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Comparison of Conventional Single Titanium Miniplate with Modified Y Titanium Miniplate Osteosynthesis for Mandibular Angle Fractures – A Finite Element Analysis

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Abstract

Aim: To compare the efficacy of conventional single titanium miniplate versus modified Y titanium miniplate created according to Champy's lines of osteosynthesis for mandibular angle fractures by finite element analysis.

Materials and methods: Finite element models were constructed using MIMICS software after importing it from the CT of a human skull and then unfavourable fracture of the mandibular angle was created. The geometric models for the conventional titanium straight plate (Control model) and 2x6 mm titanium screws were generated by reverse engineering using Solid Edge® 2004. The modified Y titanium plates (Study models) of three angulations (10, 20, 30 degrees) were designed using ANSYS 15.0 software. The finite element analysis was carried out and the amount of displacement between the fractures fragments were measured between the control and the study models.

Results: The modified Y titanium miniplate (Study) had significantly less displacement in the superoinferior (Y axis) and the mediolateral direction (Z axis) when compared to the conventional single titanium straight miniplate (Control).

Conclusion: The Modified Y titanium miniplate showed better stability and minimal displacement when compared to the conventional straight plate in the treatment of mandibular angle fractures.

Keywords: Angle, Fracture, Miniplate, FEM, Modified Y miniplate.

Introduction

Mandible is one of the most frequently fractured bone in the maxillofacial region.[1] The fracture of the mandibular angle is the most frequently encountered fracture with an incidence of 30%.[2] The most common causes of maxillofacial injuries are road traffic accidents followed by fall, interpersonal violence, sports injury, work related accidents, pathology, rarely animal bites and ballistic injuries. Males are most commonly affected than females.[1]Ellis described the mandibular angle fracture as the line that begins at the ramus from the anterior border and runs either anteriorly then inferiorly towards the body of the mandible or posteriorly then inferiorly towards the gonial angle.[3]The treatment options for mandibular angle fracture includes indirect skeletal fixation following closed reduction or direct skeletal fixation following open reduction.[4] Various types of internal fixation includes single miniplate on the upper border, double miniplates one on the upper border and one on the lower border, 3 D miniplate, lag-screw fixation and bio resorbable plates.[3,4,5,6.]Although various treatment modalities exist, use of a single miniplate along the upper border is the commonly used method of treatment of angle fracture. However, single miniplate along the upper border is also related with complications as much as 17% due to its complex bio-dynamic environment.[5] These complications include infection, pain, swelling, wound dehiscence and plate exposure. [5] As described previously, use of single miniplate in the mandibular angle causes various post-operative complications like delayed union, infections, wound dehiscence, etc. To overcome these problems, we designed a new plate according to the Champy's line of osteosynthesis for better stability.

There is no literature so far, which describes the use of modified Y plate in isolated mandibular angle fractures. In this study FEA is used to analyse the amount of displacement occurring in the mandibular angle fracture region after fixation.

This study hypothesizes the usefulness of modified Y titanium miniplate that has been designed according to Champy's lines of osteosynthesis for mandibular angle fracture and aims at evaluating its utility using Finite Element Analysis.

Materials and methods

The approval for the study was obtained from the Institutional Review Board. SRMDC/IRB/2016/MDS/ No.407.The study was conducted in Central Institute of Polymer Engineering & Technology (CIPET).

The FEM study was performed in three stages.[7] **Figure 1**

Pre-processing stage (6 steps)

Processing stage (2 steps)

Post- processing and interpretation (1 step)

The study was done as following:-

Pre Processing Stage (Steps - 1 To 6)

Step – 1: Computerized tomography of human skull/head of 0.5 mm thickness was obtained from a 22-year-old male. The data was stored as "Digital Imaging and Communications in Medicine (DICOM)" files.

Step – 2: The CT data was introduced into the CAD based medical software "Mimics 17.0, Materialise®, Belgium" and the teeth and bone were separated in coronal/frontal, axial and sagittal/median planes sections by sections.Using the MIMICS® software, the DICOM format of the CT data was converted into STL files, which is the suitable format required for importing into FEA software (ANSYS® 15.0).

Step – 3: The model which was saved as STL (Stereo Lithographic) files were introduced into the Polyworks® 12.0 software to create surface models. A unilateral unfavourable fracture line was created, on the right side, distal to 2nd molar on the designed model.

Step – 4: Apart from the models of maxilla & mandible, the geometric models of plates and screws were generated using Solid Edge® 2004 by reverse engineering technique. **Figure 2**

Step – 5: The surface model was converted into solid model and assembly of the final model was done using CATIA® V5. A total number of four models were generated for final analysis in our study. The conventional straight plate model was taken as control model and the modified Y miniplate models (10, 20, 30 degree) were taken as study models. **Figure 3, Figure 4, Figure 5, Figure 6**

Step – 6: The geometric models (surface and line data) were then imported into Hypermesh® (Version 11.0 Altair, USA) software for deriving the number of nodes and elements of the object. A FEA model consists of elements which are connected to each other by nodes.

The volumes created for cortical bone, cancellous bone, dentin, periodontal ligament, 2mm titanium four holed miniplate, Modified Y with 10, 20 and 30 degree plates and 2×6 mm titanium screws were meshed using tetrahedral shaped solid elements. **Table 1**

Processing Stage: (STEPS-7 & 8)

Step -7: Three-dimensional meshed model was then exported into Ansys®15.0 software for analysis. Elastic material properties used in the Finite Element Model were calculated as "Young's modulus & Poisson's ratio".Each material was defined as homogenous and isotropic. The physical properties of the constituent material comprising the model were based on previous studies. These material properties were assigned to the titanium miniplate, titanium screw, cortical bone, cancellous bone, dentin and periodontal ligament in this processing stage.[8,9] **Table 2**

Step – 8: The loads and boundary conditions are applied in the processing stage

Boundary Conditions

The temporal bone & maxilla were restrained from movement in all directions during mastication and were fixed to zero displacement.

