 3D plating system. Patiguli et al. [8] confirmed in their study that 3D miniplates are the best option in management of mandibular fractures. 3D plating system has found to use lesser foreign material, reduces operation time, cost beneficial, lower post-operative complication rates and was superior to conventional miniplate system [9–11]. Agarwal M et al. [12] carried out a randomised clinical trial and compared 3D plate with conventional miniplate system in cases with symphysis and parasymphysis fractures of mandible and found that 3D plating system was difficult to adapt in fractures involving the mental nerve.

The major disadvantages of the 3D plate were untoward damage or dissection of the mental nerve and inability to

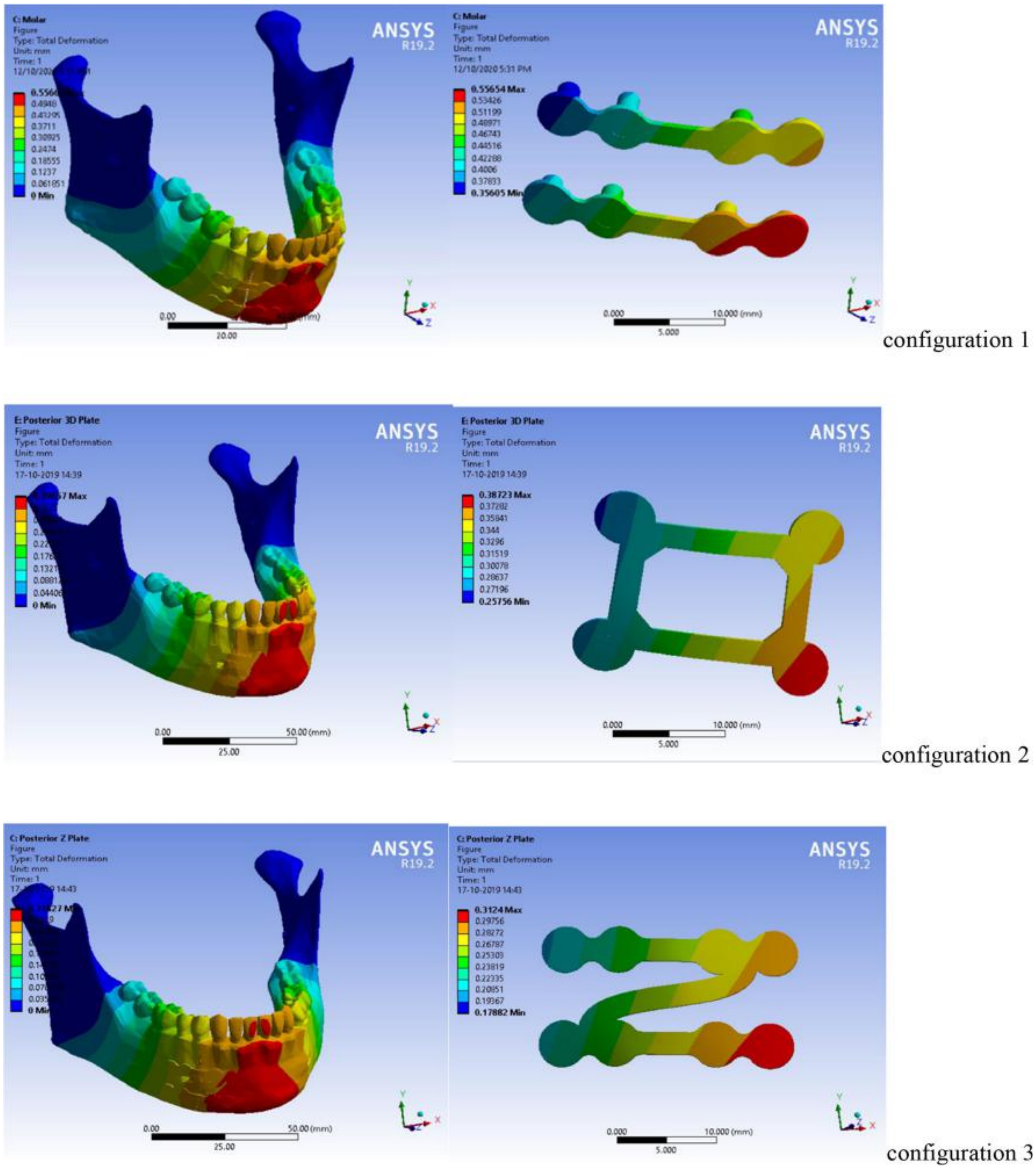


Fig. 2 Total deformation after molar loading in three different types of plates and their effect on fractured mandible

