USE OF 3 - DIMENSIONAL MINIPLATE IN MANDIBULAR ANGLE FRACTURE FIXATION – A CLINICAL AND FINITE ELEMENT STUDY

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CERTIFICATE

This is to certify that this dissertation titled **"USE OF 3- DIMENSIONAL MINIPLATE IN MANDIBULAR ANGLE FRACTURE FIXATION- A CLINICAL AND FINITE ELEMENT STUDY"** is a bonafide record of work done by **Dr.RIDHI VASUDEVA** under our guidance and to our satisfaction during her postgraduate study period **2009-2012.**

This dissertation is submitted to **THE TAMILNADU Dr. M.G.R.MEDICAL UNIVERSITY,** in partial fulfillment for the award of the Degree of **MASTER OF DENTAL SURGERY – ORAL AND MAXILLOFACIAL SURGERY, BRANCH III.** It has not been submitted (partial or full) for the award of any other degree or diploma.

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CONTENTS

INTRODUCTION

Mandibular fractures constitute a frequent injury treated in craniomaxillofacial surgery, mainly caused by road traffic accidents, interpersonal violence and falls.[2] The angle is one of the most frequent sites for fractures of the lower jaw, accounting for between 20% and 36% of all mandibular fractures. [29] The presence of impacted third molar tooth which diminishes bone quality and stability plus the thinner cross section area of this region of the mandible (Tevepaugh and Dodson, 1995) contributes to the frequency of this site of fracture.

Angle fractures are considered the most critical of all mandibular fractures. This is because they generate the highest frequency of complications relative to other mandibular fractures, ranging from 0 to 32 % [4], particularly in relation to insufficient stability of fracture fixation.

The biomechanics of angle makes treatment of fractures in this region more difficult, the traditional treatment method (compression & reconstruction plates) has the highest complication rate (17%) in some populations which include abscess formation, osteomyelitis, malunion, nonunion and malocclusion.

Treatment of these fractures requires a thorough understanding of the surgical anatomy, muscle insertion, associated biomechanical forces at the angle, their action, importance of occlusion and lastly presence of third molar in the line of fracture. The ideal method of treatment of mandibular fracture should have the objectives of perfect anatomical reduction, complete and stable fixation and painless mobilization of the injured region around its fixation.

Methods for open reduction of mandibular fractures have changed and diversified enormously in recent decades, but there is still controversy regarding the optimal treatment.[4]

Thus the great variety of osteosynthesis methods in use indicates that so far no general agreement has been reached on mandibular fractures (Ellis and Ghali,1991; Ellis,1999).

Rigid internal fixation has been found to be an effective modality in the treatment of facial fractures for the past 3 decades. In the present scenario open reduction & rigid internal fixation can be achieved with a variety of different plating systems, some using an intraoral approach and some an extraoral approach.

The development of these systems for treatment of mandibular fractures has meant a change in criteria for post-surgical immobilization with a more rapid return of function, resulting in patients to resume normal function earlier. It has eliminated the need for intermaxillary fixation and facilitates stable anatomic reduction while reducing the risk of post-operative displacement.

The majority of simple, nondisplaced or minimally displaced fractures of the symphysis, parasymphysis and mandibular body can be adequately treated by osteosynthesis with 1 or 2 miniplates. Fixation of more complex fractures like comminuted fractures and fractures of the mandibular angle is much more controversial.

Philosophy of compression plating and the method of miniplate osteosynthesis compete with each other. Use of miniplate osteosynthesis allows early mobilization and has the advantage of being easy to bend and adapt and also found to be cost effective. Though fixation of such plates has been shown to simplify the surgery and reduce the surgical morbidity, it failed to surpass the predictability of rigid fixation. However, questions concerning the stability provided by miniplate fixation of mandibular angle fracture have become a point of contention among surgeons, based on recent clinical and experimental studies some authors described inferior border distraction caused by application of loading forces close to the fracture line.

Some authors found an unacceptably high rate of complications (28%) using two miniplates and others reported no differences in outcome when a single plate was compared with two plates.

These shortcomings have led to the development of three - dimensional titanium miniplates. 3 –D titanium plates and screws were developed and were reported by Farmand and Dupoirieux.[33] It is hypothesized that a single matrix miniplate (3-D miniplate) would provide both a functional level of stability requisite of fixation with minimum operative time and relatively low complication rate.

It consists of two 4- hole miniplates joined by three or four interconnecting cross struts. In combination with the screws monocortically fixed to the outer corticalis, the rectangular plate forms a cuboid which provides three dimensional stability.[29] The plates are adapted to the bone according to champy’s principles.[33]

The geometry of 3-D strut plate conceptually allows for an increased number of screws, stability in three- dimension and resistance against torque forces while maintaining a low profile and malleability.

Finite element analysis (FEA) is a commonly employed experimental research technique which enables us to study the effects of geometrical and material variations under load and internal mechanical process.[70] Originally used in structural analysis, it has now revolutionized dental biomedical research.

It allows modeling of structures or systems that approximates reality.

A ‘system’ which is assessed in FEA is usually made up of a continuous membrane, plate, shell or solid, single or in combination. It is divided into a finite number of “elements” for analysis purposes. An element is connected, supported, and loaded at its vertex and other specified location on edges or inside, called “nodes”.[75]

Each node can have a number of independent action (force or moment) or displacement (deflection or rotation) components called “Degrees Of Freedom” (DOF) along a certain direction.

FE method requires a huge amount of computation, so its application is supported by advanced computer technology. ANSYS and ABAQUS are two well – known FE softwares used for analysis. ANSYS has three fundamental modules. They are Preprocessor, Solution and General Postprocessor modules.

Pre processor - The creation of a FE model is done by preprocessor module. It includes: Step 1: Selection of the type of element

Step 2: Assigning material properties to the model - Elastic modulus and Poisson’s ratio

Step 3: Creation of model geometry – 2D or 3D

Step 4: Mesh generation- division of the model into small and finite elements

Step 5: Application of structural loads and constraints to the model

Solution - Solving of the model using the solution module.

Post processor – Results of the analysis can be accessed using the general post processor module.[80]

Thus when factors like clamping conditions and loading stress are known, the deformations and tensions of these elements (Bathe, 1990) can be calculated at each node. Due to their mutual interlinking (the same displacement and rotation of the nodes in all dimensions of space), the same applies to the deformation of overall structure. In turn derived parameters (stresses, expansions etc) can be calculated from this and consequently predictions can be made of possible failure.

Mechanical analysis using a finite element analysis have demonstrated that stability at the fracture interface differs with different plating strategies in both angle fracture models and condyle fracture models. [41]

The aim of this study is to evaluate and describe our clinical experience with the use of 3 – dimensional plating system in mandibular angle fracture fixation.

It also focuses on the biomechanical behavior of fractured mandible (evaluation of the displacement and stress fields) in cases of fractures of the mandibular angle using finite element analysis (FEA).

AIM AND OBJECTIVES

To evaluate the treatment results of open reduction and internal fixation using 3 Dimensional miniplate for fixation of mandibular angle fracture in regard to:

- Surgical outcome
- Biomechanical stability using **Finite Element Analysis (FEA)**

REVIEW OF LITERATURE

The recording of incidence of mandibular fractures appeared as early as 1650 B.C, when **Egyptian, Smith Papyrus** described the examination, diagnosis and treatment of mandibular fractures and other surgical ailments.

Around 450 B.C, **Hippocrates the “father of medicine”** was the first to describe the basic principles of modern fracture repair, reduction and stabilization. He described direct re -approximation of the fracture segments with the use of circumdental gold wires. He also advocated wiring of adjacent fragment with external bandaging to immobilize the fracture.

Salerno (1180) described the importance of establishing occlusion in the management of mandibular fracture.

Gugleilmosalicetti (1492) introduced the theory of maxillomandibular fixation by stating that “tie the teeth of the uninjured jaw to the teeth of the injured jaw”.

Hansmann (1886)[38] was the first to develop and present a procedure for subcutaneous fixation of bone fragments with a plate screw-system. He is, therefore, the inventor of plate osteosynthesis.

Lambotte (1907)[38] established the term osteosynthesis. He is consideredas the father of modern internal and external splinting, as he invented the external fixation and variousscrews and plates made from aluminium, brass, copperand silver. The first screws were conical and had flattenedround heads with a simple screwdriver slot. Latermodels were cylindrical with machine cut threads andhad self-drilling tips.

Collins (1920) and Eggers and Roosth (1959)[38] developed plates which possessed long and slotlike holes. With thisso-called internal contact splint the fracture ends could be approximated after the screws had been inserted. This modification later became the ‘‘compression plate’’.

Danis (1949)[38] presented the first compression plate for osteosynthesis. His work‘‘The´orie et pratique de l’osteosynthe`se’’ leads to a change in osteosynthesis to introduce primary stability.

Luhr (1968)[38] introduced ‘‘compression osteosynthesis’’ of the mandible. By usinga vitallium plate containing eccentric holes and selfcutting screws with a conical head, he created axial compression.

Spiessel (1969)[38] modified the “dynamic compression plates” used for limb surgery to match the dimensions of the mandible and applied them clinically. These plates were fixed at the buccal lower border of the mandible using bicortical screws. In addition, tension banding was secured by either a second plate in the alveolar ridge, wire ligatures, or arch bars to neutralize tensile stress.

Miniplates osteosynthesis

Brons and Boering (1970)[38] inserted small finger plates for mandibular fractures which were originally used in hand surgery. They placed the plates at the lower border of mandible which was biomechanically unfavourable.

Thus with miniplates the path of static compression was switched to that of dynamic compression.

Michelet et al (1973)[38] applied vitallium miniplates in more than 300 mandibular fractures. He placed them along the tensile trajectories and insetedmonocortical screws to avoid injury to tooth roots. Post operatively mandibulo – maxillary immobilization was not necessary in most cases.

Champy et al (1975)[38] modified this method to make it clinically more applicable. He developed an ideal line for osteosynthesis in ithe mandible - a line of maximum tensile stress running from the oblique line along the base of the alveolar ridge to the mental foramen. Here a single miniplates is sufficient. Additional torque required a 2nd more basal plate.

Prein et al (1976)[38] developed the so called “reconstruction plates” or the “load bearing plates” which allowed none or only minor movement between plate and bone fragments. They were used to bridge the gaps of complex comminuted fractures, infected fractures and fractures of the atrophic mandible.

Edward Ellis (1993)[20] evaluated a sample of 52 patients with fracture of the mandibular angle treated with AO reconstruction plate. The plate was three dimensionally bendable. The three screws on each side of fracture with this plate provided neutralization of functional forces in the absence of compression. Use of this plate for mandibular angle fracture was found to be very predictable and was associated with low rate of complications.

Mostafa Farmand (1995)[21] developed a new titanium plating system - the 3D plating system. A total of126 patients with trauma, craniofacial, orthognathic and reconstructive surgery were treated. 245 three dimensional plates of different size and shape were inserted. 43plates were used on cranium, 112 plates in the midface and 90 plates on the mandible. No patient had intermaxillary fixation. At the time of plate removal after 9 months, all the plates and screws were seen incorporated nicely into the bone. There were only 3 infections. Thus the complication rate related to the plates was low.

Vivek Shetty et al (1995)[39] conducted an invitro study to determine and compare the initial mechanical stability and functional capability of six contemporary internal fixation systems used to fix mandibular angle fractures. The fixation system comprised of the compressive system and the adaptive systems. Compressive systems included the 1) eccentric dynamic compression plate 2) Wurzburg plate 3) Luhr plate 4) solitary lag screw technique. The Champyminiplate and the Mennen clamp plate represented the adaptive fixation systems. The fixation stability provided by these differed significantly. Even at low masticatory loads the adaptive systems had instability which was 2 to 3 times less than that of compressive systems. With this it was concluded that compressive fixation systems were biomechanically superior to adaptive systems and provide good immediate functional stability to reduced mandibular angle fractures.

Edward Ellis III (1996)[17] evaluated the use of a single noncompression miniplate for stabilization of fractures of the mandibular angle in 81 patients. The plate was fixed with 2.0 mm self threading screws placed through a transoral incision. 13 patients (16%) experienced complications requiring surgical intervention. Most of the complications (n =1l) were minor and could be treated in the office. Most commonly, intraoral incision and drainage and later removal of the bone plate were required. All patients with minor complications had clinical union. Only two complications required hospitalization for intravenous antibiotics and further surgery. Hence it was concluded that the use of a single miniplate for fractures of the angle of the mandible is a simple, reliable technique with a relatively small number of major complications.

Richard Haug et al (1996)[36] compared the conventional technique of mandibular angle fracture plating with two biomechanically dissimilar techniques in their abilities to resist vertical loads similar to masticatory forces. Three groups of five synthetic hemimandibles with simulated fracture repairs were used for comparison.They reported that plate size or pattern has little bearing on clinical fracture fixation but that the monocortical screws appear to be a weak link in the system.

J .M.Wittenburg et al (1997)[27] performed a biomechanical study investigating the effectiveness of fixation devices of simulated angle fractures in sheep mandibles. The fractures were stabilized by a Leibinger 8 – hole 3-D plate, Synthes 8- hole mesh plate Synthes 6 hole reconstruction plate. Each mandible was tested in bending class III cantilever model. The 3- D plate showed plate deformation in bending > 230 N. The gap and displacement values for the mesh and 3-D plate were comparable to those of the reconstruction plate. These results indicate that a 3-D or mesh plate can be used for fixtion of mandibular angle fractures.

J.Tams et al (1997)[28] conducted a study to determine and compare bending and torsion moments across mandibular fractures for different positions of the bite point and different sites of the fracture. It was found that angle, body and symphysis fracture, each have a characteristic load pattern. These load patterns should play a decisive role in the treatment of mandibular fractures with regard to number and positioning of plates.

To formulate criteria for number and positioning, as well as mechanical properties and design of the plate systems, the load across the fractures have been analyzed using three – dimensional models of the mandible. For angle fracture, the maximum value of the bending moments was approximately 12 times higher than the maximum torsion moments. To neutralize positive bending moments that results in tension in the alveolar region and compression at the lower border,the bone plate should be positioned as “ high” as possible, i.e. in the alveolar region. But if two plates are used then, the upper plate should be positioned high while the other is placed on the lower border. The upper plate has to carry the largest loads and hence should be the larger one.

Jasser Ma’aita et al (2000)[25] evaluated the association of mandibular angle fractures with the presence and state of eruption of the mandibular third molar.A retrospective study was conducted by utilizing records and radiographs of 615 patients as data source. Angulation of third molar was measured by using method of Shillen in which angles were classified as vertical +/ - 10, mesioangular and distoangular +/ - 11 to 70, and horizontal more than+/ - 71. The results showed that the mandibular angle that contains an impacted third molar is more susceptible to fracture when exposed to an impact than an angle without third molar.

K.L.Gerlach et al (2002)[30] evaluated maximal biting forces in 22 patients with mandibular angle fractures treated with miniplates osteosynthesis according to Champy. An electric test procedure for evaluating the load resistance between the incisors, canines and molars was carried out 1 to 6 weeks following the treatment and additionally in 15 controls also. This revealed that after surgical fracture treatment 1week postoperatively only 31%

of the maximal vertical loading found in controls was registered. These values increased to 58% at the 6 th week postoperatively.

Guimond et al (2005)[12] evaluated the complication rate with the use of 2.0- mm 3 – dimensional curved angle strut plate for mandibular angle fracture fixation. A retrospective evaluation of 37 patients with noncomminuted mandibular angle fractures fixated with a transorally placed 2.0- mm 3 – dimensional curved angle strut plate was done. The results revealed that only two patients developed infections requiring plate removal and reapplication of fixation. Both the patients had a molar in the fracture line that was left in place during 1st operation. One patient developed a mucosal wound dehiscence without consequence. All the patients who developed a sensory deficit as a result of surgery reported full recovery of sensation. Thus the study suggested that the multidimensional strut plate carries low morbidity and infection rates that may prove to be comparable to the “gold standard” reconstruction plate.

Babu S. Parmar et al (2007)[10] evaluated the efficacy of 3-D stainless steel miniplates in the treatment of mandibular fracture. Seven patients were treated with 3x 2 hole 3D miniplates and three were treated with 2x2 holeplate. At the end of 1stmonth none of the patients complained of difficulty in mouth opening or mastication and paraesthesia of inferior dental nerve .only 2 patients were encountered with complications. The results from this study suggest that fixation of mandibular fracture with 3-D plate provides three dimensional stability with low morbidity and infection rates. The only probable limitation of these plates is excessive implant material due to extra vertical bars.

Juergen Zix et al (2007)[29] evaluated the clinical usefulness of 3- Dimensional (3D) miniplate for open reduction and monocortical fixation of mandibular angle fractures. In 20 consecutive patients, noncomminuted mandibular angle fractures were treated with open reduction and fixation using a 2 mm 3D miniplate system in a transoral approach. Postoperatively none of the patient developed infection (0%). But two patients with normal preoperative sensation developed sensory deficit after surgery which regained normal sensation after 3 months. The most important complication observed in this study was the fracture of the straight 3-D plate. This was attributed to several factorslike multiple bending, improper placement of plates, insufficient fracture reduction or overdrilling of the screw holes which have negative effect on the stability of fixation resulting in plate fracture. It was thus suggested that 3D plating system is a suitable method for fixation of simple mandibular angle fractures. It is an easy-to-use alternative to conventional miniplates, However, its application should be limited to cases where the fracture site has sufficient interfragmentary stability. The curved 3D plate can be considered more stable and more safe for fracture fixation at the mandibular angle than the straight plate.

A Siddiqui et al (2007)[6] compared the use of one miniplate (n = 36) with that of two miniplates (n = 26) for the treatment of mandibular angle fracture in a randomised trial. 36 patients had one / more complications i.e. 22 patients (61%) with a single plate and 14 patients (54%) with two plates. It was thus concluded that two miniplates are no more effective than one in the treatment of angle fractures.

Aleysson o paza et al (2008)[2] conducted a retrospective study where 115 mandibular angle fractures were reviewed. It was concluded that angle fracture management outcomes are affected by many factors beyond method of fixation. These include thinner cross sectional area than that of the tooth bearing region and biomechanical forces acting on the mandible (including the position of the masticatory muscles).

Rudolf Seeman et al (2010)[37] assessed the complication rates of mandibular angle fractures treated by open reduction. The 10 year retrospective study included 322 patients with 355 surgically treated mandibular angle fractures. The data showed that successful treatment occurred in 93.69% of fractures with 1open reduction and in 6.31% with 2 open reductions. Of surgically treated patients 71.47% (238) were completely free of complications. No significant differences were found between mandibular fractures treated with 1 miniplate or 2 miniplates and similar osteosynthesis failure rates were shown for both.