Applied Muscle Loads

The functional loads of masseter **Figure 7**, temporalis **Figure 8** and medial pterygoid **Figure 9** muscles were applied.[10] **Table 3**

Applied Occlusal Loads

The occlusal loads of teeth were applied which is 300N.[11] **Figure 10**

Post Processing Stage

Step – 09: The results were processed; the displacement of each individual part in the system were captured.

Evaluation of Displacement

The amount of displacement across the fracture line was measured in 'mm' for the following 3 regions in 3 planes:- (Fig-17)

Displacement along the superior border **Figure 11**

Displacement along the inferior border **Figure 11**

Lingual splay **Figure 12**

The three planes /directions are following

X–Anteroposterior plane (The anterior displacement is denoted by a positive value and the posterior displacement is denoted by a negative value).

Y–Superoinferior plane (The superior displacement is denoted by a positive value and the inferior displacement is denoted by a negative value).

Z–Transverse plane (The medial displacement is denoted by a positive value and the lateral displacement is denoted by a negative value).

Results Table 4, Table 5, Table 6

Inferior border displacement is same i.e 0.048 mm in 10 and 20 degree plates and 0.049 mm in case of 30 degree plate and the displacement is slightly more i.e 0.050 mm in control group.

The displacement along the superior border is same in 20 and 30 degree plate and control group i.e 0.039 mm and it is slightly reduced in case of 10 degree plate i.e 0.038 mm.

The lingual splay is same i.e 0.048 mm in 20 and 30 degree plate and control group and it is slightly reduced i.e 0.047 mm in case of 10 degree plate.

The inferior border separation along y axis is minimal i.e 0.052 mm in case of 10 degree plate when compared to 20 and 30 degree plate which has a displacement of 0.053 mm and 0.054 mm respectively and is the highest in case of control group i.e 0.058 mm.

The superior border separation along y axis is lowest in case of 10 degree and 20 degree plates i.e 0.043 mm each when compared to 30 degree plate which has a displacement of 0.044 mm. The displacement is the highest in case of control group 0.047mm.

The lingual splay is low in case of 10 degree plate i.e 0.051 mm when compared to 20 and 30 degree plate which has a displacement of 0.052 mm and 0.053 mm respectively and the displacement is the highest in case of control group i.e 0.058 mm.

The inferior border separation along z axis is minimal i.e 0.010 mm in case of 10 degree plate whereas it is slightly higher in 20 and 30 degree plates i.e 0.011 mm and 0.012 mm respectively and is the highest in case of control group i.e 0.024 mm.

The superior border separation along z axis is lowest in case of 10 degree plate i.e 0.031 mm and is slightly higher in case of 20 degree and 30 degree plate i.e 0.032 mm each and is the highest in case of control group 0.035mm.

The lingual splay is same in case of 10, 20 and 30 degree plates i.e 0.099 mm whereas it is slightly increased in case of control group i.e 0.100 mm.

Discussion

Maxillofacial fractures accounts for the most common type of fractures due to its exposure than its other counterparts. The mandible is the most commonly fractured bone among the facial bones which is succeeded by the fracture of nasal bones and the zygoma.[1] In the mandible the angle is the most commonly fractured location (30%) followed by condyle (23%), symphysis (22%), body (18%), ramus (2%), and coronoid process (1%).[2]

The angle region is more prone for fracture because of a variety of factors. The factors include

Change of grain pattern in the bone from horizontal to vertical.[4]

Presence of impacted mandibular third molar which would reduce the bone stock.[4]

Dynamic action of the medial pterygoid muscle and the masseter.[4]

Presence of maximum tensile strain in the second and the third molar region along the inner surface of the mandible.[4]

The diagnostic modalities used in the detection of angle fracture includes OPG, PA skull view, lateral oblique view of mandible and Computed tomographic scans.[12]

A fracture at the angle prevents the elevator muscles that are attached in the ascending ramus from having any direct effect on the remainder of the mandible.[4]

Therefore, there is a tendency for the proximal fragment to ride superiorly, medially and anteriorly since the action of the medial pterygoid is medial i.e. at about 30° to the vertical axis. [4] Clinical studies indicate that the displacement occurs at the time of injury due to the stretch reflex that occurs in the pterygo-massetric sling by the traumatizing force. [4] Thus, the posterior fragment is held in the displaced position by the stretch reflex imposed upon the muscles by pain whereas the distal fragment is displaced anteriorly in the contra-lateral direction.[4]

Angle fractures can be classified as favourable and unfavourable based on the muscle pull and fracture line in two planes i.e. a horizontal plane and a vertical plane.[13]

In a horizontally or a vertically favourable fracture when viewed in their respective planes the fracture line is in such a way that the proximal fragment and the distal fragment are splinted by the action of the masseter, the medial pterygoid and the temporalis muscle which are attached to the ascending ramus.[13]

Conversely In a horizontally or a vertically unfavourable fracture when viewed in their respective planes the fracture line is in such a way that the proximal fragment is displaced further away from the distal fragment due to the action of the masseter, the medial pterygoid and the temporalis muscle which are attached to the ascending ramus.[13]

In a horizontally favourable fracture of the mandibular angle the fracture line extends from the upper border propagates forwards and downwards to the lower border whereas in a horizontally unfavourable fracture the fracture line extends from the upper border and propagates downwards and backwards to the lower border.[4]