adapt in fractures involving mental foramen and of two-miniplate system were higher complication rate, lower interfragmentary stability, increased hardware failure and higher incidence of malocclusion [8]. The above mentioned disadvantages thus justifies the need to create a novel design. The Z Plate (Fig. 4) provides cross-stabilization and stress distribution between two horizontal bars. De Jesus et al. [13] observed higher complication over bone due to high loading forces and tension on screws when only one screw was used on each side of the fracture. Thus, our plate was designed on the concept of Niederdellman and Schilli [14] in providing at least two screws on either side of fracture segment to prevent rotational movement of the fragments. In our Z plate design, the screw hole diameter was 2 mm and intra-screw hole distance of 5.40 mm was considered. The oblique bar was intended to connect two horizontal bars which maintains 5 mm equal and adequate distance at any point. It provides better stability and leads to faster adaptation of plate. Although additional oblique bar increased the material hardware, it aids in better strength and cross-stabilization. The open ends of the plate are designed in such a manner that it allows the plate to be

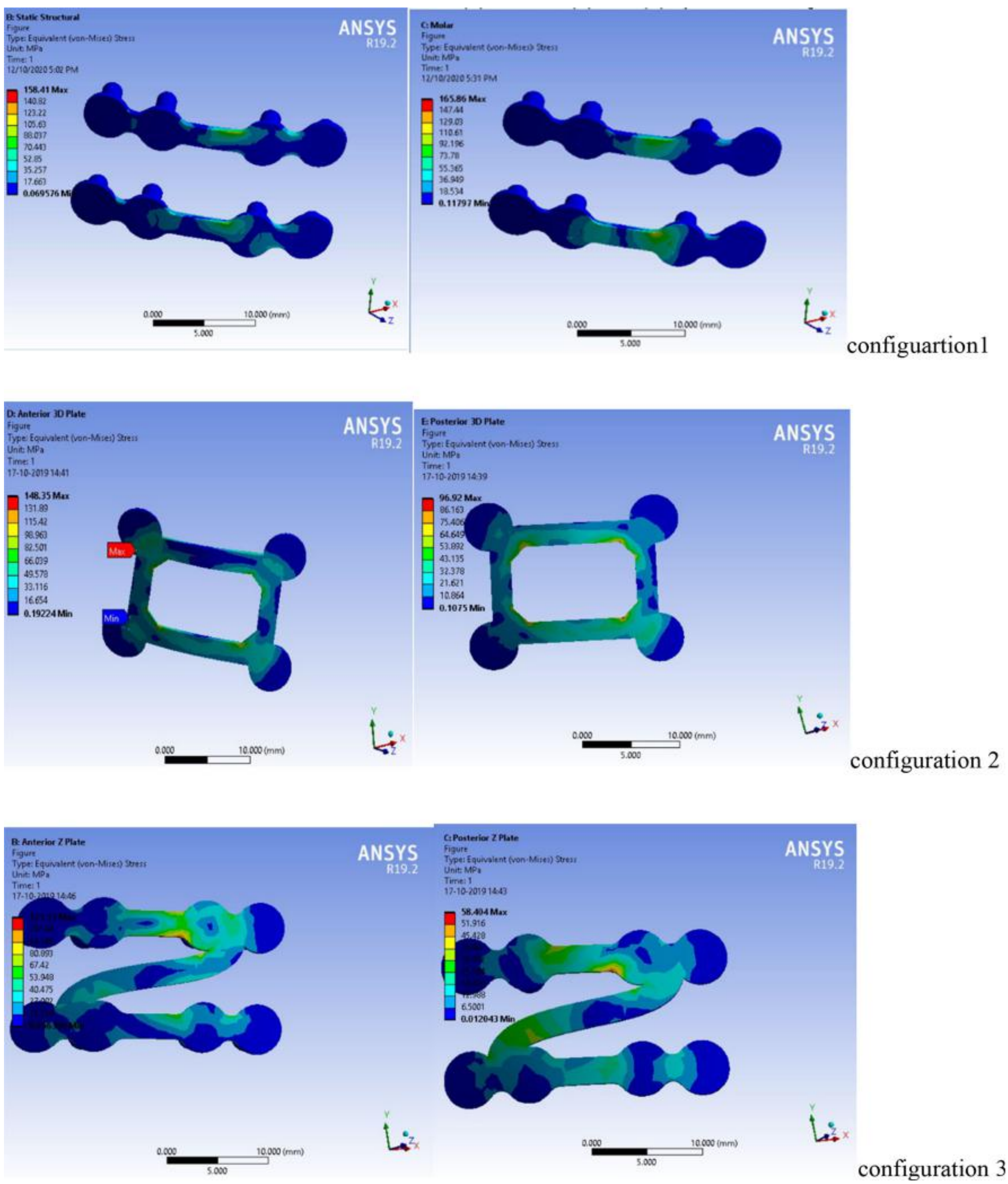


Fig. 3 Von Mises forces on three different plates after canine and molar loading, respectively