Manoj kumar jain et al (2010)[33] compared the 3- D imensional and standard (Champy's) miniplate fixation in the management of mandibular fractures. A prospective randomized clinical trial was carried out for a period of 1 year. Patients were divided into 2 groups by lottery method. Fixation was done using either 3 D 2 mm stainless steel plates (group I) or standard miniplate (group 2) using Champy's principle of osteosynthesis . Patients were followed for 2 months for wound dehiscence, infection, mobility, postoperative occlusion and radiological evaluation of reduction and fixation. In group I, 2 patients had mild segmental mobility, 2 patients had surgical site infection and 2 patients involving mental nerve had involved roots of teeth (P =.07). Radiological evaluation showed a significant difference in fixation between the 2 groups, especially in cases involving mental nerve and oblique fractures. Thus they concluded that Champy's miniplates system is a better and easier method than the 3 D miniplates system for mandibular fracture fixation. It is difficult to adapt and is unfavourable to use in cases of oblique fractures and those involving mental nerve.

Eduardo Hochuli -Vieira et al (2011)[14] evaluated the clinical outcome of 45 patients with mandibular angle fractures treated by intraoral access and a rectangular grid miniplate with 4 holes and stabilized with monocortical screws. The infection rate recorded was 4.44% (2 patients), and in 1 patient it was necessary to replace hardware. This patient also had a fracture of the left mandibular body. 3 patients (6.66%) had minor occlusal changes that were resolved with small occlusal adjustments. Before surgery, 15 patients (33.33%) presented with hypoesthesia of the inferior alveolar nerve; 4 (8.88%) had this change until thelast clinical control, at 6 months. It was concluded that the rectangular grid miniplate was stable for the treatment of simple mandibular angle fractures through intraoral access, with low complication rates, easy handling, and easy adjustment, with a low cost. Concomitant mandibular fracture may increase the rate of complications. This plate should be indicated in fractures with sufficient interfragmentary contact.

FINITE ELEMENT ANALYSIS

Clough RW (1960)[47]at the 2nd conference on electronic computation of the American society of civil engineers presented a paper in which he coined the term “FINITE ELEMENT” and applied it on his paper “Finite Element Method in plain stress analysis”.

Farah JW, Craig RC (1974)[54]worked and produced an article “Finite element analysis on a restored asymmetric 1st molar”. He created history by bringing finite element method (FEM) study in dentistry for the first time, proving its efficiency to be better than photo elastic study in terms of easy modeling and more defined stress analysis. Since then finite element method (FEM) is widely used in dentistry.

Weinstein AM et al (1976)[86] was the first to use Finite element analysis in implant dentistry. They performed a two dimensional plain stress analysis of porous rooted dental implants and compared it with results obtained from mechanical tests performed on actual implanted specimens.

Thomas J. Teenier et al (1991)[84] investigated the effects of drug-induced local anesthesia on the generation of first molar bite force and electromyographic (EMG) activity in adults. No statistically significant differences in bite force or integrated EMG levels were observed between the unanesthetized and anesthetized sides, nor on the anesthetized side at different levels of anesthesia.

Gregory S. Tate et al (1994)[57] recorded voluntary bite forces at varying periods in 35 males treated with rigid internal fixation for fractures of the mandibular angle. Bite forces were also obtained in 29 male controls for comparison. It was found that molar bite forces in patients were significantly less than in controls for several weeks after surgery. Further, molar bite forces on the side of the fracture were significantly less than on the non fractured side. The results of this study indicate that recommendations for the amount of fixation required for a given fracture may be reduced.

Carl E. Misch et al (1999)[46] suggested that the trabecular bone in the human mandible possesses significantly higher density, elastic modulus, and ultimate compressive strength in the anterior region than in either the middle or distal regions. The absence of cortical plates decreases the bone elastic modulus. These findings quantitatively confirm the need for clinical awareness in altering implant treatment plans and/or design in relation to bone density and the presence of the cortical plates**.**

Arne Wagner et al (2002)[43] investigated the biomechanical behavior of the mandible and plate osteosynthesis in cases of fractures of the condylar process using finite element analysis. Individual human mandible geometry, the specific bone density distribution, and the position andorientation of the masticatory muscles were evaluated by performing computed tomography scans and a sequentialdissection of the cadaver mandible. Three-dimensional finite-element analysis was performed for different fracturesites, osteosynthesis plates, and loading conditions. They concluded that whenever possible, of 2 plates for osteosynthesis of fractures of the condylar neck in combination with bicortically placed screws. The stiffness of asingle osteosynthesis plate made of titanium in a diametrical dimension of approximately 5.0 x 1.75 mm was foundto be equivalent to the physiological bone stiffness in the investigated fracture sites. The actual stiffness of such afixation plate is approximately 3 times higher than the stiffness of devices commonly in use.

Jose R. Fernandez et al (2003)[65] developed a three-dimensional finite element model of a fractured human mandible treated with plating technique to simulate and to study the biomechanical loads and the stress field distribution. In this work, using the finite element method, complete clinical conditions (after surgical reduction, post-operatory period, and complete healing period) were simulated. The mandibular fracture was located in the symphysis region and one or two titanium miniplates, fixed with monocortical screws, were evaluated. The behavior of a reduced human mandible with screwed miniplates, as well as its complete healing, was investigated and described. They concluded that the finite element analysis can play an important role in the study of the mechanics of mandibular fractures with some limitations. In spite of difficulties in the interpretation of experimental data, our FEM model provides insight and consistent results that may be useful in evaluation of other plates, fracture types and fracture sites.

Kay- Uwe Feller et al (2003)[66] computed the load on different osteosynthesis plates in a simplified model using finite element analysis, evaluated whether miniplates were sufficiently stable for application at the mandibular angle. Data from 277 patients with 293 fractures of the mandibular angle was seen. A computation model using finite elements was established in order to compute mechanical stress occurring in osteosynthesis plates used for fixation of fractures of the mandibular angle. In the second part of this study, the data from all patients treated for fracture of the mandibular angle were evaluated retrospectively. Age and sex of the patients, cause of fracture, state of dentition, type of therapy as well as complications were noted. They concluded that in comminuted fractures and in non-compliant patients, the use of a stronger osteosynthesis material should be considered while in all other cases application of a single 1.0mm miniplate was regarded as sufficient for fixation using open reduction.

Tyler Cox et al (2003)[85] used finite element analysis (FEA) to assess whether rigid fixation by resorbable polymer plates and screws can provide the required stiffness and strength for a typical mandibular angle fracture.Two separate 3-dimensional FEA models of the mandible were generated using 8-noded hexahedral elements. The jaw segments in 1 model were fixed with titanium plates and screws as those in common use today. The jaw segments in the other model were fixed with resorbable polymer plates and screws as used in a developmental product currently in trials. A commercial finite element solver was then applied to this mesh to compute stresses and bone interfragmentary displacements for both titanium fixation and resorbable fixation. Calculated displacements were compared with each other and to established norms for healthy bone regrowth. Calculated stresses were compared with the yield strength of each material.The study results indicated that titanium fixation more rigidly fixes the 2 bone segments in relative position. However, they also show that resorbable polymers provide sufficient stiffness to meet currently established norms for fracture immobility. They concluded that the resorbable polymer-based plates and screws are of adequate strength and stiffness for their successful application to the rigid fixation of mandibular angle fractures.

Gallas Torreira et al (2004)[70] developed a three-dimensional finite element model of the human mandible to simulate and analyze biomechanical behavior in two standard trauma situations. This computer-based study was made to assess the stress patterns within human mandibles generated by impact forces. The mandibular model was generated using 7073 nodes and 30119 tetrahedra. A commercial finite element solver was then applied to this mesh to compute stresses generated in standard trauma situations (a blow in the symphysis region and another one to the body of the mandible). The results indicated that following a blow to the symphysis region, maximum stress areas were located at the symphysis, retro molar and condylar regions. In the case of a blow to the mandibular body, the maximum stress areas were located at the contra lateral angle, the ipsilateral body and the ipsilateral condylar neck regions.

E. Erkmen et al (2005)[51] evaluated the mechanical behavior of different fixation methods used in bilateral sagittal split ramus osteotomy the analysis for mandibular advancement, four different fixation configurations of six hole fragmentation mini plates with monocortical screws and lag screws and posterior loading conditions in the molar and premolar region. The mechanical behavior of selected lag screws with linear or triangular configuration and double parallel or single oblique six hole mini plates with monocortical screws were compared by FEA after 5 mm BSSRO advancement procedure. They stated that finite element analysis method (FEA) appears suitable for simulating complex mechanical stress situations in the maxillofacial region. They concluded that the use of 2.0 mm lag screws placed in a triangular configuration following the BSSRO advancement surgery provides sufficient stability with any rotational movement and less stress fields at the osteotomy site, when compared with the other rigid fixation methods.

P.Schuller- Gotzburg et al (2009)[77] compared the effects and the stress in bone resulting from the different methods of applying (caudal versus buccal) the bridging plate using a three dimensional (3D) finite element (FE) model of the mandible. The jaw was loaded at a predefined point. In the caudally positioned bridging plate,FEA showed lesser stresses around the fixation screws of the plate. Hence they concluded that caudal position of the bridging plate has biomechanical advantages and facilitates fixation of the plate and fixation of bone graft on the jaw stumps.

Lihe Qian et al (2009)[68] investigated the interactions of implant diameter , insertion depth, and loading angle on stress / strain fields in a three – dimensional finite element implant / jaw bone system and determined the influence of the loading angle on stress / strain fields while varying the implant diameter and insertion depth.

M. S. Atac et al (2009)[72] evaluated the mechanical behavior of 2- versus 4-plate fixation and bony structures after Le Fort I impaction surgeries using three-dimensional finite element analysis (3D-FEA). Two 3D-FEA models were created to fixate the impacted maxilla at the Le Fort I level as 2-

plate fixation at the piriform rims (IMP-2 model) and 4-plate fixation at the zygomatic buttresses and piriform rims (IMP-4 model). The stresses in each maxillary model were computed. The models were loaded on one side, at the molar – premolar region, in vertical, horizontal and oblique directions to reflect the chewing process. They concluded that the use of 4-plate fixation following Le Fort I advancement surgery provides fewer stress fields on the maxillary bones and fixation materials than 2-plate fixation from a mechanical point of view.

M. S. Atac et al (2009)[73] investigated the biomechanical behavior of different fixation models in inferiorly and anteriorly repositioned maxilla following Le Fort I osteotomy. Two separate three dimensional finite element models, simulating the inferiorly advanced maxilla at Le Fort I level, were used to compare 2- and 4-plate fixation. The stresses occurring in and around the bone and plate – screw complex were computed. The highest Von Mises stresses on the plates and maximum principal stresses on the bones were found in INF-2, especially under horizontal and oblique loads, when compared with INF-4. They concluded that the traditionally used 4-plate fixation technique, following Le Fort I inferior and anterior repositioning surgery, without bone grafting, provides fewer stress fields on the maxillary bones and fixation materials.

Tomohisa Nagasao et al (2009)[83] investigated the risks associated with dynamic loading of the reconstructed mandible with implants. Computer aided design simulations of 8 mandibles were produced. These models were then modified by removing part of the right body and restoring the defect with bone from rib or fibula. Thereafter an implant was embedded in the 1st molar region of the left side for all models. Using FEA, the stresses occurring at the implant bone interface with simulated mastication were calculated. The normal models and the reconstructed mandibles showed no significant differences in this regard. It was concluded that placement of an implant on the non reconstructed side following partial resection and mandibular reconstruction presented no significant risk.

M. Motoyoshi et al (2009)[71] evaluated the stress in the bone when an orthodontic mini – implant is close to the roots of adjacent teeth using finite element models. They also investigated the causes of high implant failure in the mandible. Four FEMs were used: the implant touches nothing; the implant touches the surface of the periodontal membrane; part of the screw thread is embedded in the periodontal membrane; and the implant touches the root. The effect of cortical bone thickness was evaluated using values of 1, 2 and 3 mm.Maximum stress values and stress distribution on the bone elements was determined. Maximum stress on the bone increased when the mini-implant was close to the root. When the implant touched the root, stress increased to 140 MPa or more, and bone resorption could be predicted. Stress was higher for a cortical bone thickness of 2 mm with a higher risk for bone resorption. A mandible with an average cortical bone thickness of 2 mm may have a greater risk for implant loosening than a maxilla with the same degree of root proximity, which may be related to lower success rate in the mandible.

Peter Bujtar et al (2010)[78] analyzed detailed models of human mandibles at 3 different stages of life with simulation of supra normal chewing forces at static conditions.Finite element analysis (FEA) was used to generate models from cone-beam computerized tomograms (CBCT) of 3 patients aged 12, 20, and 67 years, using numerically calculated material parameters. Estimated chewing forces were then applied to the simulations.The results reflected higher elasticity in younger models in all regions of the mandible. Thus the experimental models showed that physiologic load stress and strain distributional changes of the mandible vary according to age.

Baohuiji et al (2010)[44] evaluated the stress distribution and stress shielding effect of titanium miniplates used for the treatment of symphyseal fractures using finite element (FE) analysis.Two 3-D FE models of symphyseal fractured mandibles reduced by technique 1, reduction with a single miniplate, and technique 2, reduction with 2 miniplates, respectively, were developed. Three basic loading conditions namely intercuspal position (ICP), incisal clenching (INC) and left unilateral molar clenching (L- MOL) were simulated. The ratios of stress shielding of miniplates came out to be different. Ratios of the lower miniplates in technique 2 weremuch higher than the upper miniplates and the miniplates in technique 1 during all conditions, and that value of the lower miniplate gained a maximum value of 83.34%

during left unilateral molarclenching. The stress areas wereconcentrated on the central section of the miniplates. However, the stress distribution varied with masticatoryconditions.

Thus they demonstrated that miniplate stress distribution and stress shielding effect ratio were affected notonly by the way in which the mandible was loaded but also by the number of the miniplates fixing the fracture.

Hang wang et al (2010)[59] analyzed the stress distribution in a symphyseal fractured human mandible reduced by 2 different methods - reduction with 1 miniplate or with 2 miniplates - by using finite element (FE) analysis, and then compared the results with an intact mandible. Three-dimensional FE models of an intact mandible and symphyseal fractured mandibles reduced by 2 fixation methods were developed to analyze mandibular stress distribution and bite forces under 2 basic loading conditions, namely, clenching in the intercuspal position and left unilateral molar clenching. Groups of parallel vectors were used to simulate 9 pairs of masticatory muscles involved in the 2 static biting tasks.Stress distributions in reduced mandible with 1 or 2 miniplates were more or less different from that of the intact mandible. The maximum stress occurred at the biting point. Whereas the subcondylar region was a stress – bearingarea. During left unilateral molar clenching, bite forces reduced after fracture. Bite force and the stress distribution pattern in the mandible reduced with 2 miniplates were closer to that in the intact mandible. They suggested that the effect of the miniplates in stabilizing the continuity-broken mandible influence the restorations of the stress distribution pattern and bite force. And that two miniplates have a biomechanical advantage over 1 miniplate on these restorations.

S.Miyamoto et al (2010)[81] analyzed stress distributions in craniofacial structures around implant-supported maxillary prostheses. Using post-hemimaxillectomy computed tomography (CT) of a patient, a three dimensional (3D) solid model was constructed using Digital Imaging and Communications in Medicine data (DICOM data) for maxillofacial and cranial bones. The effects of different prosthesis designs on stress distributions in craniofacial bones and osseous tissues around the implants were biomechanically investigated using 3D finite element analysis. Maxillary prostheses were designed with 2 implants in the zygoma on the affected side and 2–3 implants in the maxillary alveolar bone on the unaffected side, without using a cantilever. Zygomatic implants provided suitable stress dispersal to the zygomatic and craniofacial bones on the affected side. Hence this information was useful for designing maxillary prostheses.

M. Hudieb et al (2011)[70] investigated the biomechanical effects of crestal bone osteoplasty and flattening procedures carried out in edentulous knife-edge ridges to restore bone width before implant placement on the virtually placed implants using finite element methods. Three-dimensional models representing a knife-edged alveolar bone with two different crestal cortical bone thicknesses (1.6 mm, thin group; 3.2 mm, thick group) were created. Gradual crestal bone osteoplasty with 0.5 mm height intervals was simulated. Cylindrical implants with abutments and crowns were constructed and subjected to oblique loads. Maximum stress was observed at the cervical region around the implant neck. Different osteoplasty levels showed different stress values and distributions. Highest compressive stress was observed in the flat models (60.8 MPa and 98.3 MPa in thick and thin groups, respectively), lowest values were observed when osteoplasty was limited to the sharp edge (36.8 MPa and 38.9 MPa in thick and thin groups, respectively). The results suggested that eliminating the sharp configuration in knife-edge ridges improved stress and strain outcomes, but flattening the alveolar crest and/or uncovering the cancellous bone resulted in a marked increase in compressive stress and strain values in the peri-implant bone that may influence the longevity of implants placed in these ridges.

MATERIALS AND METHODS

This study included 6 patients with non- communited mandibular angle fractures who reported to the department of oral & maxillofacial surgery, Ragas Dental College & Hospital, Chennai from September 2009 to September 2010. All the patients were treated with open reduction and internal fixation using 2mm 3-D titanium miniplate system in a transoral approach. Surgery was performed in a standardized manner and patients were systematically followed up until 1year postoperatively.

On admission a detailed history was taken and clinical features like age, gender, type of trauma and duration from trauma to admission were recorded. Preoperative radiological examination was performed using panoramic radiographs and PA view of mandible. The following radiological findings were recorded preoperatively:

- Status of dentition
- Presence of tooth in the line of fracture
- Fracture site
- Presence of additional mandibular fractures
- Degree of fracture dislocation

Informed consent was taken prior to surgery and the source data was collected in a proforma.

The surgery was done under general anaesthesia with nasoendotracheal intubation. Arch bars were placed in all dentate patients one day prior to surgery. The plates were placed near the tension trajectories of the mandible. Concomitant fractures of the mandibular parasymphysis were fixated with 2 4-hole 2mm miniplates.

Inclusion criteria :

Patients with clinical & radiological evidence of mandibular fracture.