In an angle fracture of the mandible which is vertically favourable the fracture line propagates from the buccal surface/side anteriorly and rearward through the lingual surface/side posteriorly whereas in a vertically unfavourable fracture the fracture line propagates from the lingual cortical plate anteriorly and backwards through the buccal cortical plate posteriorly.[4]

The clinical features may include pain, swelling in the angle region, tenderness along the inferior border, difficulty and pain during mouth opening, deviation of the mandible towards affected side during mouth opening, ecchymosis in the buccal vestibule, step deformity behind the third molar region, inter fragmentary mobility, paraesthesia or hypoesthesia along the distribution of the inferior dental nerve and deranged occlusion.[6]

The treatment options for mandibular angle fracture includes indirect skeletal fixation following closed reduction or direct skeletal fixation following open reduction.[4]

The various methods used for indirect skeletal fixation following closed reduction includes wiring methods like indirect or direct interdental wiring or multiple (continuous) loop wiring, usage of arch bars, usage of splints like gunning splints or cap splints and fixation using external pins.[4]

The various methods used for direct skeletal fixation following open reduction includes fixation using plates and screws, fixation using bone clamps, fixation using bone screws or staples, non-rigid fixation using direct wiring of the fragments, usage of mesh (Titanium), intramedullary pinning and circumferential straps.[4]

Plates and screws are the most commonly used method of internal fixation following open reduction there are a variety of plates that can be used in case of fixation of an angle fracture following open reduction.

The various options include, single straight miniplate at the upper border, double straight miniplates one along the upper border and one along the lower border, 3D miniplate, compression plating (eccentric dynamic /dynamic) along the inferior border, inferior border plating using rigid reconstruction plate and the use of bioresorbable plates.[3]

The ideal line of osteosynthesis for the mandible was given by Champy and colleagues in the year 1976. They performed several experiments to find the ideal line of osteosynthesis for mandibular fractures and came up with the following conclusions, in the anterior region between the two mental foramina the line of tension lies immediately below the root apices and the line of compression lie near the inferior border. In the body the line of tension lies immediately below the tooth apices. In the angle there are two lines of tension one along the external oblique ridge and one below the external oblique ridge on the lateral surface which runs anteriorly towards the ramus.[14]

Seeman et al did an extensive review of 335 cases in the management of mandibular angle fracture and found that the rates of complications were similar when comparing single miniplate and double miniplate fixation.[15] In contrast the study of E. Ellis et al where he compared different osteosynthesis technique for the management of fracture of the angle of the mandible single miniplate osteosynthesis showed lesser complications when compared to the double miniplate osteosynthesis.[3] Though the single miniplate is found to be effective in the management of fracture of the mandibular angle when compared to its counterparts it is also associated with a series of complications like infection of the implant, wound dehiscence, mal-union, delayed union or non-union, fibrous union, and malocclusion.[3] Intermaxillary fixation following single miniplate fixation was employed by many centers to prevent the complications as the miniplate is considered as a semi-rigid fixation.[16] So, to minimize the complications following the traditional single plate osteosynthesis a need for a new plating system is required which is going to be effective in its function in terms of reducing the displacement among the fractured fragments and also in resisting the dynamic forces of the muscles acting on the angle region.

Therefore a newer plating system was designed which is nothing but the modified Y titanium miniplate which has three different configurations (10, 20 and 30 degree) and its efficacy was compared in-vitro with the conventional straight plate by using the technique of finite element analysis.

There are several bio mechanical methods of evaluating the fixation methods following the reduction of mandibular angle fracture in vitro. The Biomechanical models can be broadly classified into two types which are Virtual and Biomechanical. It can be further sub classified as.[11]

1.Virtual

Virtual model e.g. CT models.

Computational model e.g. Finite element model.

a. Static

b. Dynamic

2. Biomechanical

3. D printed models

Cadaveric models of human bone

Models of animal bone

Models of bone substitutes

This study highlights on the usage of Finite element in comparing the amount of displacement in three planes among the fractured segments using a novel plating system i.e. modified titanium Y plate of three different angulations (10, 20 and 30 degrees) with conventional straight mini plate in the treatment of mandibular angle fracture.

Julie kimsal did a study in which they compared three types of plating methods and found out that the method in which they did double plating had minimal von mises stress in the plates and screws when compared to upper border plating using a single plate and lower border plating using a single plate.[17]

Feller et al did a Finite element analysis in case of management of trauma to the angle in combination with a clinical study including 277 cases and found that the single miniplate was superior in management of the trauma to the angle of the mandible.[18]

Yun feng liu compared conventional plating system i.e. single miniplate and double miniplate with a customised plate which they designed and found out that the amount of strain, displacement and stress was less when compared to the conventional plating techniques.[19]

In our study we compared conventional single miniplate along with modified Y titanium miniplate of three different configurations i.e.(10, 20, 30 degree), we found that the newly designed miniplate was more efficient in preventing the displacement among the fractured fragments. In particular the 10 degree variant of the modified Y titanium miniplate was much superior to the 20 and the 30 degree variant.

Conclusion

This invitro study implies that the model of modified Y mini plate of three configurations were superior in the aspect of limiting the displacement in the upper and the lower border and also in preventing the splaying of the fragments in the lingual surface when compared to the conventional plating of single miniplate along the superior border in the management of mandibular angle fracture. Further the 10-degree variation of the modified Y miniplate was more effective when compared to their counterparts. Further clinical trials are required to comment more on its efficacy in limiting the complications in mandibular angle fracture.