positioned atraumatically near fracture segments involving mental nerve. Neurosensory disturbances following mandibular fracture are well-known entity. A study done by Behnaz et al. [15] in 2016 showed 39.1% ($n = 194$) frequency of inferior alveolar nerve injuries. Qinyong et al.'s [16] study concluded that post-operative neurosensory examination exhibited delayed neurological recovery in 12%($n = 173$) of cases with fractures located distal to mental nerve and 15% ($n = 123$) of cases with fractures between lingula and mental foramen. Studies have shown multiple factors such as fractures near or involving mental foramen, improper soft tissue handling, fixation of the miniplate close to or over the mental foramen have led to neurosensory disturbances.

Based on the studies of Tams et al. [17], perpendicular plates failed to resist bending movements and torsional forces occurring in the parasymphyseal region of the mandible. Our plate successfully overcomes this drawback as it resists these biomechanical movements. Krishna et al. [18] compared the double-micro-plating system for both

Table 1 Results of structural deformation and equivalent stresses on mandible with 3D plate and *Z* plate after canine loading

Canine	Left mandible		Right mandible		Plate		Mandible	
	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)
Without fracture	–	–	–	–	–	–	24.40 MPa	0.1654 mm
Two-miniplate system	28.29 MPa	0.3188 mm	56.794 MPa	0.3296 mm	158.41 MPa	0.33 mm	–	–
3D plate	30.20 MPa	0.2616 mm	50.15 MPa	0.2386 mm	148.3 MPa	0.2680 mm	–	–
Z plate	37.67 MPa	0.173 mm	26.08 MPa	0.159 mm	121.3 MPa	0.177 mm	–	–

Table 2 Results of structural deformation and equivalent stresses on mandible with 3D plate and *Z* plate after molar loading

Molar	Left mandible		Right mandible		Plate		Mandible	
	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (mpa—megapascals)	Total deformation (mm—millimetre)	Equivalent stress (MPa—megapascals)	Total deformation (mm—millimetre)
Without fracture	61.85 MPa	0.2729 mm	–	–	–	–	61.85 MPa	0.2729 mm
Two-miniplate system	82.34 MPa	0.5566 mm	103.62 MPa	0.5103 mm	165.86 MPa	0.55 mm	–	–
3D plate	127.8 MPa	0.3965 mm	82.98 MPa	0.3405 mm	96.92 MPa	0.3872 mm	–	–
Z plate	70.75 MPa	0.3182 mm	76.28 MPa	0.2729 mm	58.40 MPa	0.3124 mm	–	–

Fig. 4 *Z* plate design

conventional and locking plating systems and single-plating system and concluded that double-plating system was subjected to less stress than single-plating system.

The total structural deformation after canine and molar loading was observed to be less with *Z* plate when compared with 3D plate and miniplate. The equivalent von Mises force for plate after canine and molar loading had shown 3D plate and two-miniplate yielding to fracture formerly in comparison with *Z* plate under the same load and stress. After performing the structural analysis, we have found that the stress on the fractured mandible is lowest with *Z* plate than 3D plate and two-miniplate system, which suggests fractured mandible is not the one taking the maximum load. Major load is passing from *Z* plate to unfractured side. Comparing the stress values between the plates, *Z* plate has found to have least stress value, meaning *Z* plate will have better life compared to 3D plate and two-miniplate under identical loading conditions. Unlike canine loading, loading in molars is planer symmetric, that is, loads as well as supports are equal on both sides of the mandible. Since *Z* plate has lowest stress levels as compared to the other two, it is proven to be a better design.

Based on result of our study, we can positively state that the new miniplate is better in terms of stability and strength, provides a much more rigid fixation that resists micromovements and reduces the yielding. However, there are few limitations that can be encountered during plate fixation in comminuted or oblique fractures and fractures involving micrognathic mandible. Further long-term in vivo studies are required to determine clinical utility in terms of occlusion, the stability of miniplate, fractured fragments, operating time, ease of use, surgical access and mental nerve paresthesia which are ongoing in our department.