Exclusion criteria:

1. Infected Fractures
2. Comminuted Fractures
3. Lingual splaying of fractured fragment
4. Medically Compromised Patients
5. Completely Edentulous Patients

3- D TitaniumMiniplate Configuration (fig.2)

- Length of the horizontal bar : 5mm
- Length of interconnecting cross struts : 5mm
- Width of bars and interconnecting cross struts : 0.8 mm
- Profile height :1mm

Screw Configuration: Length of screw: 6mm and 8mm

Diameter of screw: 2mm

Properties of titanium:

A metallicelement, titanium is recognized for its high strength-to-weight ratio. It is a strong metal with a low density of 4.51 g.cm^{-3}at 20°C. It is ductile, lustrous, and metallic-white in color.The relatively high melting point (more than 1,650 °C) makes it useful as a refractory metal. It has - low electrical and thermal conductivity, making it a good insulator.It is nonferromagnetic; thus patients with titanium implants can be safely examined with MRI.

Its chemical behavior shows many similarities with that or silica and zirconium. Its chemistry in aqueous solution, especially in the lower oxidation states, has some similarities with that of chrome and vanadium. This metal forms a passive but protective oxide coating (leading to corrosion-resistance)when exposed to elevated temperatures in air. It is biocompatible and non- toxic. Hence plates and screws made of titanium can be safely used in patients.

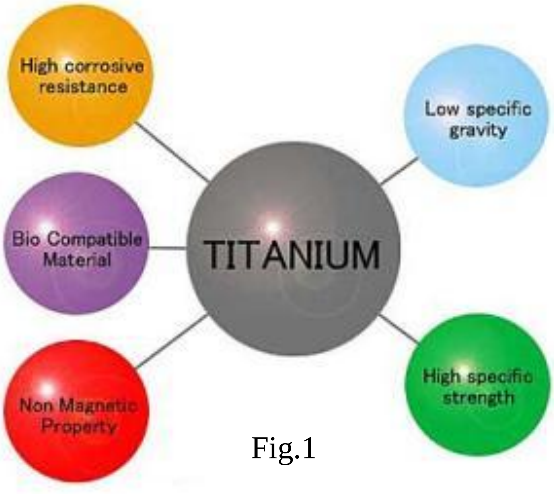


Fig.1

Armamentarium

- Mouth mirror and probe
- 2% lignocaine with 1:100000 adrenaline
- Periosteal elevator – Howarths and Molts
- Erich’s arch bar
- Stainless steel wire – 26 gauge
- Wire twister
- Wire cutter
- Bard parker handle no 3
- Blade no – 15
- Transbuccal trocar and cannula
- 3- Dimensional titanium miniplate – 8 hole
- 2mm x 6mm , 2mm x 8mm monocortical titanium screws
- Langenback retractor
- Mosquito forceps
- Plate bender
- Drill bit – 1.5mm diameter
- Micromotor and straight handpiece
- Screw driver
- Screw holder
- Needle holder
- Suture material : 3-0 vicryl and 5-0 prolene

Surgical Technique

Nasoendotracheal intubation was done. Patient was prepped and draped. Throat pack was placed. Using 2% lignocaine with 1:100000 adrenaline, infiltration was given in the buccal vestibule near the fracture site. A curvilinear incision was made in the buccal sulcus extending from the mesial of 1st molar to the distal of the 3rd molar with the help of BP blade no 15.Subperiosteal dissection was done and the fracture was exposed and reduced. The patient was put into MMF and the occlusion stabilized. A 3-dimensional miniplate was then adapted over the reduced fracture in such a way that the vertical bars were aligned perpendicular to the external oblique ridge. It was then secured with 2mm x 8mm monocortical titanium screws over the tension band zone according to Champy's line of osteosynthesis..The upper screws in the plate were placed first by direct access. The maxillomandibular fixation was then released for adequate access. This was followed by a 6 to 8 mm stab incision made extraorally at the angle of mandible corresponding to the fracture site. With the help of a transbuccal trocar a stab wound wasmade through the skin incision which communicated intraorally. A 1.5mm diameter drill bit was then passed through the transbuccal cannula to create holes for securing the plate with screws. After the lower screws were placed, the operative site was irrigated with betadine and saline. Intraoral closure was done with 3-0 vicryl. Extraorally the skin was closed with 5-0 proline. Throat pack was removed and patient was extubated. Extraoral pressure dressing was applied.

All the patients were maintained under antibiotic coverage.

Intravenous antibiotics were given for two days followed by 3-5 days of oral antibiotics. Injection dexamethasone was given 8mg BD for two days and stopped without tapering.

Fluids were advised for the first day and soft diet subsequently for 2-3 weeks. Gradually the diet was shifted to solid as per comfort of the patient.

Post operative follow up:

All the patients were evaluated on the 1st post op day, at the end of 2 weeks, 6weeks, 3months, and 6 months respectively. The following parameters were assessed:

- Derangement of occlusion
- Neurosensory deficit
- Mouth opening
- Infection
- Loosening of screws
- Malunion

FINITE ELEMENT ANALYSIS OF 3-D PLATING SYSTEM IN MANDIBULAR ANGLE FRACTURE FIXATION

To evaluate more about 3 D miniplate in different clinical situations, a Finite element study was carried out on a mandibular angle fracture model. The biomechanical behavior of 3 D plate, mandible and exact stresses in the bone were measured after application of bilateral masticatory load. Following cases were evaluated:

Design no1 - Fracture line distal to mandibular 2nd molar, from the alveolar crest to and through the lower border stabilized with 3-Dminiplate. (fig.5)

Design no2 - Fracture line between mandibular 1st and 2ndmolar, from the alveolar crest to and through the lower border stabilized with 3- D miniplate. (fig.6)

Design no 3 - Fracture line distal to mandibular 2nd molar, from the alveolar crest to and through the lower border not stabilized with any plate.

Steps involved in the study:

STEP 1 - CT SCAN AND DESIGN OF 3-DIMENSIONAL MANDIBLE MODELS

Computerized tomography data were obtained from a Siemens Somatome Sensation Multislice for a full human skull at every 1.0 mm in the horizontal plane. The data were from a 22 year old male who had full dentition and normal occlusion. The CT data were then imported into CAD based medical software **Mimics** (Materialise, Belgium) in image format in order to convert the scans into a suitable format for importation into any FEA/CAD program. Manual editing was then done in order to separate the dentate mandible from the skull data.

STEP 2

The geometric models of the 3- D plate and screws were modeled using **Solid Edge 2004Software** by using reverse engineering technique (measuring the dimensions of the brackets using precision tools).

STEP 3 - CREATION OF FEA MODEL

The geometric models (surface and line data) were then imported into **Hypermesh** software for meshing. The process of converting geometric model into a finite element model is called meshing. A FEA model consists of elements which are connected to each other by nodes.

The volumes created for cortical bone, cancellous bone, dentin and Speriodontal ligament were meshed using tetrahedral shaped solid elements.

ELEMENT TYPE USED (4-NODED TETRAHEDRAL ELEMENT)

Solid45 element description

SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, stress stiffening, large deflection, and large strain capabilities.

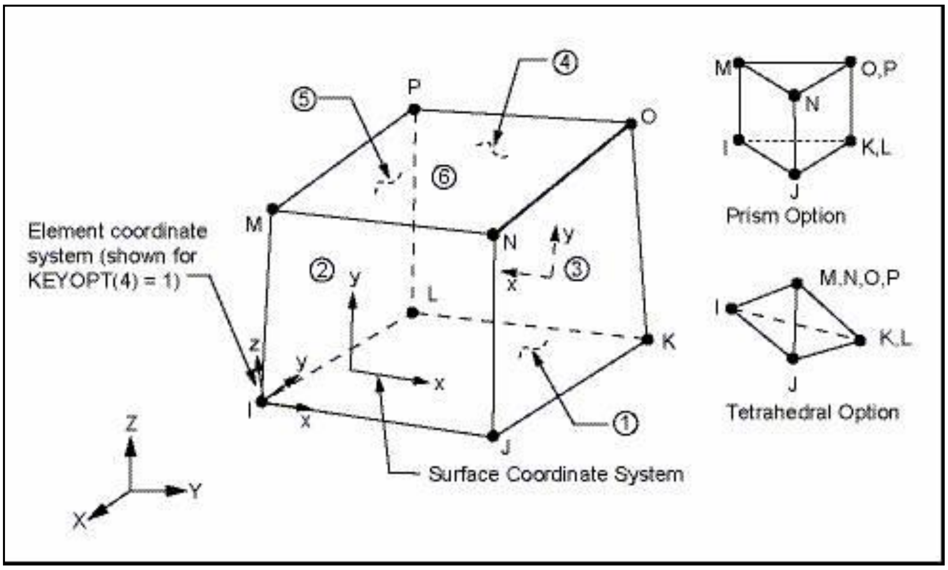


Fig.4: SOLID 45 3- D ELEMENT WITH 8 NODES AND 3 DOF AT EACH NODE

NODES AND ELEMENT DETAILS

	No. of elements	**No. of nodes**
DESIGN NO 1	614358	121491
DESIGN NO 2	599625	119564
DESIGN NO 3	581973	116783

STEP 4

Two fracture lines were created as mentioned earlier and then the segments were stabilized using 3- dimensional Plate and monocortical screws

STEP 5

Assembled finite element model of the Fractured Mandible with plate and screws was then imported into **Ansys 12.1 software** for analysis. Pre-processing, solving and post-processing are three stages in Ansys.

STEP 6 – PRE- PROCESSING STAGE

Elastic material properties used in the finite element model were Young's modulus& Poisson's ratio.

Young's Modulus / Elastic Modulus / Modulus Of Elasticity– It is a measure of the relative stiffness or rigidity of a material within its elastic range.

$$\text{E (elastic modulus)} = \frac{\text{stress}}{\text{strain}}$$

Poisson's Ratio- It is a ratio of lateral to the axial strain, within the elastic range.

Each material was defined as homogenous and isotropic. The physical properties of the constituent materials comprising the model were based on previous studies.[41]

These material properties (young's modulus and Poisson's ratio) of the Dentine, Cortical bone, cancellous bone, PDL, Plate and Screws were entered in the **pre-processing** stage.

	Elastic Modulus (Mpa)	**Poissons ratio (in %)**
Cortical Bone	13800	0.26
cancellous Bone	345	0.31
Dentine	18600	0.31
PDL	50	0.45
Plate and screw (Ti)	100,000	0.3

STEP 7

The loads and boundary conditions were applied in the solution stage.

Boundary conditions: (fig.11)

The mandible was restrained from movement in all directions during mastication. Seven regions including the condyle, coronoid processes, angle and the mandibular symphysis were fixed to zero displacement.

Applied Loads: (fig.12)

Biting force of **480N** on **premolar region** and **660N** on **molar region** was been applied. All these forces are acting along the vertical direction (long axis of the tooth).

STEP 8 - SOLVING STAGE

Each load case was solved separately.

STEP 9 –POST PROCESSING STAGE

The results were post processed and the displacement and von-misses stress contours of each individual parts in the system were captured.

Evaluation of stresses:

All stress values were a measure of von misses stress recorded in MPa (Mega Pascal).

Von Misses Stress: It refers to a theory called the "Von Misses - Hencky criterion for ductile failure".

In an elastic body that is subject to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed. That is, at any point within the body there are stresses acting in different directions, and the direction and magnitude of stresses changes from point to point.

The Von Mises criterion is a formula for calculating whether the stress combination at a given point will cause failure.

There are three "Principal Stresses" that can be calculated at any point, acting in the x, y, and z directions. The x,y, and z directions are the "principal axes" for the point and their orientation changes from point to point. The Von Misses criteria is a formula for combining these 3 stresses into an equivalent stress, which is then compared to the yield stress of the material. (The yield stress is a known property of the material, and is usually considered to be the Failure stress.)

The equivalent stress is often called the "Von Misses Stress". Basically, it is not a stress, but a number that is used as an index. If the "Von Misses Stress" exceeds the yield stress, then the material is considered to be at the failure condition.

Following areas von mises stresses were measured:

1. Von mises stress distribution on 3- D miniplate
2. Von mises stress distribution on individual screws
3. Von mises stress in cortical bone around plates & screws
4. Von mises stress in cancellous bone around plate & screws
5. Von mises stress in the mandible
6. Von mises stress in the periodontal ligament

Measurement of deformation / displacement:

Amount of deformation / displacement was measured in mm for the following regions:

1. 3-D miniplate plate
2. Screws
3. Cortical bone
4. Cancellous bone
5. Periodontal ligament
6. Full mandible

Software details

Ct scan of the mandible was taken into **MIMICS SOFTWARE.**

Mimics software allows to process and edit 2D image data (CT, µCT, MRI, etc.) to construct 3D models with the utmost accuracy, flexibility and user-friendliness. The powerful segmentation toolsallows to segment medical CT/MRI images, take measurements and engineer directly on 3D model. From there we can export our 3D data to a wide range of output formats and engineering applications; such as FEA, design, surgical simulation, additive manufacturing and more.

In this study, CT data was imported into CAD based medical software mimics, in image format in order to convert the scans into suitable format for importation into FEA program.

- Surface data of the mandible, plate and screw generated using **solid edge 2004 software.**
- Finite element model generated using **Hypermesh 9.0 software.**
- Analysis was carried out using **ANSYS 12.1 SOFTWARE.**
- **ANSYS** is a finite element analysis (FEA) code widely used in the computer-aided engineering (CAE) field.

This software allows to construct computer models of structures, machine components or systems; apply operating loads and other design criteria; and study physical responses, such as stress levels, temperature distributions, pressure, etc. It permits an evaluation of a design without having to build and destroy multiple prototypes in testing. It is modularised as a standalone software package with three fundamental modules. They are preprocessor, solution and general postprocessor modules.

Color coding for stress

- Blue - minimum stress
- red - maximum stress
- in between shades - variation of stress from minimum to maximum

Color coding for displacement

- Blue - minimum stress
- red – maximum stress

- in between shades - variation of displacement from minimum to maximum

Hardware details

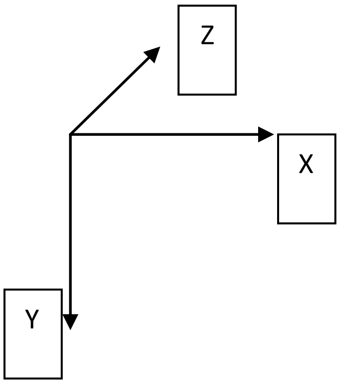
- Intel core 2 duo processor
- 4GB ram
- 320GB hard disk