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Legends Table and Figure

Table 1: Nodes and elements derived from the models

Number Of Models	No. Of Elements	No. Of Nodes
MODEL NO 1 - Straight plate	59654	18006
MODEL NO 2 - Modified Y plate 10 Degrees	90746	26371
MODEL NO 3 - Modified Y plate 20 Degrees	90373	26281
MODEL NO 4 - Modified Y plate 30 Degrees	90800	26432

Table 2: Material properties

Object Properties	Elastic Modulus(Mpa)	Poissons's Ratio (In %)
Cortical bone	13700	0.33
Cancellous bone	1370	0.33
Teeth	20300	0.26
PDL	0.666	0.49
Plates and Screw	105000	0.34

Table 3 - Applied muscle forces

Muscles	Force (N)
Masseter	17.91
Temporalis	3.58
Medial Pterygoid	3.00

Table 4 - Comparison of displacement along X axis (anteroposterior) among the study and the control groups

Parameter		Study			Control
		10^o Plate	20^o Plate	30^o Plate	Conventional Plate
Displacement on application of masticatory force	Inferior border separation	0.048	0.048	0.049	0.050
	Superior border separation	0.038	0.039	0.039	0.039
	Lingual splay	0.047	0.048	0.048	0.048

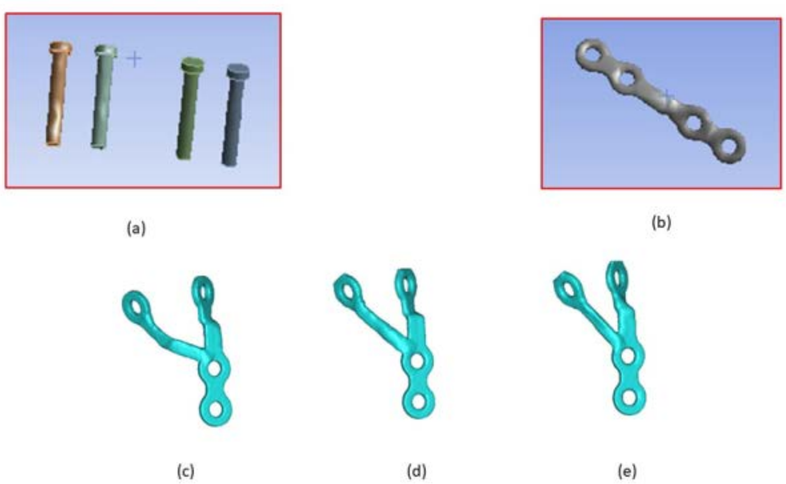
Table 5 - Comparison of displacement along Y axis (superoinferior) among the study and the control groups

Parameter		**Study**			**Control**
		10º Plate	**20º Plate**	**30º Plate**	**Conventional Plate**
Displacement on application of masticatory force	Inferior border separation	0.052	0.053	0.054	0.058
	Superior border separation	0.043	0.043	0.044	0.047
	Lingual splay	0.051	0.052	0.053	0.058

Table 6 - Comparison of displacement along Z axis (transverse) among the study and the control groups.

Parameter		**Study**			**Control**
		10º Plate	**20º Plate**	**30º Plate**	**Conventional Plate**
Displacement on application of masticatory force	Inferior border separation	0.010	0.011	0.012	0.024
	Superior border separation	0.031	0.032	0.032	0.035
	Lingual splay	0.099	0.099	0.099	0.100

Figures



a) Screws
b) Straight plate
c) Y Plate of 10 degree angulation
d) Y Plate of 20 degree angulation
e) Y Plate of 30 degree angulation