Conclusion

The mandible is a robust bone which is frequently subjected to occlusal and muscular forces. Many complications can arise during fracture fixation out of which mental nerve paresthesia is frequently seen. An in vitro study of a novel design *Z* plate was performed using computerized finite element analysis, and comparison was then made with a 3D plate and two- miniplate. After applying occlusal bite force, our result has shown the lowest stresses and least total structural deformation with *Z* plate compared to other plates. This study concludes that the newly designed *Z* plate is superior in terms of stability, strength and stress distribution.

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Declarations

Conflict of interest Design patent was registered with Controller General of Patents, Designs, and Trademarks, Government of India, with design no. 327731–001, class 24–01, dated on 2 March 2020. Local dealer (Orthomax Company) will be helping us with the manufacture of titanium (Grade-4) *Z* plates.

References

1. Srinivasan B, Balakrishna R, Sudarshan H, Veena GC, Prabhakar S (2019) Retrospective analysis of 162 mandibular fractures: an institutional experience. Ann Maxillofac Surg 9(1):124
2. Rashid A, Eyeson J, Haider D, van Gijn D, Fan K (2013) Incidence and patterns of mandibular fractures during a 5-year period in a London teaching hospital. Br J Oral Maxillofac Surg 51(8):794–798
3. Kushner GM, Alpert B (1998) Open reduction and internal fixation of acute mandibular fractures in adults. Facial Plast Surg 14(01):11–21
4. Farmand M (1993) The 3-D plating system in maxillofacial surgery. J Oral Maxillofac Surg 51(3):166–167
5. Korioth TW, Versluis A (1997) Modeling the mechanical behavior of the jaws and their related structures by finite element (FE) analysis. Crit Rev Oral Biol Med 8(1):90–104
6. Bakke M (2006) Bite force and occlusion. Sem Orthod 12(2):120–126
7. Torreira MG, Fernandez JR (2004) A three-dimensional computer model of the human mandible in two simulated standard trauma situations. J Cranio-Maxillofac Surg 32(5):303–307
8. Wusiman P, Taxifulati D, Weidong L, Moming A (2019) Three-dimensional versus standard miniplate, lag screws versus miniplates, locking plate versus non-locking miniplates: Management of mandibular fractures, a systematic review and meta-analysis. J Dent Sci 14(1):66–80
9. Malhotra K, Sharma A, Giraddi G, Shahi AK (2012) Versatility of titanium 3D plate in comparison with conventional titanium miniplate fixation for the management of mandibular fracture. J Maxillofac Oral Surg 11(3):284–290
10. Al-Moraissi EA, El-Sharkawy TM, El-Ghareeb TI, Chrcanovic BR (2014) Three-dimensional versus standard miniplate fixation in the management of mandibular angle fractures: a systematic review and meta-analysis. Int J Oral Maxillofac Surg 43(6):708–716
11. Wusiman P, Yarbag A, Wurouzi G, Mijiti A, Moming A (2016) Three dimensional versus standard miniplate fixation in management of mandibular fractures: a systematic review and meta-analysis. J Cranio-Maxillofac Surg 44(10):1646–1654
12. Agarwal M, Meena B, Gupta DK, Tiwari AD, Jakhar SK (2014) A prospective randomized clinical trial comparing 3D and standard miniplates in treatment of mandibular symphysis and parasymphysis fractures. J Maxillofac Oral Surg 13(2):79–83
13. De Jesus GP, Vaz LG, Gabrielli MF, Passeri LA, Oliveira TV, Noritomi PY, Jürgens P (2014) Finite element evaluation of three methods of stable fixation of condyle base fractures. Int J Oral Maxillofac Surg 43(10):1251–1256
14. Niederdellmann H, Akuamoa-Boateng E (1978) Internal fixation of fractures. Int J Oral Surg 7(4):252–255
15. Poorian B, Bemanali M, Chavoshinejad M (2016) Evaluation of sensorimotor nerve damage in patients with maxillofacial trauma; a single center experience. Bull Emerg Trauma 4(2):88
16. Song Q, Li S, Patil PM (2014) Inferior alveolar and mental nerve injuries associated with open reduction and internal fixation of mandibular fractures: a seven year retrospective study. J Cranio-Maxillofac Surg 42(7):1378–1381
17. Tams J, Van Loon JP, Rozema FR, Otten E, Bos PR (1996) A three-dimensional study of loads across the fracture for different fracture sites of the mandible. Br J Oral Maxillofac Surg 34(5):400–405
18. Krishna LS, Anand BK, Rajan R, Bindu TH, Reddy PR. Finite element analysis of a fractured mandible fixed with microplates