Directions in which deformation occur

X—-- mesio-distal direction

Y---- Axial / vertical direction

Z-----Bucco-lingual direction



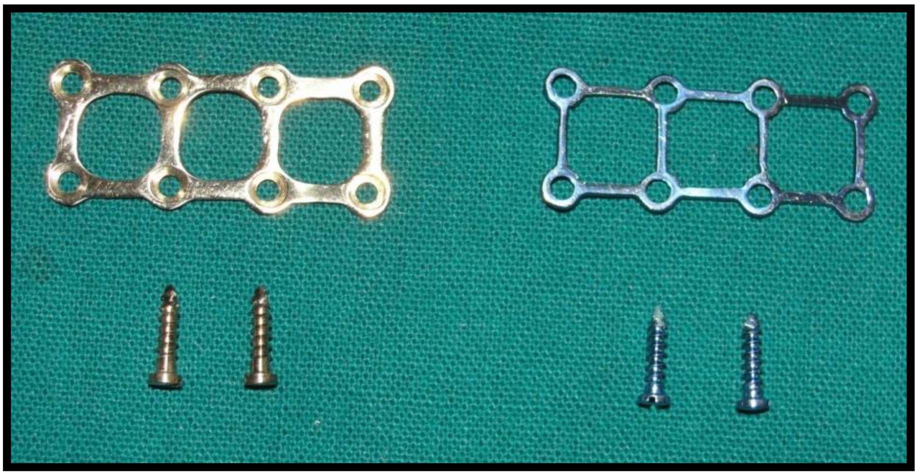


Fig.2: 8 HOLE 3D MINIPLATE

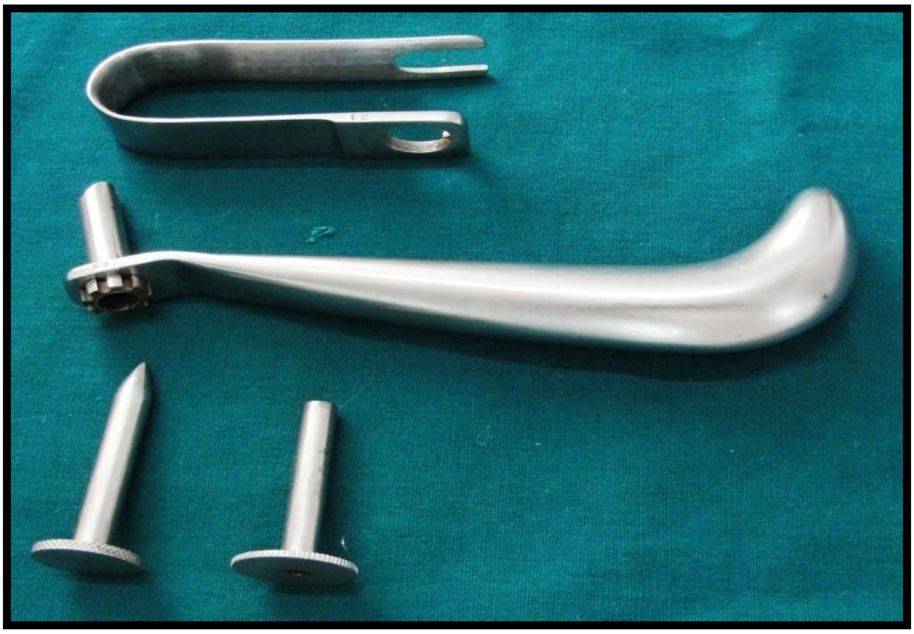


Fig.3: TROCAR AND CANNULA

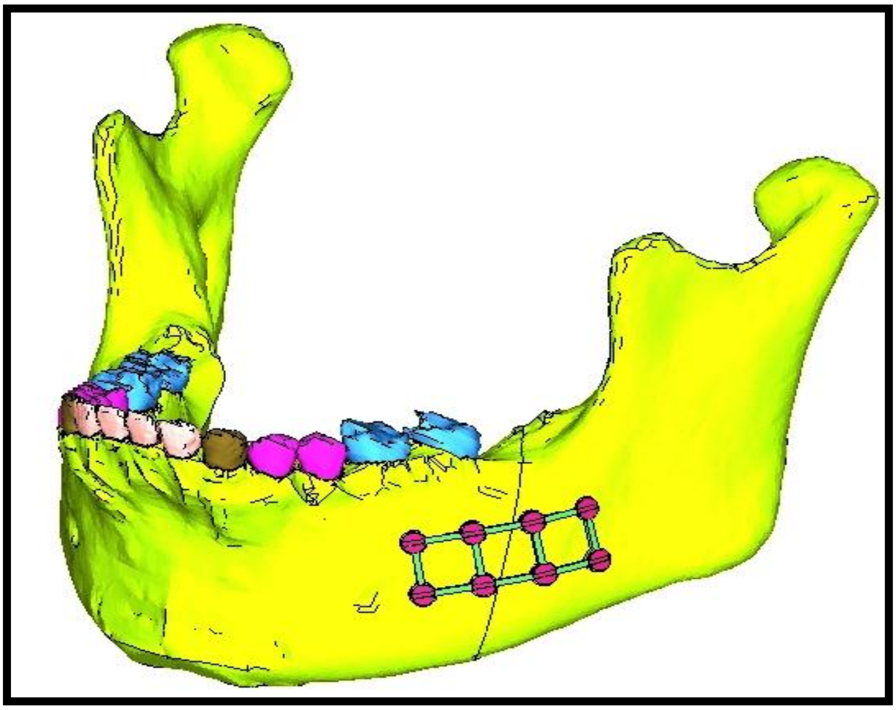


Fig.5: DESIGN NO 1- FRACTURE LINE DISTAL TO MANDIBULAR 2nd MOLAR

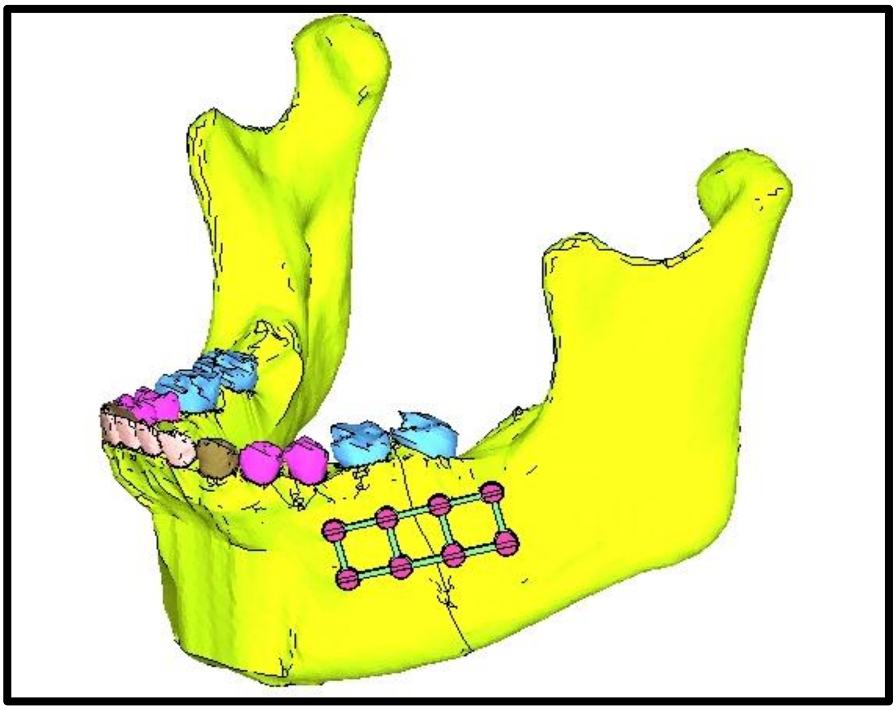


Fig.6: DESIGN NO 2- FRACTURE LINE BETWEEN MANDIBULAR 1ST AND 2ND MOLAR

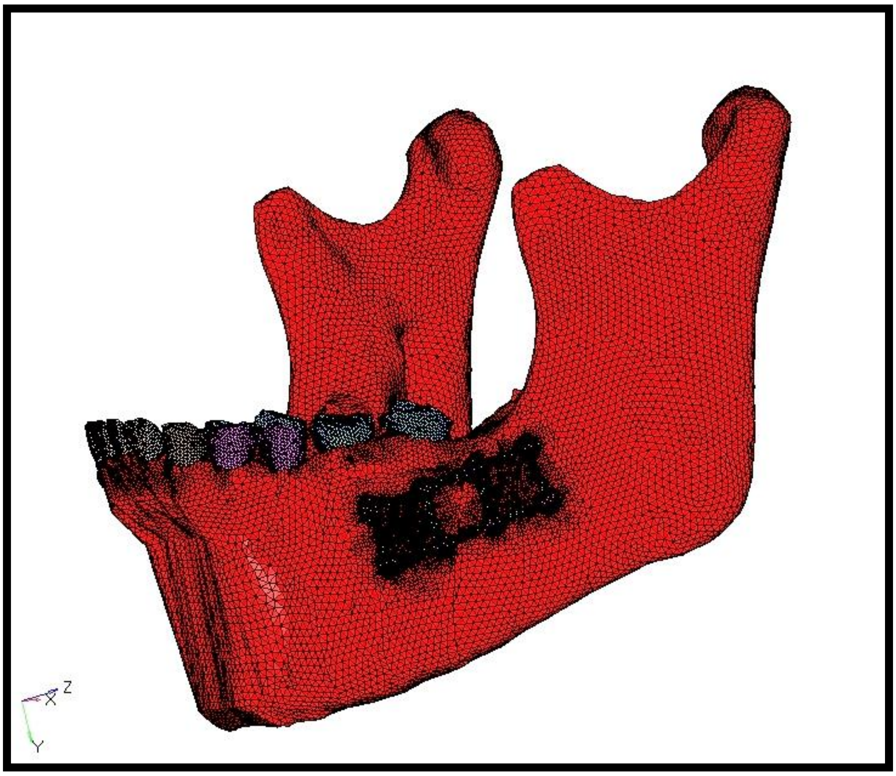


Fig.7: MESHED MODEL OF FRACTURED MANDIBLE- DESIGN NO 1

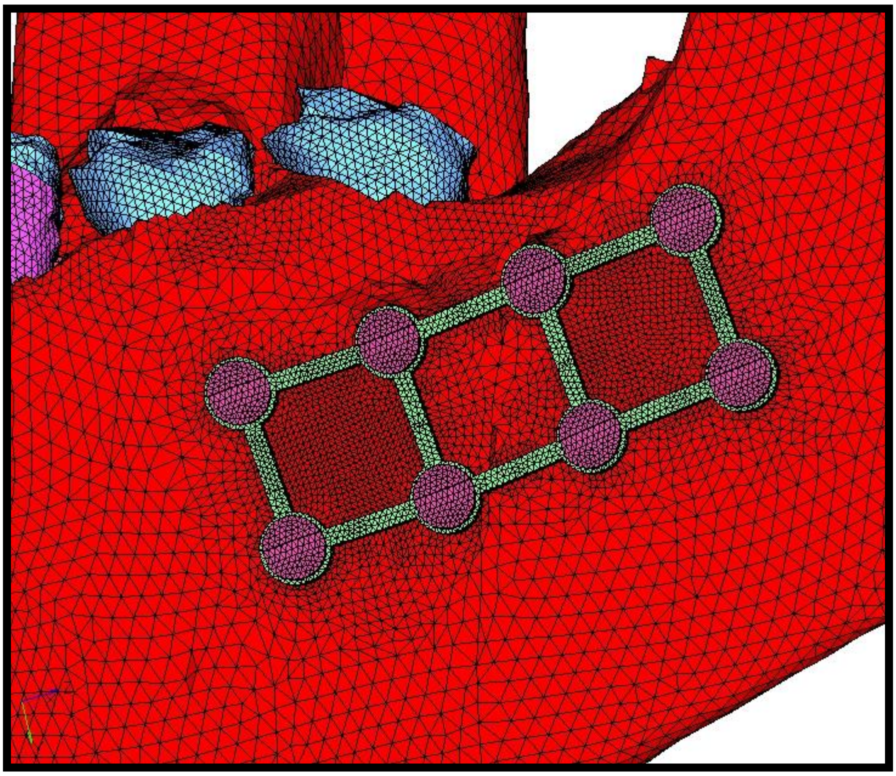


Fig.8: MESHED MANDIBLE WITH 3-D MINIPLATE - DESIGN NO 1

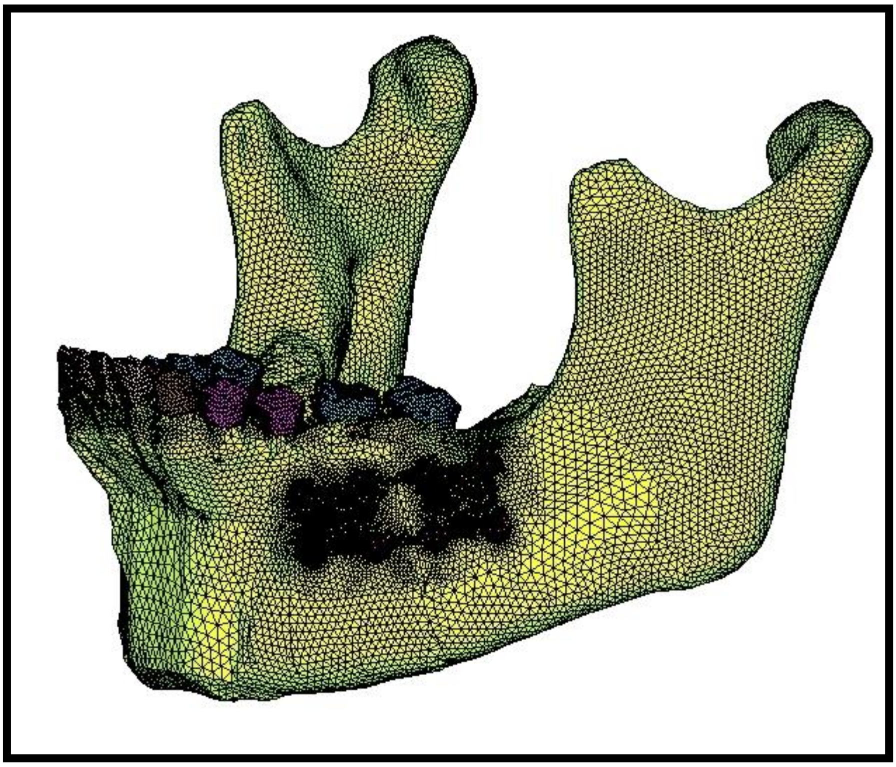


Fig.9: MESHED MODEL OF FRACTURED MANDIBLE- DESIGN NO 2

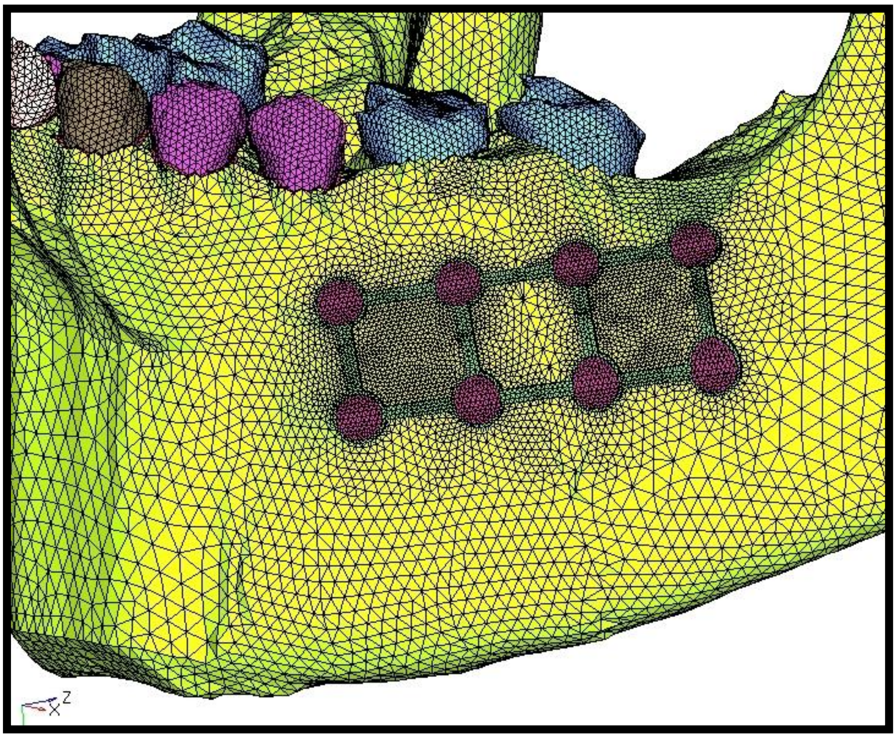


Fig.10: MESHED MANDIBLE WITH 3-D MINIPLATE - DESIGN NO 2

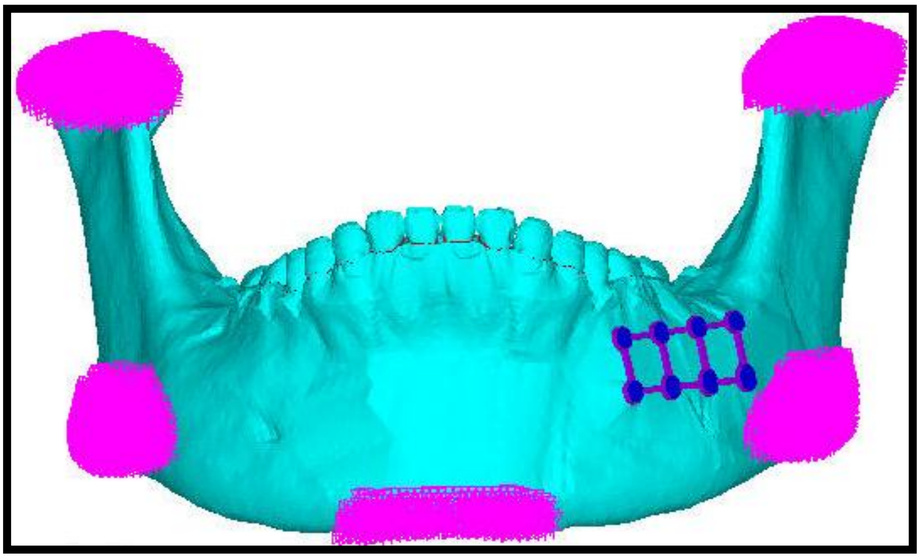


Fig.11: BOUNDARY CONDITIONS

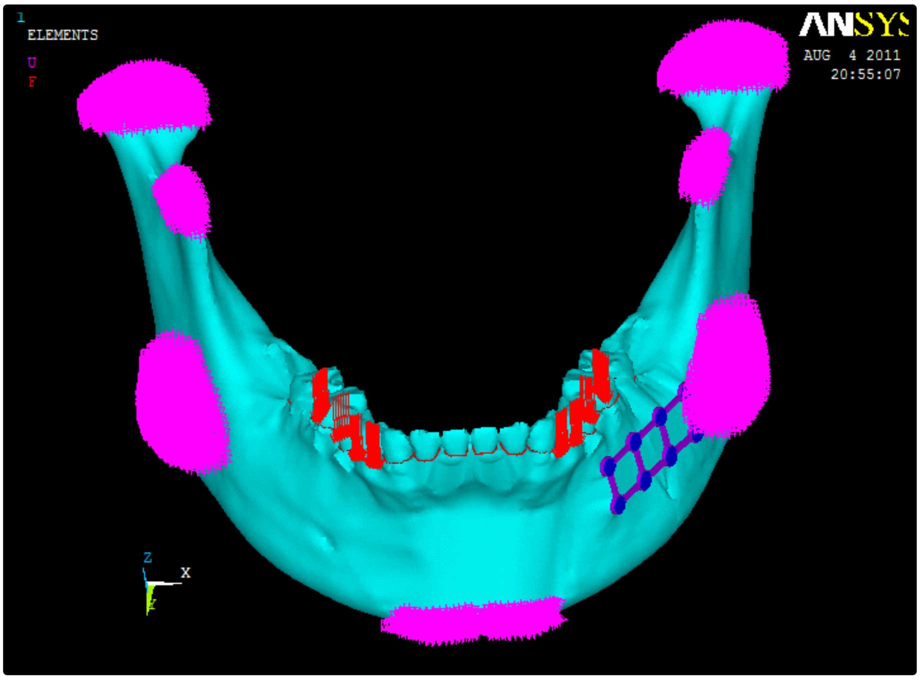


Fig.12: BOUNDARY AND LOADING CONDITIONS

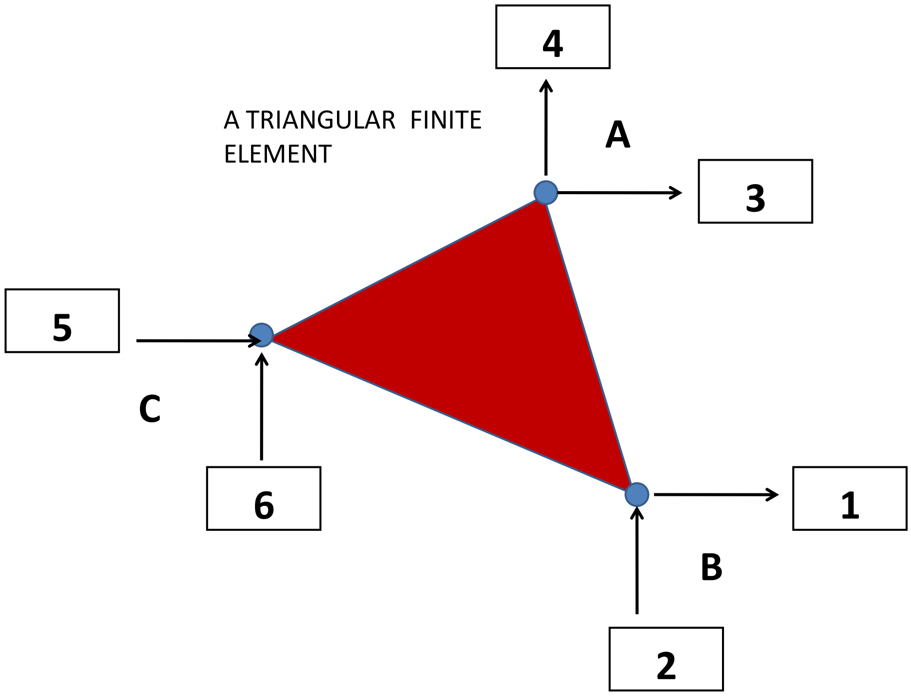


Fig.82: TRIANGULAR MEMBRANE ELEMENT ABC WITH THREE NODES (A, B AND C), THREE BORDERS AND SIX DOF

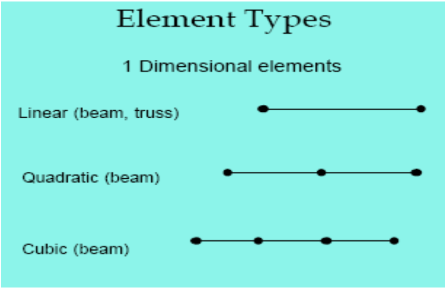


Fig.83: ONE DIMENSIONAL ELEMENT

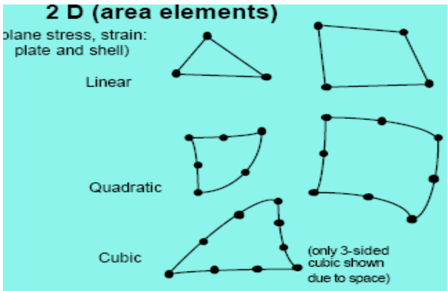


Fig.84: TWO DIMENSIONAL ELEMENT

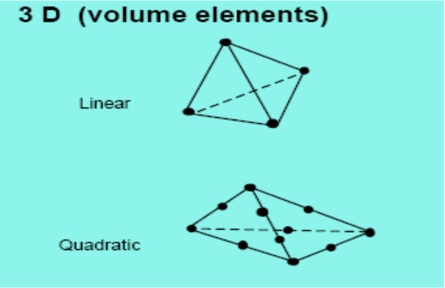
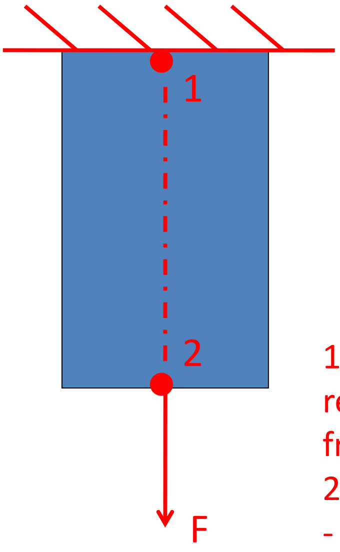