Figure 2

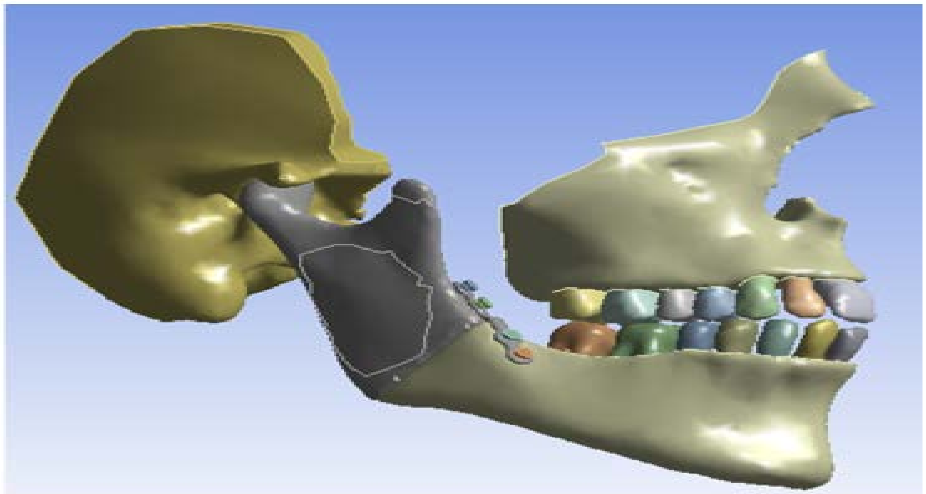


Figure 3

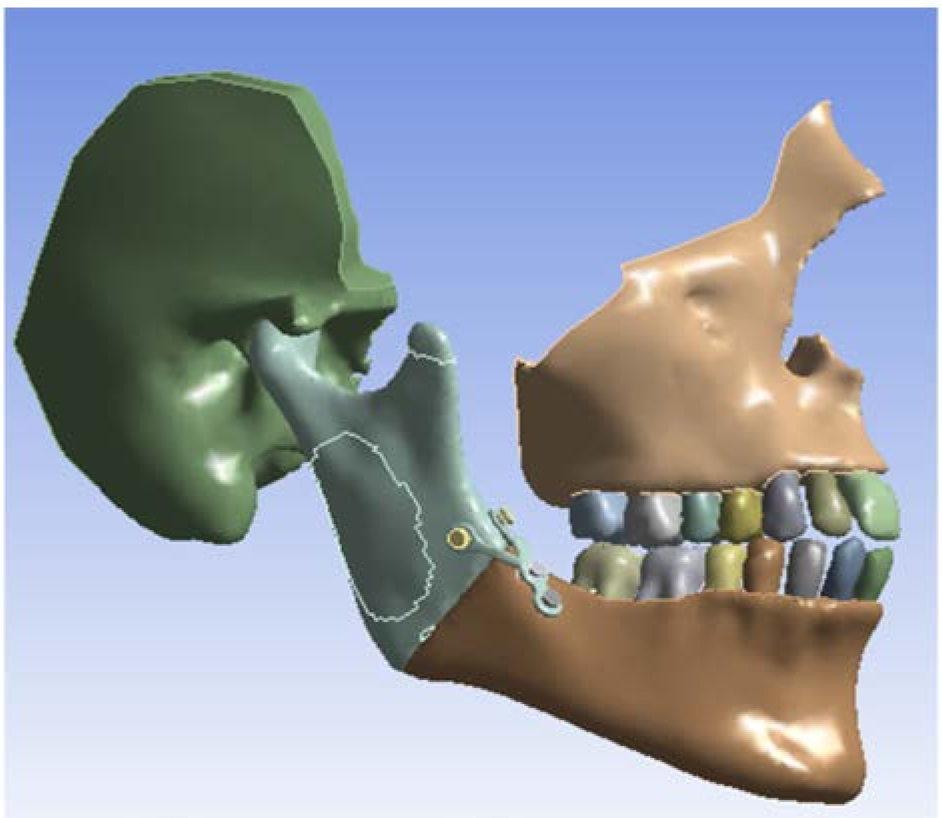


Figure 4