Fig.85: THREE DIMENSIONAL ELEMENT



1- top fixed node – restrained degree of freedom
2 - bottom free node - unrestrained degree of freedom
F – tensile load

Fig.86: RESTRAINED AND UNRESTRAINED DEGREE OF FREEDOM

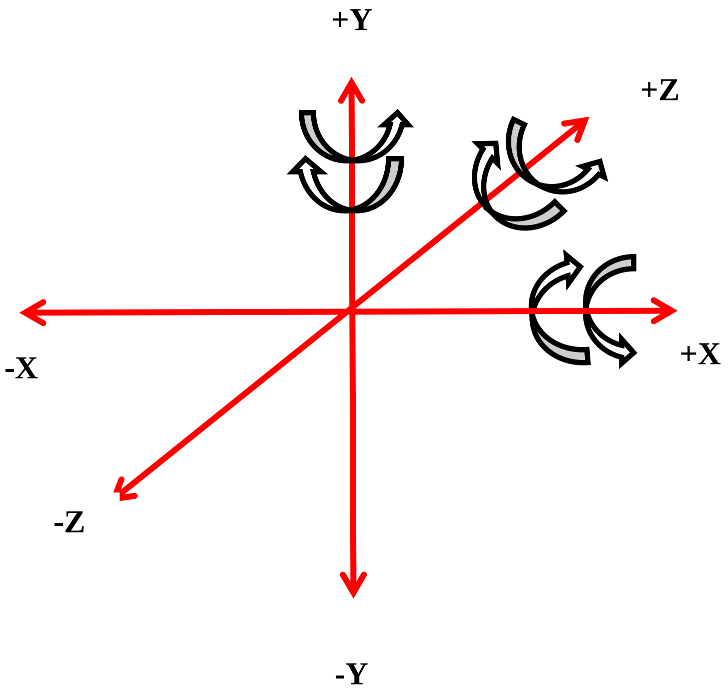


Fig. 87: DEGREE OF FREEDOM- 12

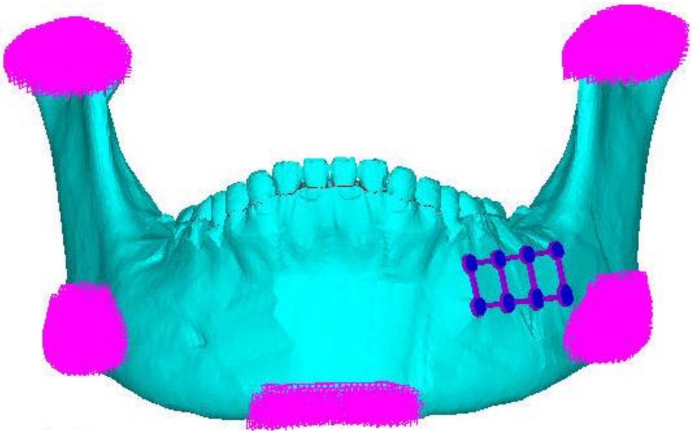


Fig.88: BOUNDARY CONDITIONS

RESULTS

6 patients with mandibular angle fracture, reporting to the department of oral & maxillofacial surgery, Ragas Dental College & Hospital, Chennai from september 2009 to September 2010, requiring open reduction and internal fixation were selected for the study.All the patients were systematically monitored until 1 year post operatively

Demographic details of the patients were recorded. All the patients were males of the third and fourth decade.They were fully dentulous. They presented with horizontally unfavourable mandibular angle fracture. Interpersonal violence was the most comman etiology followed by road traffic accident. A concomitant fracture was present in 3 patients. The second most comman fracture was at the contralateral parasymphysis. In 4 patients, there was a third molar tooth in the line of fracture. In 2 of these patients, the tooth had to be removed to help aid reduction of fracture and its subsequent stabilization.

None of the patients developed wound dehiscence or infection postoperatively. Nosegmental mobility was detected clinically. Adequate mouth opening was present for all the patients at last follow up visit. Four out of six patients had satisfactory postoperative occlusion while two patients had mild derangement of occlusion present. All but one patient had normal sensory function of the inferior alveolar nerve 1 year after surgery. One patient had dysesthesia at the lower lip region on the same side as the fracture. This patient presented with paresthesia preoperatively. Radiographically, no hardware related complications like plate fracture were seen.Plate removal has not been necessary in any of the patients till date.

MASTER TABLE.1

OUTCOME VARIABLES	**PATIENT NO 1**	**PATIENT NO 2**	**PATIENT NO 3**	**PATIENT NO 4**	**PATIENT NO 5**	**PATIENT NO 6**
Occlusion at last follow up	intact	deranged	deranged	intact	intact	intact
Clinical union at last follow up	present	present	present	present	present	present
Neurosensory deficit	Absent	Absent	Absent	Present	Absent	Absent
Final interincisal dimension	46 mm	36mm	50mm	47mm	48mm	49mm
Infection	Not present	Not present	Not present	Not present	Not present	Not present
Hardware failure	Not present	Not present	Not present	Not present	Not present	Not present

RESULTS OF FINITE ELEMENT ANALYSIS

DESIGN NO 1

MASTER TABLE.2

COMPONENT	**VON MISSES STRESS (IN Mpa)**	
	Max	**Min**
3-D plate	296.467	795E-03
Screws	125.87	0
Full model	296.467	.000795
Periodontal ligament	5.103	0.023
Cortical bone	216.015	.005548
Cancellous bone	32.885	0.005

MASTER TABLE.3

COMPONENT	**DEFORMATION IN X – AXIS (in mm)**		**DEFORMATION IN Y – AXIS (in mm)**		**DEFORMATION IN Z – AXIS (in mm)**	
	Max	Min	Max	Min	Max	Min
3-D plate	.051674	.018818	.094025	.015972	.035711	-.01325
Screws	.057284	.018594	.116047	.01651	.036704	-.012069
Full model	.076133	-.043442	.197784	-.001167	.105539	-.027036
Periodontal ligament	0.07	-0.02	0.18	0.02	0.09	-0.00
Cortical bone	0.076	-0.020	0.143	-0.001	0.094	-0.027
Cancellous bone	.070	-0.019	0.154	-0.000	0.080	-0.020

DESIGN NO 2

MASTER TABLE.4

COMPONENT	VON MISSES STRESS (IN Mpa)	
	Max	Min
3-D plate	379.699	3.447
Screws	157.117	0.00
Full mandible	379.699	.005572
Periodontal ligament	5.243	0.016
Cortical bone	112.051	.005572
Cancellous bone	9.608	0.005

MASTER TABLE.5

COMPONENT	DEFORMATION IN X – AXIS (in mm)		DEFORMATION IN Y – AXIS (in mm)		DEFORMATION IN Z – AXIS (in mm)	
	Max	Min	Max	Min	Max	Min
3-D plate	.054118	.001742	.102388	.038588	.030269	-.00872
Screws	.064981	.002575	.122705	.039048	.032606	-.0132
Full mandible	.081727	-.051977	.177222	-.001826	.106233	-.050044
Periodontal ligament	0.082	-0.028	0.177	0.011	0.099	-0.049
Cortical bone	.076	-0.028	0.146	-0.002	0.099	-0.050
Cancellous bone	0.081	-0.023	0.143	-0.001	0.085	-0.026

DESIGN NO 3

MASTER TABLE.6

COMPONENT	VON MISSES STRESS (IN Mpa)	
	Max	Min
Full mandible	**74.392**	**.005033**
Periodontal ligament	**5.127**	**0.030**
Cancellous bone	**48.898**	**0.004**

MASTER TABLE.7

COMPONENT	DEFORMATION IN X – AXIS (in mm)		DEFORMATION IN Y – AXIS (in mm)		DEFORMATION IN Z – AXIS (in mm)	
	Max	Min	Max	Min	Max	Min
Full mandible	.110661	-.036457	.243965	-.002412	.159536	-.010909
Periodontal ligament	0.085	-0.016	0.232	0.014	0.139	0.003
Cortical bone	0.081	-0.036	0.198	-0.002	0.139	-0.011
Cancellous bone	.068	-0.020	0.209	-0.000	0.122	-0.008

DISCUSSION

Human mandible is a membrane bone during its embryonic stage, and its physical structure resembles a bent long bone with 2 articular cartilages and 2 nutrient arteries. This arch of cortico - cancellous bone projects downward and forward from the base of the skull and constitutes the strongest and most rigid component of the facial skeleton[24]. However, it is more commonly fractured than the other bones of the face, because of its prominent and exposed position.

Fractures of the angle account for between 20% and 36% of all mandibular fractures. [29]

This is attributed to the following reasons:

a) The presence of third molars.
b) A thinner cross - sectional area than the tooth bearing region.
c) Biomechanically the angle can be considered a “lever” area.

In addition , the fact that the angle of the mandible is where there is an abrupt change in the shape from horizontal body to vertical rami which implies that the region might be subjected to more complex force than a more linear geometric shape.[18]

The biomechanical forces acting on the mandible, the position of insertion of masticatory muscles and the presence or absence of dentition influences fracture location. Variable rotations and displacements occur in the proximal and distal segments of fractured mandible as a result of the opposing muscular forces of the elevator group of muscles, (i.e masseter, medial pterygoid, lateral pterygoid and temporalis) and the depressor muscles (i.e geniohyoid, genioglossus , mylohyoid and digastric muscles) respectively.

Other factors like site, type, direction, magnitude of the impact, bone density and type of object that struck the patient also play a role in the etiology of mandibular angle fracture.[14]

Stable plate osteosynthesis has become an indispensable component of cranio-maxillofacial surgery in treatment of fractures and osteotomies of face. Since the presentation of plate fixation for cranio-maxillofacial surgery almost 30 yrs ago, several systems with different characteristics have been introduced.

Generally, the mandibular angle fractures are treated surgically, by either rigid or semirigid fixation. Rigid fixation is promoted by the AO / ASIF. In this concept, compression, tension, torsion and shearing forces, which develop under functional loading, are neutralized by thick solid plates fixed along the lower border of mandible by bicortical screws. Usually an extraoral approach is required which increases operative time , and is accompanied by risk of damage to facial nerve and extraoral scar formation.[29] Also the adaptation to bone is more difficult and time consuming . The rigid systems with their possible disadvantages are replaced more and more by functionally oriented miniplate systems.

<u>Disadvantages of Rigid Plates</u>[35]

⇩

✹ Fragment movement , when tightening the screws

↓

malocclusion → defect

✹ minimal adaptability of the fragments with elastics

↓

movement of teeth

✹ tension on the bone

↓

loosening of the screws

In the treatment of fractures of the facial skeleton, the functional stable osteosynthesis is replaced by the so - called exercise withstanding osteosynthesis. For this kind of fixation, there is no need for thick and strong plates. The semirigid fixation with special miniplates and microplatesis one of the most effective ones. This method of semirigid fixation by Champy uses one easily bendable monocortical miniplate along an ideal osteosynthesis line. The developing forces are neutralized by masticatory forces that produce a natural strain of compression along the inferior border of mandible. [29] But there has been a doubt over whether single miniplate fixation is sufficiently stable for fractures that cannot be adequately reduced. These shortcomings of rigid and semi rigid fixation led to the development of 3- dimensional (3D) miniplates.

The 3- dimensional (3D) plating system for mandibular fracture treatment is relatively new .[33]

Principles of Three – Dimensional Fixation:

The form of this 3 – D plate differs from the existing systems. The basic concept is that a geometrically closed quadrangular plate secured with bone screws creates stability in three dimensions. Stability of the plate is achieved by its configuration, not by thickness or length. The smallest structural component of the plate together with the bone screws is a cube or square stone[35]. The stability is gained over a defined surface area. By changing the length of each side, different geometric arrangements can be established. The optimal stability is maximum when the design of the plate maintains the arrangement of arms in a quadrangular manner.

The plate is not positioned along the trajectories but over the weak structure lines. It is always positioned parallel to the osteotomy or fracture line. The connecting arms of the plate between the screw holes should always be positioned rectangular to the osteotomy or fracture line.[35]

The screws adapt each part of the plate separately without any tension to the bone. The cross linking provides the stability of the system. There is no need for exact adaptation of the plates as is necessary with thicker plates.

Biomechanical Characteristics of the Three- Dimensional Plates [35]:

	MANDIBLE	3-D PLATE
TRACTION FORCE MAX	**660 N**	**690 N**
FLEXION FORCE MAX	**15 N**	**27 N**
TORSION FORCE MAX	**11 N**	**30 N**

According to Champy et al and Gerlach et al, the maximum load capacity of the mandible is normally about 250 to 650 N. The 1.0 mm standard plate can easily withstand traction forces with a value of 690 N. Despite the thin connecting arms of the plate, the three – dimensional plates are also quite stable against torsion forces. This is because the forces are distributed over a surface area and not along a single line. A torsion force of 30 N was measured in 3-D plating systems.

Previous studies on the use of the curved 2mm angle strut plate for angle fracture treatment [12,23] by Guimond et al and Feledy et al reported low complication rates and concluded that the 3 D plate is a predictable alternative to conventional miniplates. These authors emphasized that the strut plates have hardware related advantages over conventional miniplates and reconstruction plates. These advantages included easy application, which avoids a time consuming extraoral approach and associated complications, simplified adaptation to the bone without distortion or displacement of the fracture, simultaneous stabilization at both superior and inferior borders, and hence less operative time.

The present study does not agree with the simplified adaptation of the plate. A geometric miniplate like 3 – D plate is much more difficult to perfectly adapt than a linear conventional miniplate as it is trying to adapt a “plane” rather than a “line” to a curved surface. Also the operative time was increased because of the time taken for adaptation of the plate.

Another advantage of 3-D plate is their improved biomechanical stability compared with conventional miniplates. The first biomechanical study of 3-D plates was conducted by Farmand.[21] He found that the 3-D 1 mm plate was as stable as the much thicker 2-0 miniplate. Feledy and coworkers compared the 3-D matrix plate with paired miniplates in a biomechanical experiment, and found better bending stability and more resistence to out - of - plane movement in the 3-D plating system.[23] In this study, adequate stability was achieved in all the cases which was evident with post operative clinical union of bone.

It has been claimed that mobility of fragments is a causative factor in postoperative infections. Thus improvement of plate stability is a way to minimize the most common complication in mandibular fractures –

"infection".[26] With the use of open reduction and internal fixation, the reported incidence of infection ranges from 3% to 32%[18]. Infection rates in the clinical studies on 3 D plates reported in literature are 5.4% (2 out of 37)[12], 9% (2 out of 22)[23], 0%[29], 10% (2 out of 20)[33]. In the present study none of the patients developed an infection, with the infection rate of 0% which is very favourable.

Plate fracture was the main complication in a study by Zix et al,[29] in which reduced interfragmentary cross – sectional bone surface at the fracture site was cited as the most likely reason for fracture of the plate. No such hardware failure was seen in this study.

Fractures of the mandible frequently result in inferior alveolar nerve (IAN) injury and altered neurosensory function. This may be due to primary injury when the IAN lies in the line of fracture or a secondary insult due to manipulation and fixation of the fracture. Reports in the literature indicate that the prevalence of post injury / pretreatment IAN deficit ranges from 5.7% to 58.5%[32]. The prevalence of IAN injury after fracture treatment ranges from 0.4% to 91.3%. In the present study, only 1 patient had sensory deficit, which showed some recovery after 1 year of follow up. This patient had presented with paresthesia of lower lip on the same side as fracture. Thus the deficit was related to the injury and not because of intraoperative damage to the nerve.

In this study, trismus was assessed by the maximal mouth opening (interincisal width). Preoperatively all the patients had inadequate mouth opening. But at the final post operative visit, patients resumed normal mouth opening.

There was mild occlusal derangement in 2 patients. These patients had associated second fracture at contralateral parasymphysis which was also treated with conventional titanium miniplates. To overcome lack of interfragmentary stability and deranged occlusion, postoperative maxillomandibular fixation was done in these patients. But it was removed after 2 days because of the noncompliance of the patient.

FINITE ELEMENT ANALYSIS

It is a numerical technique to obtain approximate solutions to a wide variety of engineering problems.

It gives numerical approximations which results in quantitative predictions.

The term FEA was first used & coined by *Clough* in 1960 which was followed by the publication of 1st book on FEA by *Zienkiewicz & Chung*in 1967.

❖ FUNDAMENTAL CONCEPTS :

- A “System” or a “structure” (domain) which is assessed in FEA is divided into a “finite” number of elements (subdomains).
- Function is approximated separately in each sub domain.
- Elements are interconnected at some critical points known as nodal points or “nodes”.
- Physical properties like shape, dimensions & external force are imposed on the elements and the result is obtained in the form of stress & displacement.
- The resulting elemental equations are then formulated.

- The governing equations for the entire domain (global finite element equations) are derived as a summation of elemental equations leading to simultaneous algebraic equations which can be solved with aid of computer.

❖ “DATA” ASSOCIATED WITH AN INDIVIDUAL FINITE ELEMENT

This data is used in finite element programms to carry out element level calculations.

1. Dimensionality
2. Nodal points
3. Geometry
4. Degrees of freedom
5. Boundary conditions

Dimensionality:

An element can have one, two or three space dimensions.

Nodal points: **(fig.82)**

An element is connected, supported, and loaded at its vertex and other specified location on edges or inside, called “nodes”. They are located at the corners or end points of the element. It is a coordinate in space where actions (forces) & displacements of a structure under load are considered to exist.

Locations at which nodes can be positioned during discretization:

1. The point of change of cross – section.
2. The point of concentrated load acting.
3. The point of different material connection.
4. The point of load changing.
5. The point of external boundary like fixed end.

Geometry:

Geometry of an element is defined by placement of nodal points.

1. One dimensional element – line element **(fig.83)**
2. Two dimensional element – triangular & quadrilateral elements **(fig.84)**
3. Three dimensional element – tetrahedral & hexahedral elements **(fig.85)**

Degrees of freedom:

Machine component is loaded

↓

Deformations or elongations at various parts of the component

It is the direction of space along which the deformation is possible to occur after application of force. There are two types of DOF:

1. Restrained DOF
2. Unrestrained DOF

For example, a rod is considered whose one end is fixed and the other end is free. It is subjected to a tensile load at its free end **(fig.86)**. Here the top node cannot deform or move because of its fixed position and the bottom node can deform with respect to the load value. Since the top node is restricted from moving, it is said to have ***restrained degree of freedom*** whereas the bottom node is said to have ***unrestrained degree of freedom*** because of its free displacement without any restriction. In FEM, the degree of freedom is often called as ***nodal displacement***.

In actual practice, the deformation can occur among twelve directions – six linear directions (plus and minus directions of X, Y and Z co- ordinates) and six rotational directions (clockwise and anticlockwise rotations) with respect to X, Y and Z co-ordinates. **(fig.87)**

Boundary conditions: (fig.88)

The boundary condition of the FEA models is defined so that all the movements at the base of the model are restrained. This manner of restraining prevents the model from any rigid body motion while the load is acting.

Boundary conditions are of 2 types:

1. Geometric or essential boundary conditions

   These are very essential for a system. Without these the system cannot exist in equilibrium conditions (stable conditions).

2. Natural or optional boundary conditions

   In the mandibular model given below, boundary conditions are placed at seven regions: bilateral condyle, coronoid, angle and mandibular symphysis.

- ROLE OF COMPUTER AND SOFTWARE PACKAGES FOR FEM

  After defining FEA model, information like properties of elements, locations, applied loads and boundary conditions is fed into the computer. The computer then uses this information to generate & solve the equations necessary to carry out the analysis.

Some popular FEA softwares: ANSYS, ABAQUS, NASTRAN, ASKA, DYNA, COSMOS, I- DEAS.

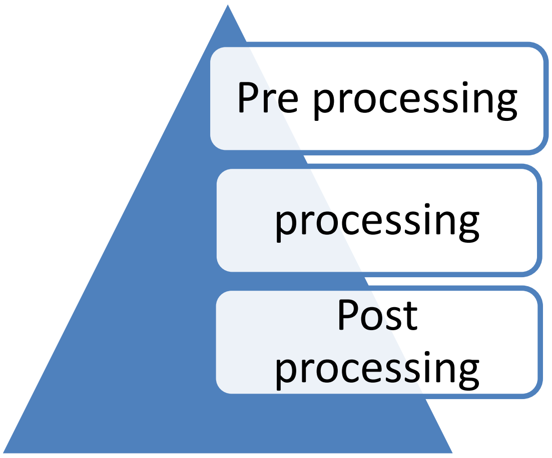
❖ APPLICATIONS OF FEM

- Civil engineering structures
- Automobile manufacturing
- Aircraft structures
- Mechanical design
- Heat conduction
- Hydraulics & water resources engineering
- Electrical machines & electromagnetics
- Nuclear engineering
- Geomechanics
- Biomedical engineering

❖ FEM AND DENTISTRY

1st fem study in dentistry was done in 1974 by Farah & Craig. He did a finite element stress analysis in a restored asymmetric 1st molar**.**FEM is useful for structures with inherent material homogeneity & potentially complicated shapes such as dental implants. It is used for analysis of stresses produced in the periodontal ligament when subjected to orthodontic forces. It is also used to evaluate the mechanical stress in plates used for fracture fixation and screw - plate - bone interface. It has found its way in investigating stress distribution in a tooth with cavity preparation & thus optimizing the design of dental restorations. The biomechanics of tooth movement can be studied with the help of it. It is being accurately used to assess the effect of new appliance systems & materials without the need to go to animal or other less representative models.

❖ BASIC STEPS OF FEA



I. PRE PROCESSING

It consists of creation of a FEA model from the geometric model by the pre processor module. Steps followed in preprocessing:

STEP 1: SELECTION OF THE TYPE OF ELEMENT

For regular shape like block, cylinder, or uniform cross section, *brick type element* is used. For irregular geometry, like 3 D model of mandible, *tetrohedro*element type is used.

STEP 2: ASSIGNING MATERIAL PROPERTIES TO THE FE MODEL

For stress strain analysis 2 essential parameters need to be defined:

1. Elastic modulus
2. Poisson's ratio

STEP 3: CREATION OF MODEL GEOMETRY

The simulation can be carried out in a 2D or 3D Geometry.

STEP 4: MESH GENERATION

A 2D or 3D model is meshed with elements defined in the 1st step & material properties defined in the 2nd step. The mesh process is to divide the geometric model created in the 3rd step into small finite divisions.

STEP 5: APPLICATION OF STRUCTURAL LOADS AND CONSTRAINTS TO THE MODEL

II. PROCESSING / SOLUTION

Here the model is solved using the solution module. Before solving the model, loading steps and output format of the solution needs to be specified.

III. POST PROCESSING

Results of the analysis can be accessed and reviewed using general Postprocessor module. The module provides 3 fundamental functions to review the results:

1. Plot result
2. List & export result
3. Plot graphs result

Plot result:

- Plot result function allows to review the results of analysis in a format of contour or vector graph.

List & export result:

- It allows to carry out process using spreadsheet software such as Excel.

❖ ADVANTAGES OF FEM

- It is a non invasive technique.
- Any problem can be split into a smaller no of problems.

- It does not require extensive instrumentation.
- Three dimensional evaluation of any structure can be done.
- Actual physical properties of the material involved can be simulated.
- Reproducibility does not affect the physical properties of the material involved.
- The study can be repeated as many times as the operator wants.
- This closely simulates natural conditions.
- Linear and non linear stress analysis can be performed.
- Static and dynamic stress analysis can be done.

❖ DISADVANTAGES OF FEM

- FEA is a time consuming process.
- The tooth is treated as pinned to the supporting bone, which is considered to be rigid & the nodes connecting the tooth to the bone are considered fixed. This assumption will introduce some error.
- The result obtained using FEM will be closer to exact solution only if the system is divided into large no of small elements. Otherwise there may be a considerable variation from the exact solution.
- FEM cannot produce exact results as those of analytical methods.
- Without a sound knowledge in mathematics, especially in matrix algebra, differentiation and integration, solving problem using FEM is highly difficult.

In the present finite element study, a 3- Dimensional mandibular model was created. Two designs of angle fractures were configured on the left side of the mandibular model. A total of 3 mandibular models were solved. In design 1, the fracture line was running distal to the mandibular 2nd molar, from the alveolar crest to and through the lower border of mandible; whereas in design 2, the fracture line ran between the 1st molar and the 2nd molar, from the alveolar crest to and through the lower border of mandible. Both the fracture lines in mandibular models for design 1 and 2 were stabilized with 8 hole3- dimensional miniplate. The fracture line in design 3 was similar to design 1 except that the line was not stabilized by any plate.

Stress distribution and displacement patterns:

It is an accepted fact that early and safe mobilization is important for fractured patients after reduction: first, it ensures the provision of all the nutrition the patient needs; and second, it avoids bone loss resulting from lack of physiologic stimulation. The stress distribution of a reduced mandible with miniplates differs from that in the intact mandible during mastication.[57]

In this study, we simulated bilateral molar clenching as the basic loading condition, to investigate stress distribution in the fractured mandibular angle reduced with 3- D miniplate and then contrasted the results with the intact mandible.

In design 1, the maximum amount of von misses stress on the 3-D plate was 296.467 Mpa. It was seen on the centre of the connecting bar between the right medial and the left medial superior holes of the plate and on the lateral aspect of the right medial hole of the lower bar of the plate. The monocortical screws which were used to fix the plate showed a maximum stress of 125.87 Mpa below the screw head in the right medial superior screw .However the maximum stress recorded on the cortical bone and the cancellous bone was 216.015 Mpa and 32.885 Mpa respectively. This indicates that majority of the stress is taken up by the plate and remainder of it is distributed between the cortical bone and the cancellous bone. The amount of deformation which occurred in the full model and its components – 3D plate, screws, PDL, cortical bone and cancellous bone was maximum in the y-axis showing more vertical deformation than mesio- distal and bucco – lingual deformation.

In design 2, the 3-D plate showed a maximum stress of 379.699 Mpa. This was seen on the superior border of the connecting bar between the right medial and the left medial superior holes of the plate. 157.117 Mpa of von misses stress was observed on the screws used for fixation of the 3-D plate.This stress maximum was on the right and left margins of screw head for right medial and left medial screws of upper bar. But the cortical bone and the cancellous bone took up a maximum von mises stress of 112.051 Mpa and 9.068 Mpa respectively. This stress distribution pattern indicates that maximum amount of stress is being sheared by the 3–D imensional plate and the monocortical screws used to fix it and relatively less amount of stress gets distributed in the cortical and cancellous bone. This is a favourable finding and substantiates the use of 3-D miniplate in mandibular angle fracture fixation. Also, vertical deformation was more than the mesiodistal and buccolingual deformation for all the components of the model in design 2.

However if we compare design 1 and 2 , the 3- D plate which is used to fix the fracture line in design 2 shows more stress than the same plate used for fixation of the fracture line in design 2. Similarly the monocortical screws in design 2 revealed more stress than the screws in design 1.

The maximum amount of stress distribution in full mandibular model for design 3 was 74.392 Mpa. Here the fracture line was not stabilized by any plate and thus the cancellous bone received the maximum amount of stress of 48.898 Mpa. Thus the distal fragment containing the dentoalveolar segment showed vertical displacement with a step at the lower border. This clearly reflects the importance of fixation and stabilization of a fracture with plates which will ensure healing by primary intention and early functional rehabilitation of the patient.

With the work done and the results obtained in this finite element study, further experience and knowledge is required in the following areas:

Firstly, regarding the boundary conditions or stops. In the present FE mandibular model, the boundary condition was not applied to the lower border. Consequently, vertical deformation or deformation in the Y- axis was more. Secondly, various patterns of fracture lines for horizontally favourable and unfavourable fractures need to be simulated in the 3-Dmandibular model in order to draw out more meaningful results.

Here there was no simulation done for the muscle forces which were exerted on the mandible at the time of clenching. But incorporation of the mechanical influence of other muscles, ligaments, temporomandibular joint (TMJ), are necessary to obtain a numerical simulation more close to the in vivo conditions. Inevitably, this makes the solving part relatively complex. The masticatory loads applied here were in a direction perpendicular to the occlusal surface of teeth. This is so because the vector of the masticatory motion mostly consists of a vertical component (y-axis). [41]But actually masticatory motion is like a teardrop cycle [41], which means the frontal plane trace of a molar is like a teardrop and not a straight line.

Material properties greatly influence the stress and strain distribution in a structure. In our study, the bony structures were simplified to be homogenous and isotropic with linear elastic behavior. Bone however, is an organic tissue with a complex anisotropic and heterogeneous microstructure with a strong nonlinear behavior. Therefore, the representation of bone in numerical models requires special attention, particularly when the bone additionally interacts with plates and screws. Also high cost is involved in FEA work and a detailed knowledge is required for understanding and operating FE softwares.

SUMMARY & CONCLUSION

Our results suggest that 3- Dimensional plating system is a suitable method for fixation of simple mandibular angle fractures. The 3- D design incorporates more implant material and the vertical bars resist torque forces, which favours stability. Post-operatively, no infection or wound dehiscence developed in the patients. Hence, the morbidity associated with the use of the plate is very low. But it is difficult to adapt than a conventional miniplate, which lead to increased operative time.

3-D plate is unfavourable to use in cases of angle fractures with lingual splaying and those involving the mental nerve. However, another study with a larger sample size would give definitive results.

Finite element analysis, originally used in structural analysis has revolutionized dental biomedical research.

It can make clinically relevant predictions about mandibular loading with various plating systems. It is also useful in evaluation of different types of fractures and fracture sites, as evident with our study results and those in the literature. The advantage of configuration of 3-D plating system is that the stress distribution to bone, both cortical and cancellous is minimal as the plate takes up and imbibes maximum stress and load, which allows optimum physiologic bone growth and healing. Hence, new plating systems can be designed and experimented virtually where the metallurgy and physical properties of plate is biologically compatible to the properties of bone. This will save a lot of time and material on animal experiments.

FEA can provide an insight into the complex biomechanical behavior of the craniofacial complex and mandible. But it is technique sensitive, requires expensive softwares and skilled analysist.

Thus simultaneous evaluation of 3-D miniplate, both clinically and by finite element analysis delineates that the plate provides adequate stability and is useful for fixation of mandibular angle fracture.

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CASE PROFORMA

NAME OF PATIENT

AGE

SEX

CASE NO

ADDRESS

REGD NO

HEIGHT

WEIGHT

BLOOD INVESTIGATIONS

NATURE OF TRAUMA

1. Interpersonal violence
2. RTA
3. Fall
4. Sports injury
5. Industrial accident
6. Others

TYPE OF FRACTURE

- Isolated angle R/L

Associated fracture

- Parasymphysis fracture

Angle fracture

- Vertically Favourable/ unfavourable
Horizontally favourable / unfavourable

SEVERITY OF DISPLACEMENT

Undisplaced

Mild

Moderate

Severe

HABITS

	Injury	Reporting	Surgery	Complications	Comp/plate removal
DATES					
Time elapsed from injury/surgery					

SURGICAL RECORD

TREATMENT PLAN	ANGLE FRACTURE	ASSOCIATED MANDIBULAR FRACTURE
	ORIF / CONSERVATIVE	ORIF / CONSERVATIVE
IF ORIF	MINIPLATE	MINIPLATE
	3D PLATE	3D PLATE
	WIRES	WIRES

ANAESTHETIST	SURGEON	ASSISTANT	YRS OF EXPERIENCE OF SURGEON
			0 – 3 3 – 6 >6

TYPE OF ANAESTHESIA	ANAESTHESIA START	SURGERY START	SURGERY END	ANAESTHESIA END
L.A G.A SEDATION				

DURATION OF SURGERY

TOTAL DURATION

INCISION	ANGLE	ASSOCIATED FRACTURE	PLATES
	EXTRA ORAL PER ORAL	EXTRA ORAL PER ORAL	STAINLESS STEEL TITANIUM RESORBABLE

CLOSURE - SINGLE SILK USE OF TROCAR

2 LAYERS VICRYL YES/NO

CATGUT

INTEROPERATIVE MEDICATION POSTOPERATIVE MEDICATION

CLINICAL ASSESSMENT FOR ANGLE FRACTURE

THIRD MOLAR

Present / absent

If present – infected / non infected

	PRE OP	1ST POST OP (2WEEKS)	2ND POST OP (6WEEKS)	3RD POST OP (3 MONTHS)	4TH POST OP (6 MONTHS)	5TH POST OP (1 YEAR)
SWELLING						
DERANGEMENT OF OCCLUSION						
PAIN/TENDERNESS						
NEURO SENSORY DEFICIT						
MOUTH OPENING						
ABILITY TO CHEW						

COMPLICATIONS IF ANY

	PRE OP	1ST POST OP (2WEEKS)	2ND POST OP (6WEEKS)	3RD POST OP (3 MONTHS)	4TH POST OP (6 MONTHS)	5TH POST OP (1 YEAR)
INFECTION						
WOUND DEHISCENCE						
LOOSENING OF SCREWS						
FRACTURE OF PLATE						
MALUNION						
NONUNION						

CONSENT FORM

I ______________________, the undersigned hereby give my consent for the required surgery for the study of 3D plate fixation being conducted by Dr. Ridhi Vasudeva, under guidance of Dr. Malini Jayaraj Professor, Dept of Oral and Maxillofacial Surgery, Ragas Dental College. I have been informed and explained the status of my problem, procedure or techniques of study. I also accept this as part of study protocol thereby voluntarily, unconditionally, freely give my consent without any form of pressure in mentally sound and conscious state to participate in the study.

DESIGN NO 1 - FRACTURE LINE DISTAL TO MANDIBULAR 2ND MOLAR, STABILIZED WITH 3- D MINIPLATE

EVALUATION OF VON MISSES STRESS (IN MPA)

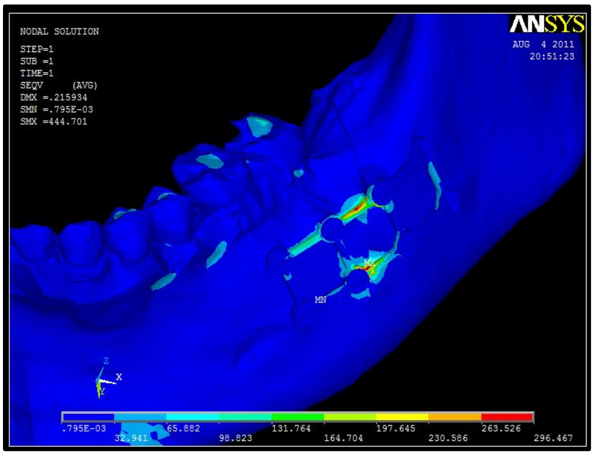


Fig.19

I. VON MISES STRESS IN THE FULL MODEL:

Step = 1
Sub = 1 ⟶ linear static analysis
Time = 1
SEQV : von mises stress
SMX : stress maximum
SMN : stress minimum
Maximum stress: 296.467 Mpa, Minimum stress: .795E-03 Mpa

- Stress max occurs on the

1. superoposterior aspect of the right medial screw of the lower bar of the plate near the fracture line .
2. The superior border of the connecting upper bar between the left medial screw and the right medial superior screw which crosses the fracture line.
3. Above picture gives the overall idea of magnitude of stress generated but doesn’t tell the exact region of higher stress, hence stress patterns for individual components are shown below.