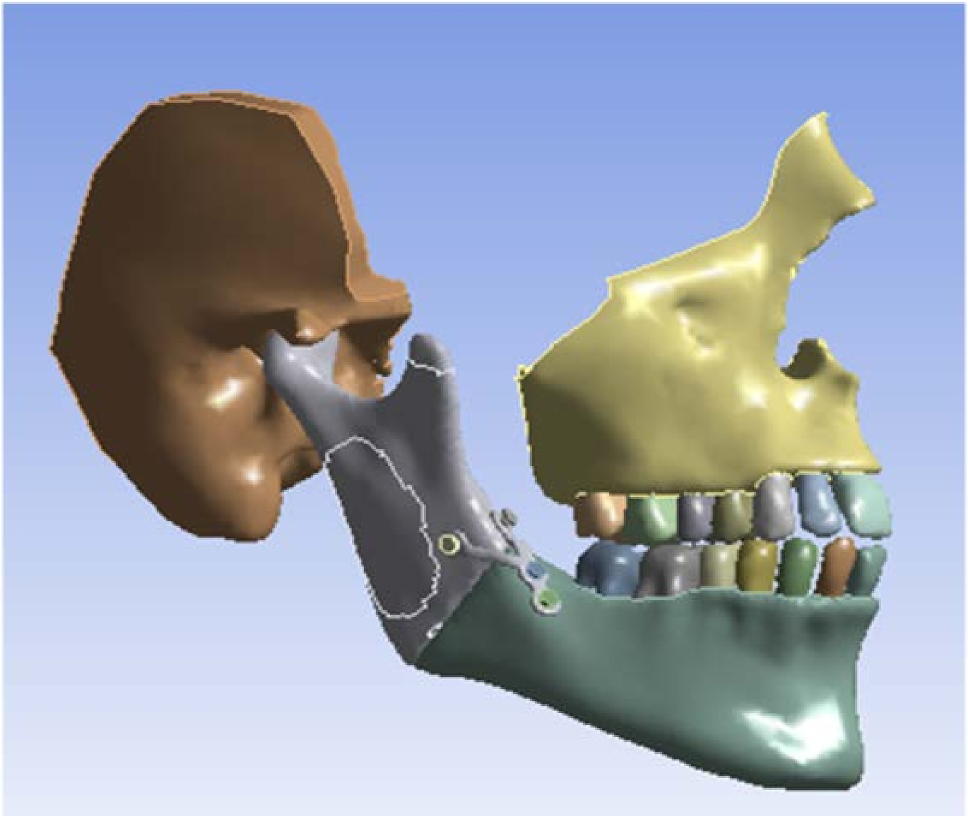


Figure 5

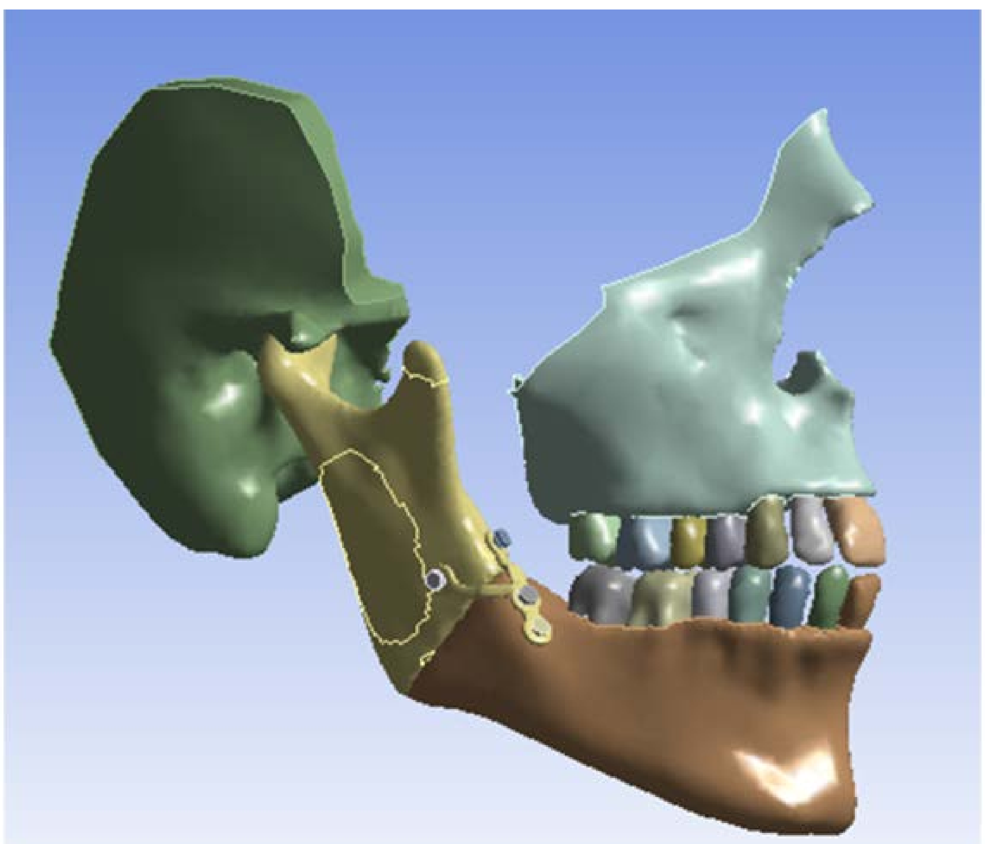


Figure 6

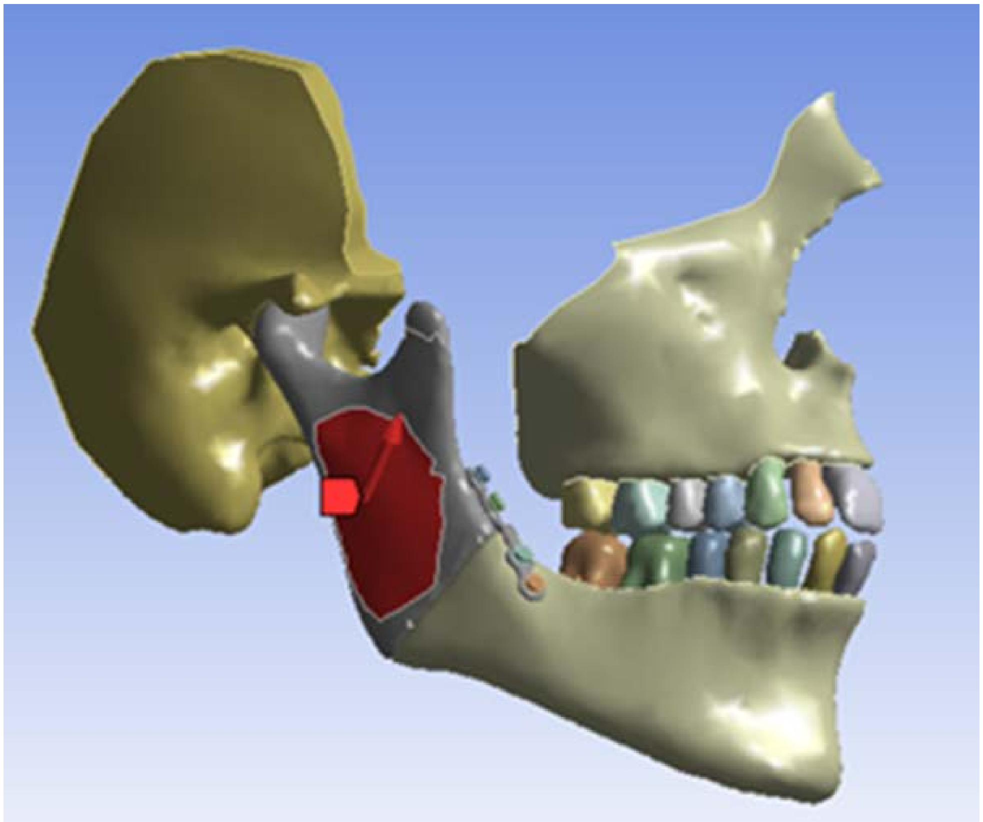


Figure 7

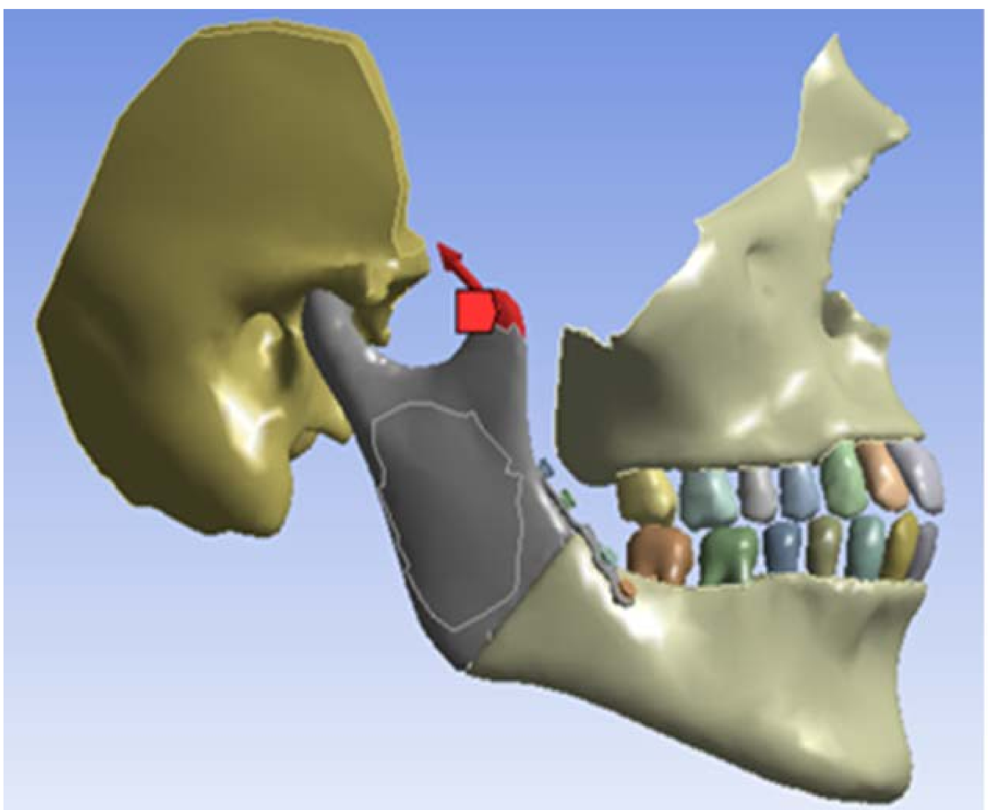


Figure 8

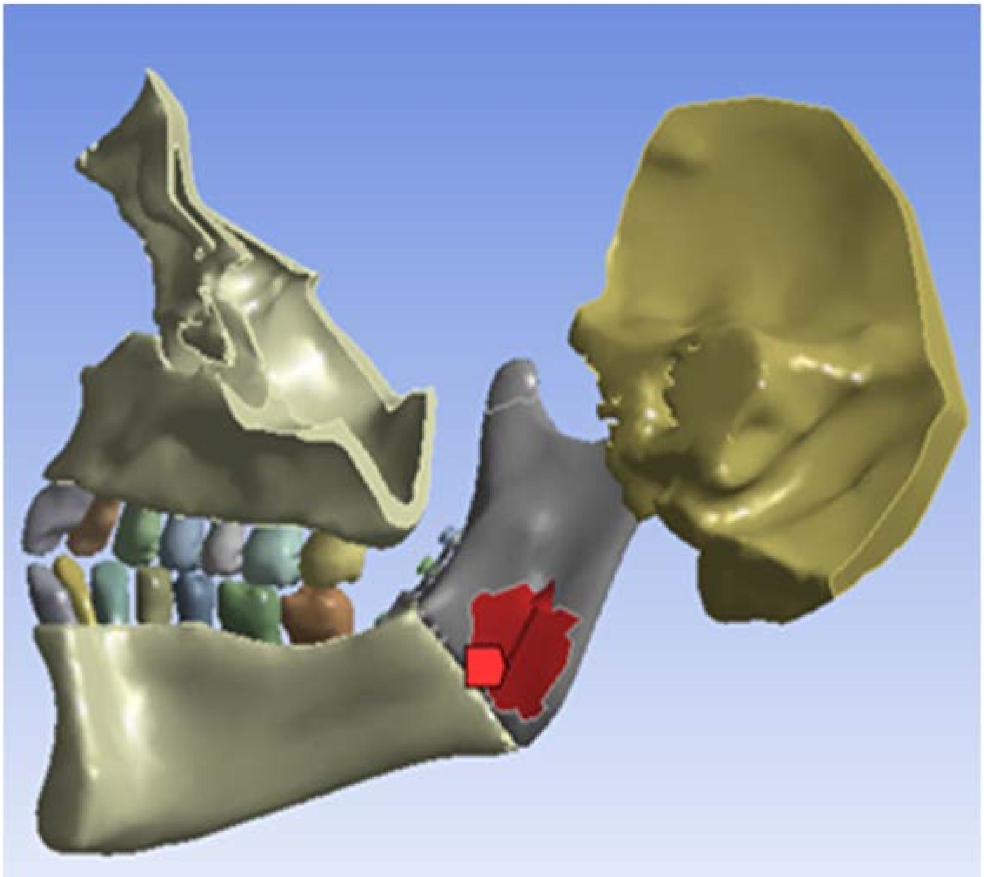


Figure 9

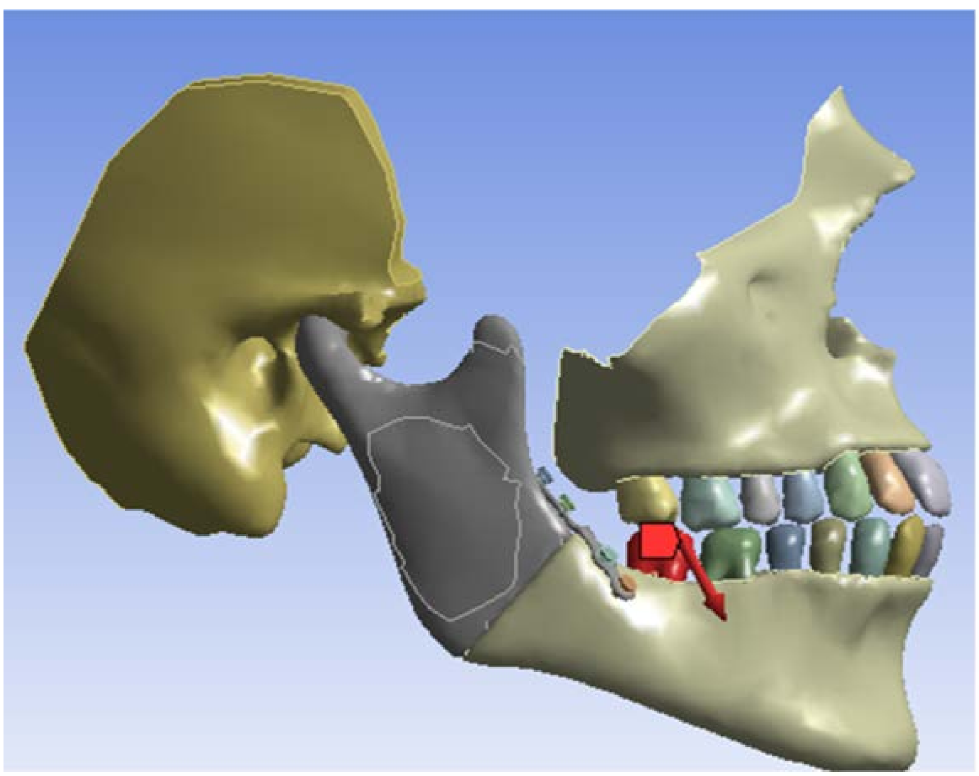