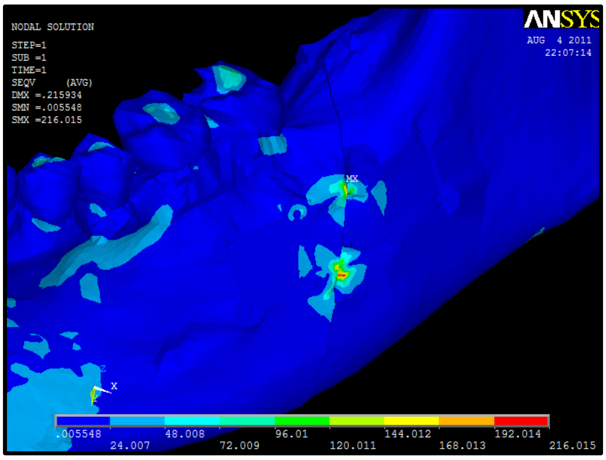


Fig.20

II. VON MISES STRESS IN THE CORTICAL BONE :

Maximum stress: 216.015 Mpa

Minimum stress: .005548 Mpa

Maximum stress is only at the small region in red colour which is the stress concentration region, and this is the region at which crack initiates before failure occurs.

1. It is present at the inferior aspect of the left margin of the fracture line.
2. Apart from the stress concentration region the average stress in the cortical bone is around 72 to 96 MPa (cyon and green colour).

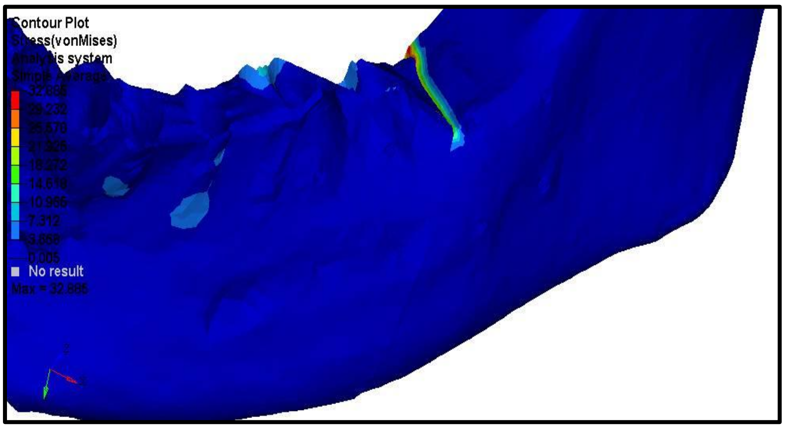


Fig.21

III. VON MISES STRESS IN THE CANCELLOUS BONE :

Maximum stress: 32.885Mpa

Minimum stress: 0.005Mpa

- Right side segment in the above image has higher stress and is due to compressive force
    1. It is seen on the lingual aspect of the fracture line near the crest.

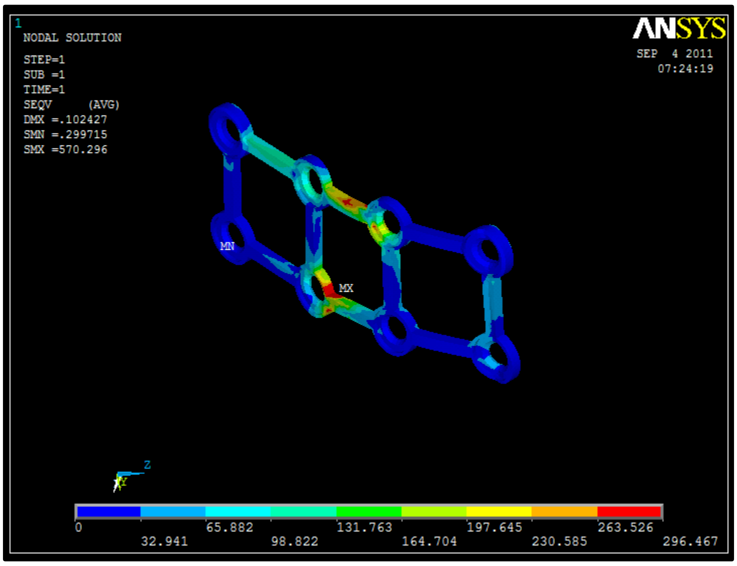


Fig.22

IV. VON MISES STRESS ON 3- D PLATE :

Maximum stress: 296.467Mpa

Minimum stress: 0.00 Mpa

- Highest stress region is in the centre bars of the plate, and since the yield strength for titanium is more than 800MPa plate is safe for the applied load.
- Stress max occurs on the
    1. Centre of the connecting bar between the right medial and the left medial superior holes of the plate.
    2. On the lateral aspect of the right medial hole of the lower bar of the plate.

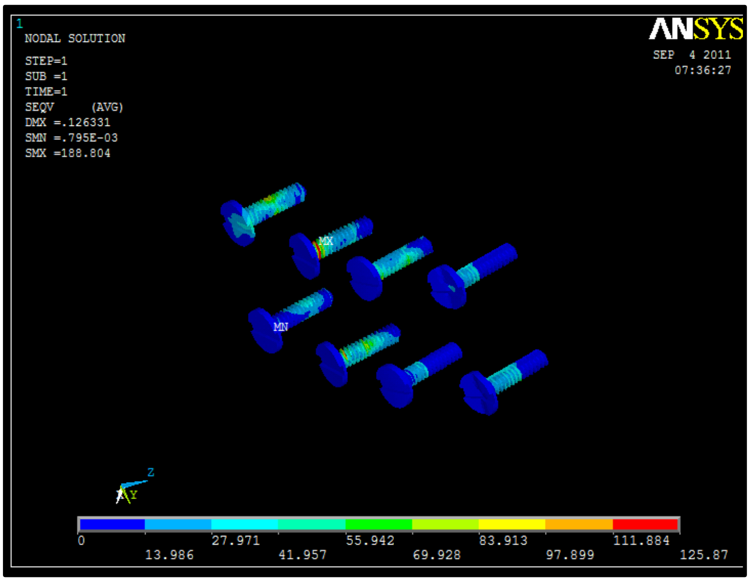


Fig.23

V. VON MISES STRESS ON THE SCREWS :

Maximum stress: 125.87 Mpa

Minimum stress: 0.00 Mpa

- Stress max occurs
    1. Below the head of the screw in the right medial superior screw.
- Highest stress region in the screw is near the neck of the screw, and since the yield strength for titanium is more than 800MPa screws are safe for the applied load

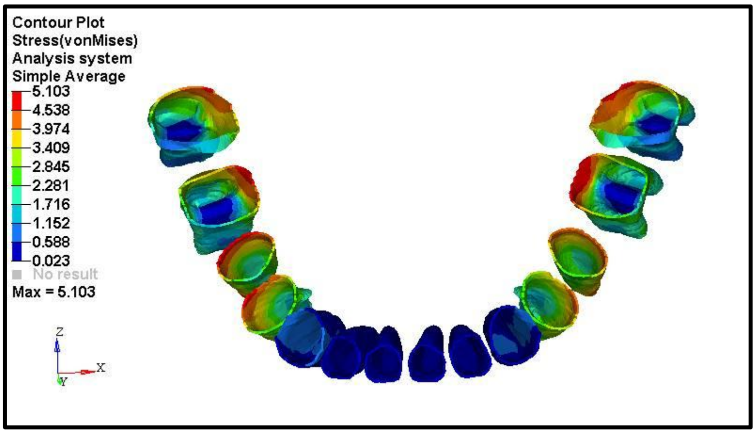


Fig.24

VI. VON MISES STRESS ON THE PERIODONTAL LIGAMENT :

Maximum stress: 5.103Mpa

Minimum stress: 0.023Mpa

Maximum stresses are observed on the posterior PDL's and also on the crest region. Front 6 PDL's are having minimum stress.

MEASUREMENT OF DEFORMATION / MOVEMENT (in mm)

I. DEFORMATION / MOVEMENT IN FULL MODEL (in mm)

X AXIS :

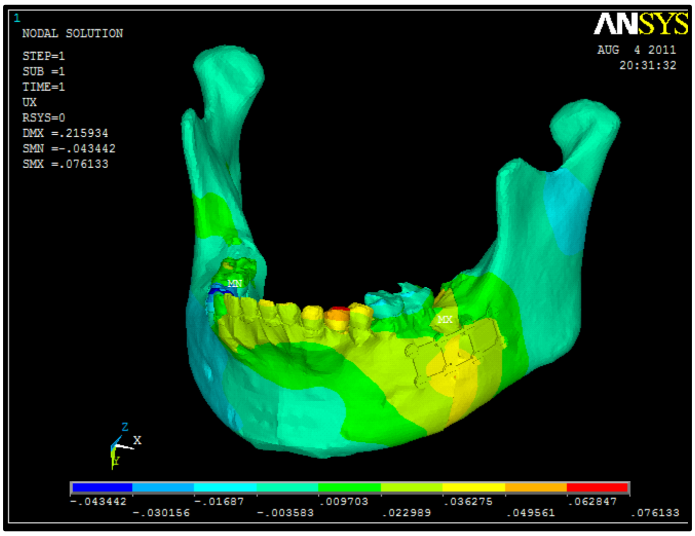


Fig.25

Step = 1

Sub = 1 → linear static analysis

Time = 1

Ux : displacement / movement in x axis

RSYS : resultant coordinate system

SMN : strain minimum

SMX : strain maximum

Maximum displacement / movementmesiodistally: .076133 mm

Minimum displacement / movementmesiodistally: -.043442 mm

Maximum displacement occurs on the cusp tip of 1st premolar on the fractured side.

Y AXIS :

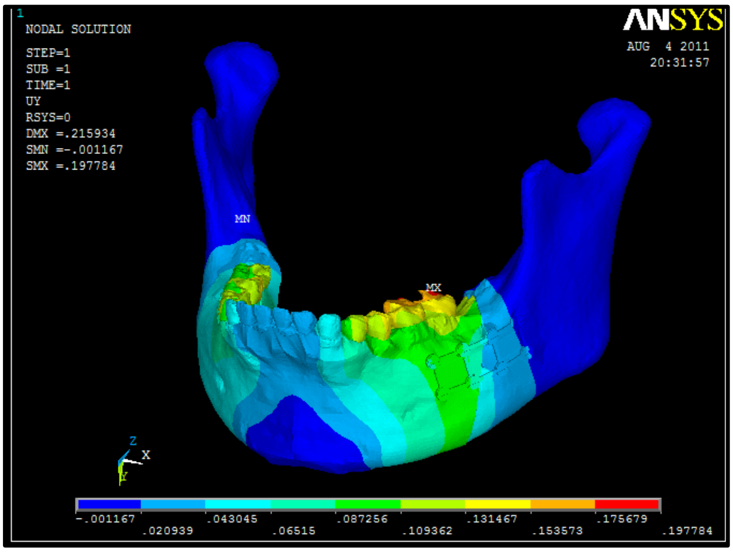


Fig.26

Uy : displacement / movement in y axis

+ve : movement upwards

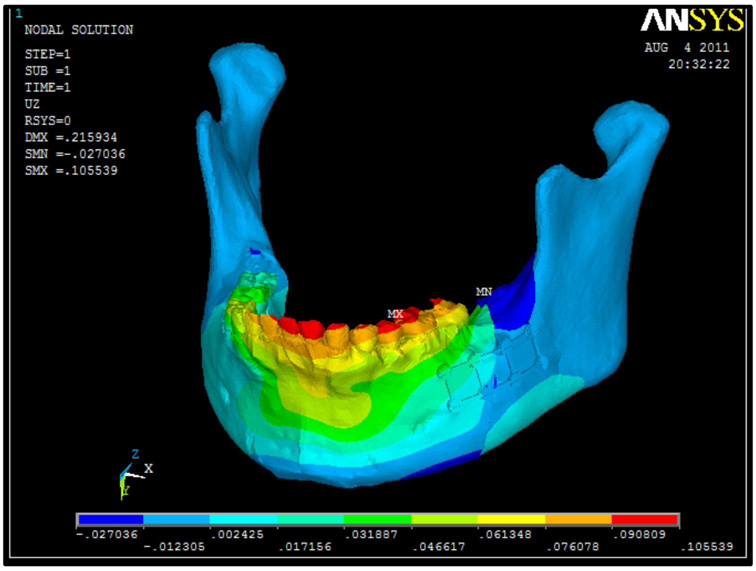
-ve : movement downwards

Maximum displacement / movement vertically : .197784 mm

Minimum displacement / movement vertically : -.001167 mm

Maximum displacement occurs on the distolingualcusp of 1st molar on the fractured side.

Z AXIS :



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UZ
RSYS=0
DMX =.215934
SMN =-.027036
SMX =.105539
```

Fig.27

Uz : displacement / movement in z axis

Maximum displacement / movement in buccolingualdirection : .105539 mm

Minimum displacement / movement in buccolingualdirection : -.027036 mm

Maximum displacement occurs over the incisal edges and cusp tips of premolars and molars on the fractured side.

II. DEFORMATION IN 3- D PLATE (in mm) :

X AXIS :

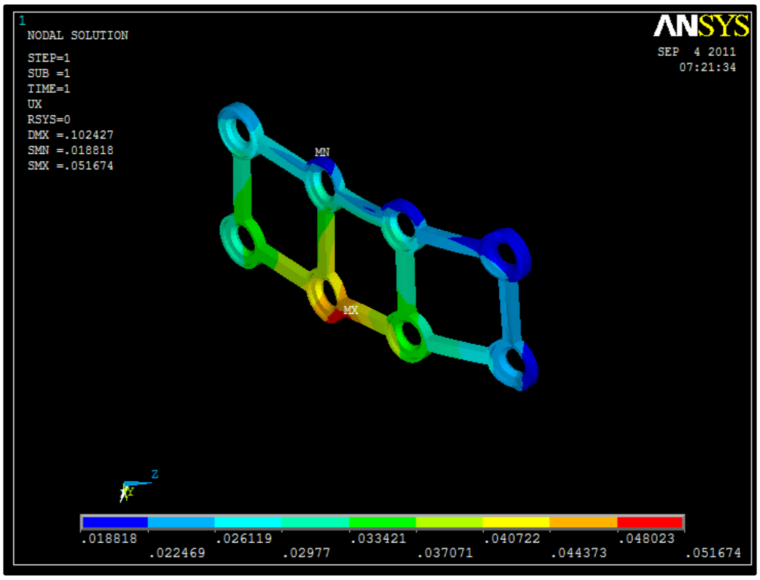


Fig.28

Maximum mesiodistal deformation: .051674 mm

Minimum mesiodistal deformation : .018818 mm

Maximum deformation is seen over the bottom of the right medial hole of the lower bar of the plate.

Y AXIS :

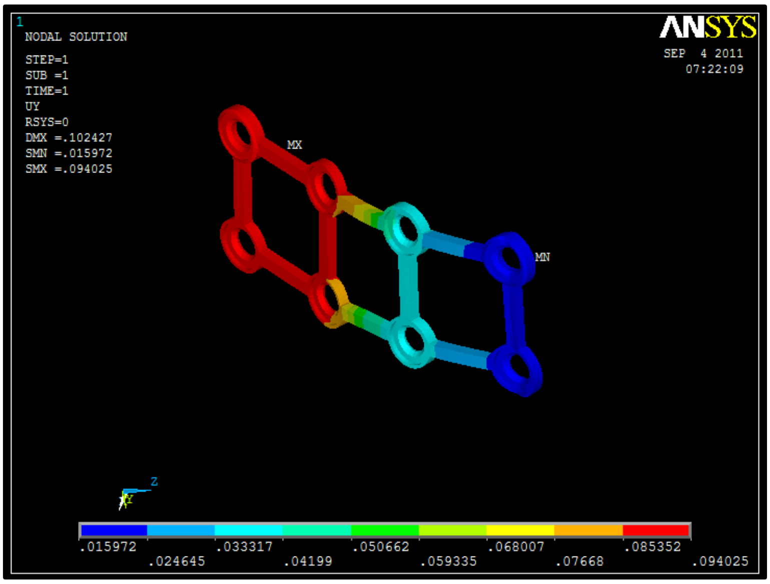


Fig.29

Maximum vertical deformation: .094025 mm

Minimum vertical deformation: .015972 mm

Maximum deformation is seen over the right side of plate involving the 2 holes of the upper bar and 2 holes of the lower bar.

Z AXIS:

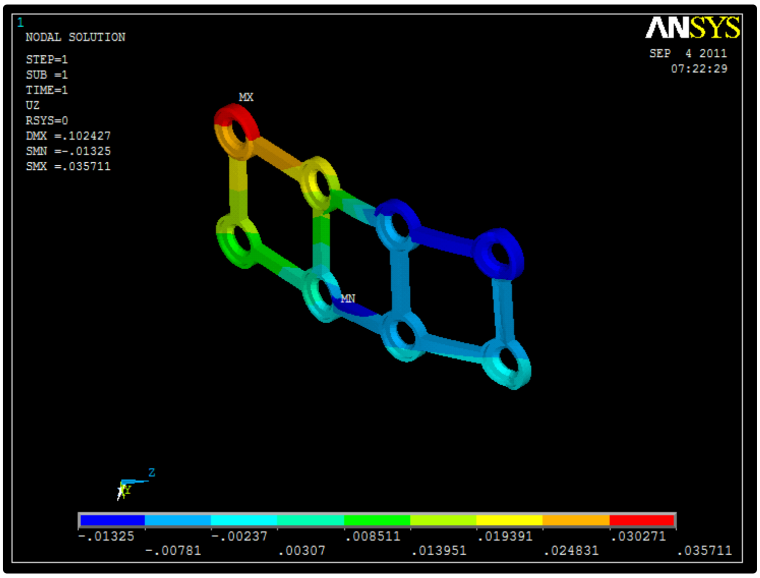


Fig.30

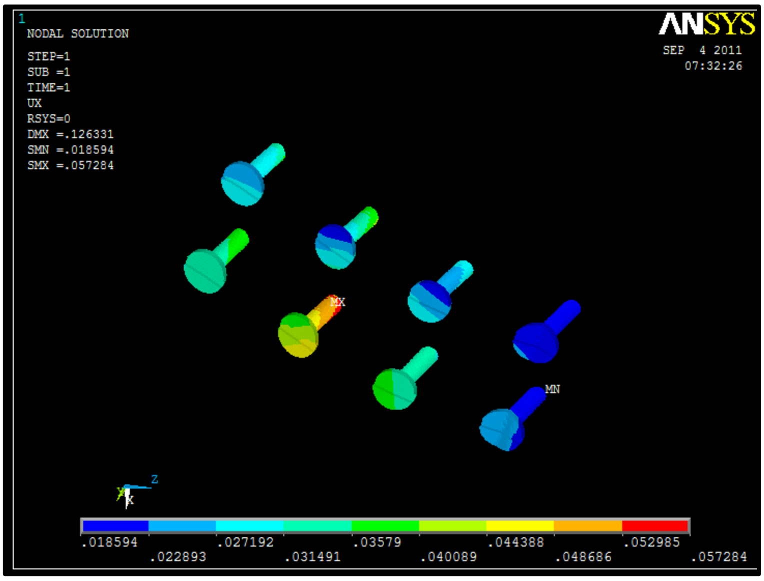
Maximum buccolingual deformation : .035711 mm

Minimum buccolingual deformation : -.01325 mm

Maximum deformation is seen over the superior aspect of the right laeral hole of the upper bar of plate.

III. DEFORMATION / MOVEMENT OF SCREWS (in mm):

X AXIS :



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UX
RSYS=0
DMX =.126331
SMN =.018594
SMX =.057284
```

Fig.31

Maximum mesiodistal deformation: .057284 mm

Minimum mesiodistal deformation: .018594 mm

Maximum deformation is seen over the apex of the right medial screw of the lower bar of the plate.