Figure 10

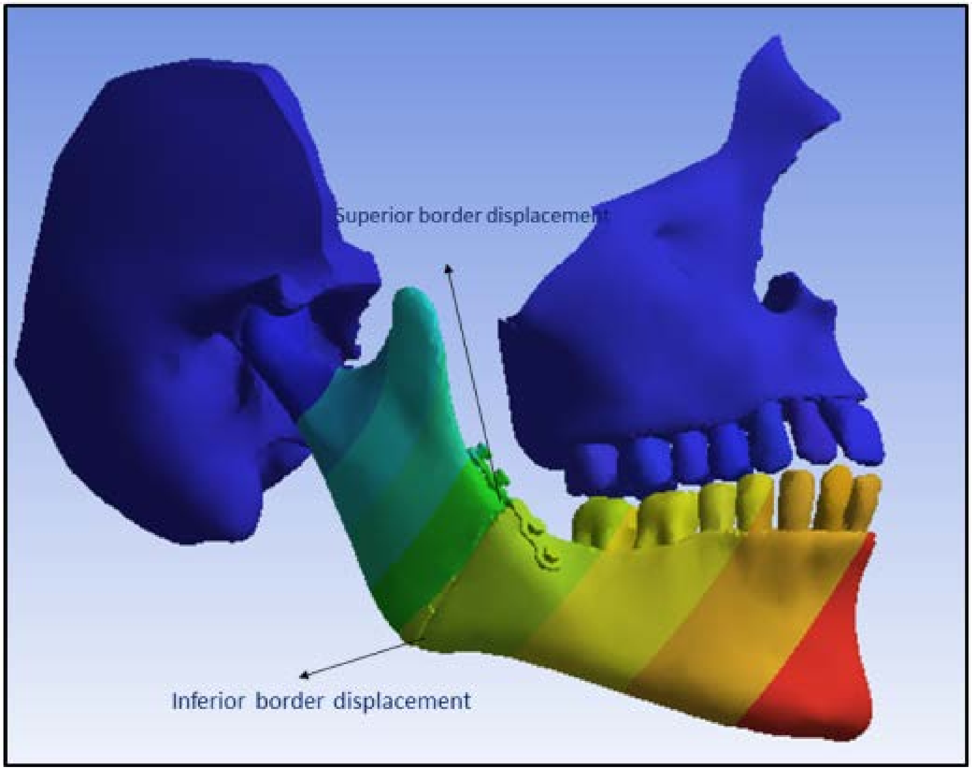


Figure 11

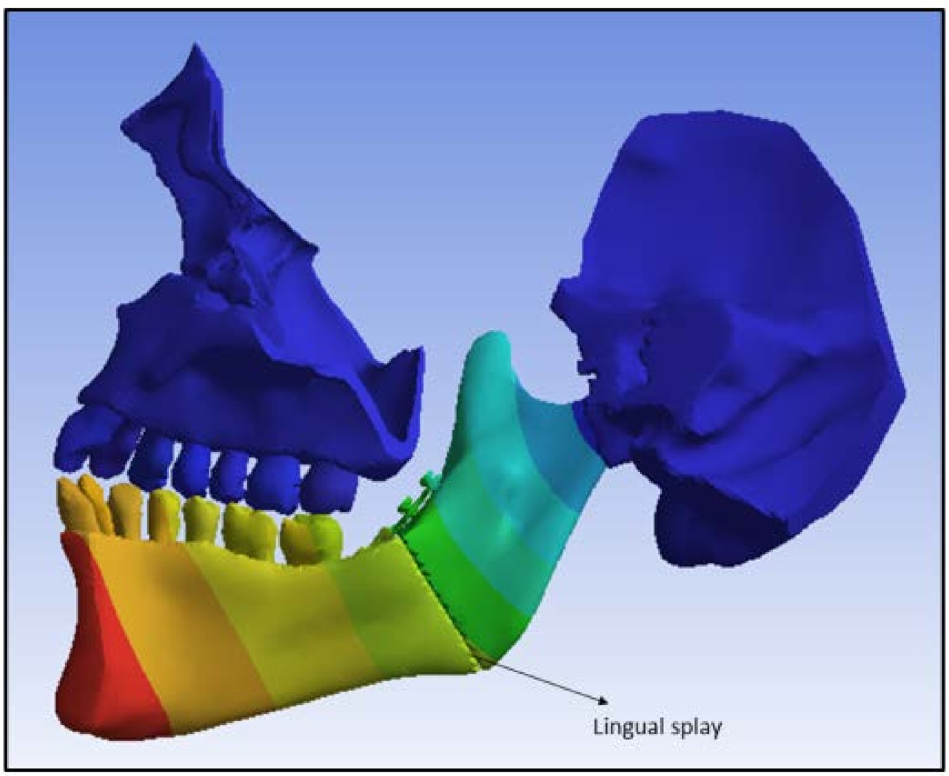


Figure 12