Y AXIS :

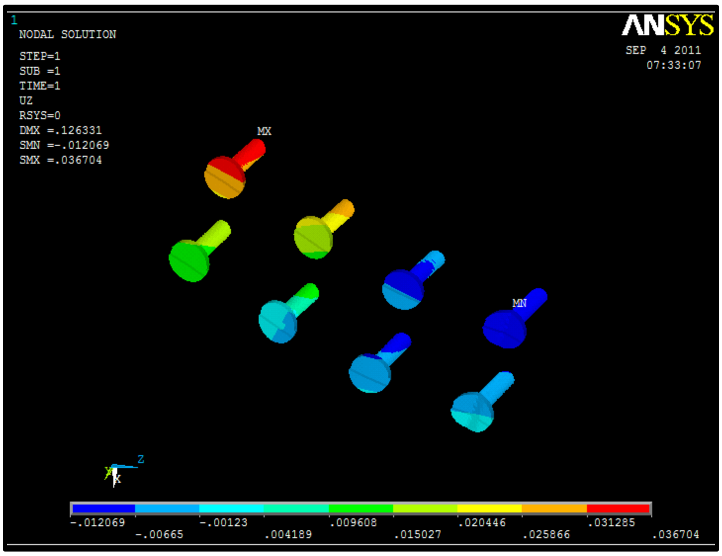
Fig.32

Maximum vertical deformation: .116047 mm

Minimum vertical deformation: .01651 mm

Maximum deformation is seen over the apex of the right medial and right lateral screw of the upper bar of the plate.

Z AXIS :



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UZ
RSYS=0
DMX =.126331
SMN =-.012069
SMX =.036704
```

```
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  07:33:07
```

Fig.33

Maximum buccolingual deformation: .036704 mm

Minimum buccolingual deformation: -.012069 mm

Maximum deformation is seen over three fouths of the right lateral screw of the upper bar of the plate.

IV. DEFORMATION IN CORTICAL BONE (in mm) :

X AXIS:

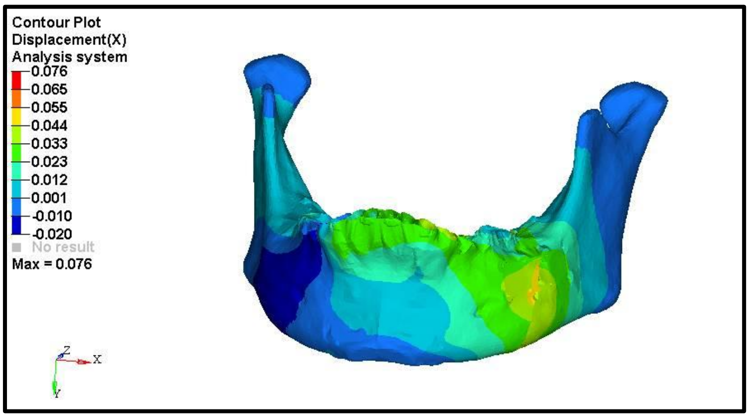


Fig.34

Maximum mesiodistal deformation: 0.076 mm

Minimum mesiodistal deformation: -0.020 mm

Increased deformation is seen over the margin of the fracture line.

Y AXIS :

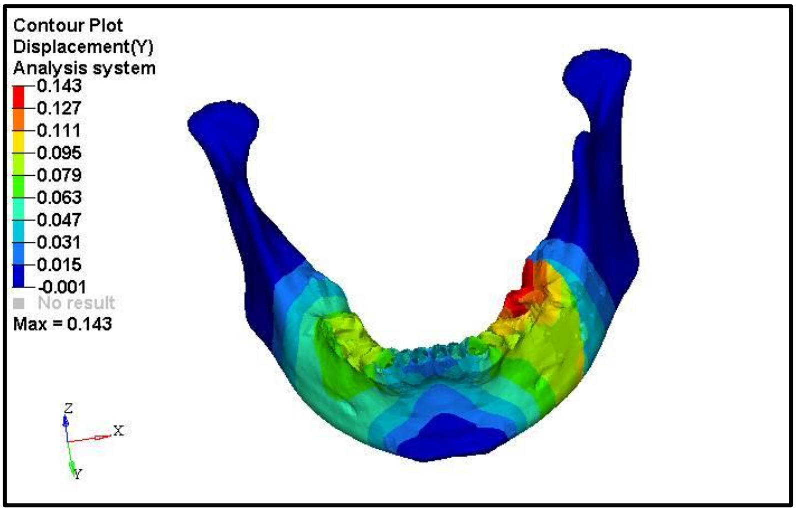


Fig.35

Maximum vertical deformation: 0.143 mm

Minimum vertical deformation : -0.001 mm

Maximum deformation is seen over the lingual aspect of the 2nd molar on the fractured side.

Z AXIS :

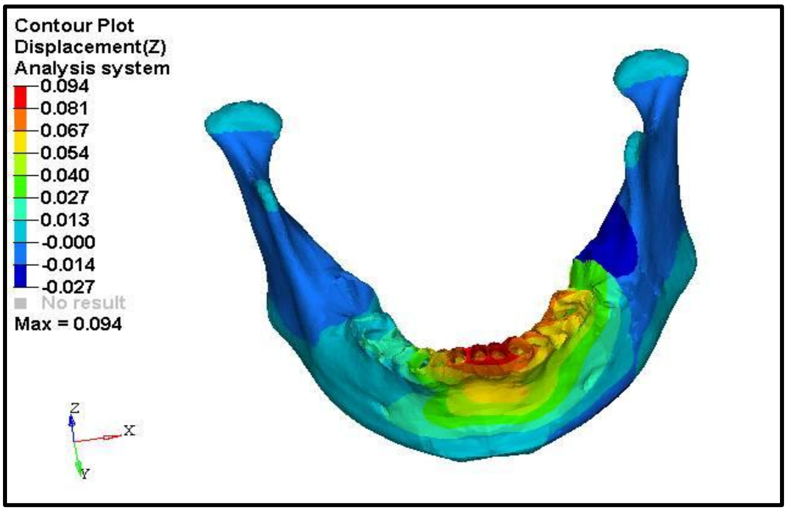


Fig.36

Maximum buccolingual deformation: 0.094 mm

Minimum buccolingual deformation: -0.027 mm

Maximum deformation is seen over the superior aspect of cortical bone in the anterior region.

V. DEFORMATION IN CANCELLOUS BONE(in mm):

X AXIS:

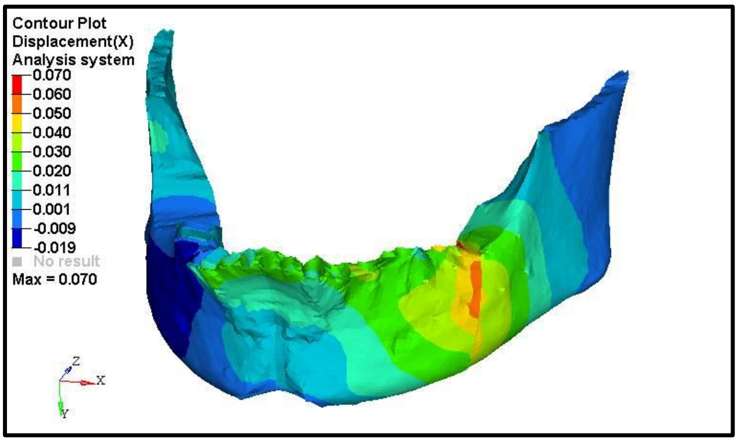


Fig.37

Maximum mesiodistal deformation: 0.070 mm

Minimum mesiodistal deformation: -0.019 mm

YAXIS :

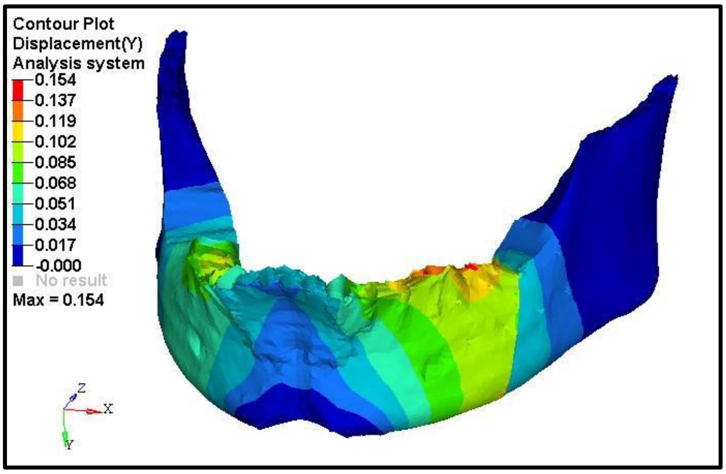


Fig.38

Maximum vertical deformation : 0.154 mm

Minimum vertical deformation : -0.000 mm

Z AXIS:

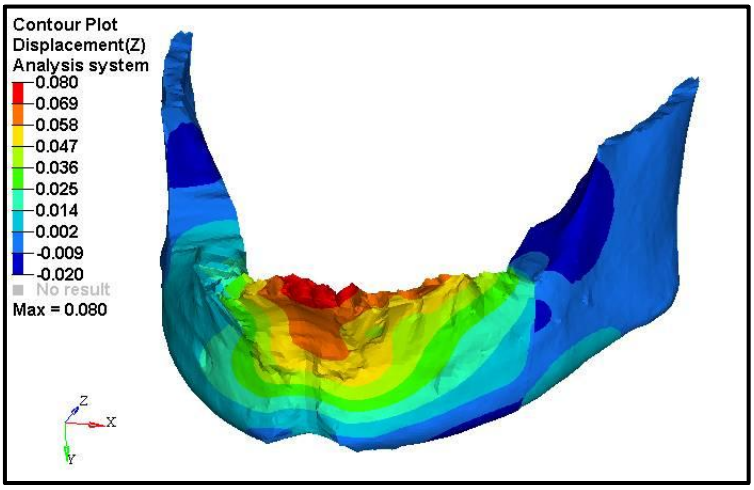


Fig.39

Maximum buccolingual deformation: 0.080 mm

Minimum buccolingual deformation: -0.020 mm

VI. DEFORMATION IN PERIODONTAL LIGAMENT(in mm):

X AXIS :

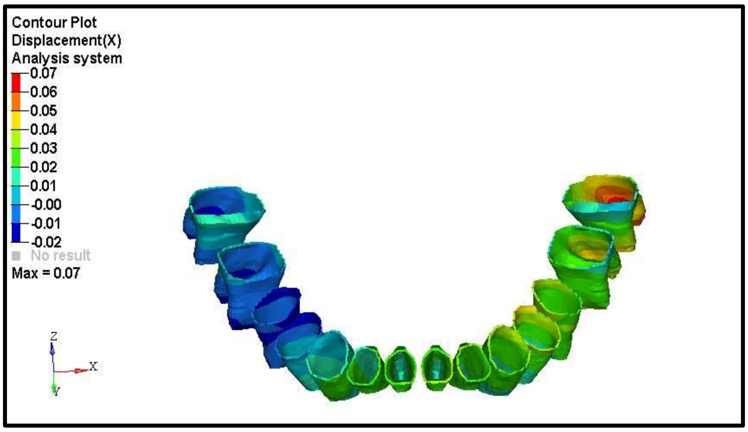


Fig.40
Maximum mesiodistal deformation: 0.07 mm

Minimum mesiodistal deformation: -0.02 mm

YAXIS :

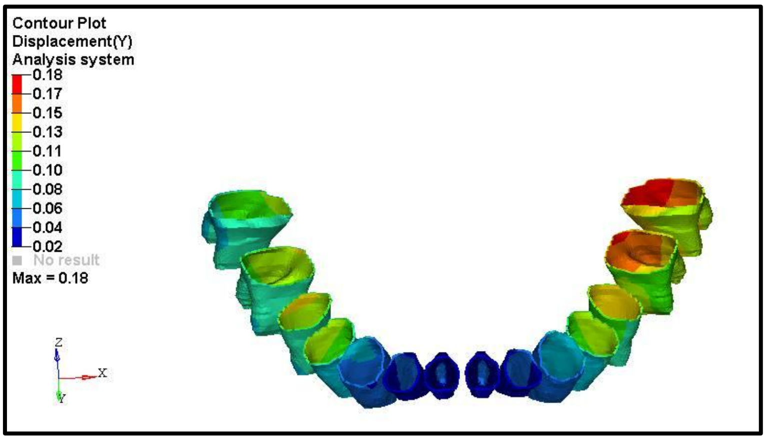


Fig.41
Maximum vertical deformation: 0.18 mm

Minimum vertical deformation: 0.02 mm

Z AXIS :

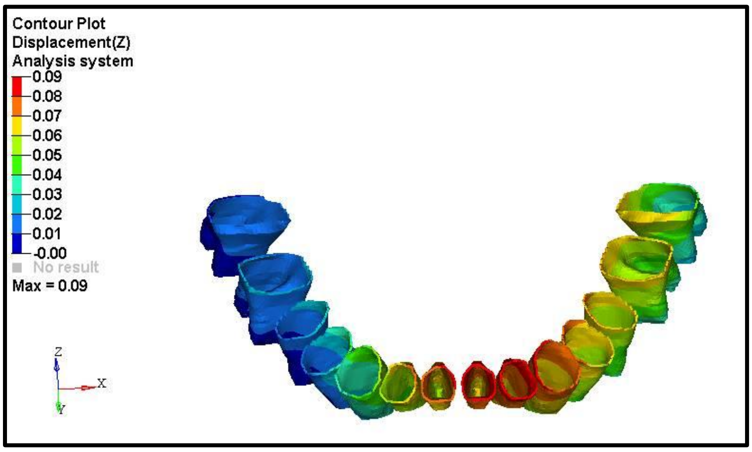


Fig.42

Maximum buccolingual deformation: 0.09 mm

Minimum buccolingual deformation: -0.00 mm

DESIGN NO 2 - FRACTURE LINE BETWEEN MANDIBULAR 1ST MOLAR AND 2ND MOLAR, STABILIZED WITH 3- D MINIPLATE

EVALUATION OF VON MISSES STRESS (IN MPA):

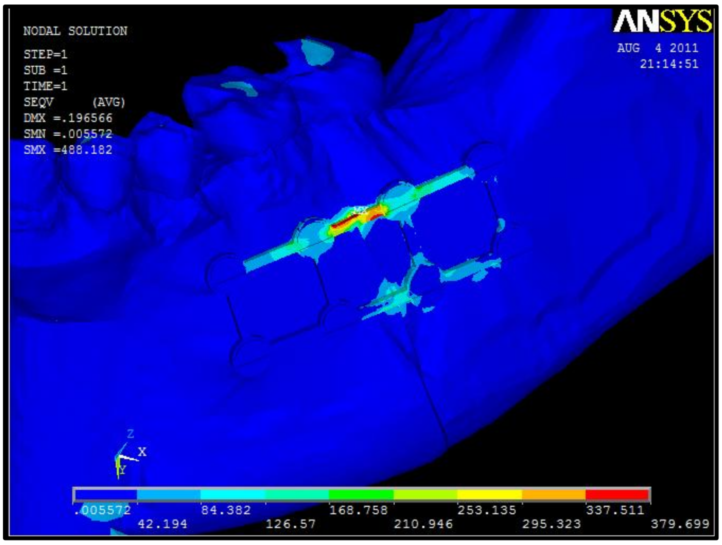


Fig.43

I. VON MISES STRESS IN THE FULL MODEL:

Maximum stress: 379.699 Mpa

Minimum stress: .005572 Mpa

1. Stress max is seen on the upper bar between the right medial screw and left medial screw on either side of the fracture line.
2. Above picture gives the overall idea of magnitude of stress generated but doesn’t tell the exact region of higher stress, hence stress patterns for individual components are shown below

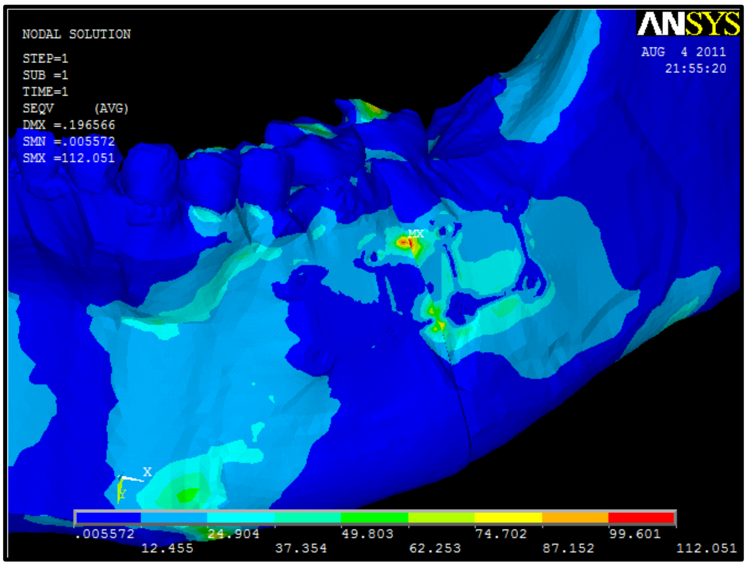


Fig.44

II. VON MISES STRESS IN THE CORTICAL BONE :

Maximum stress: 112.051 Mpa

Minimum stress: .005572 Mpa

1. Max stress is seen on the right and left superior margins of the fracture lineIt is only at the small region in red colour which is the stress concentration region, and this is the region at which crack initiates before failure occurs
2. Apart from the stress concentration region the average stress in the cortical bone is around 72 to 96 MPa(refer cyon and green colour)

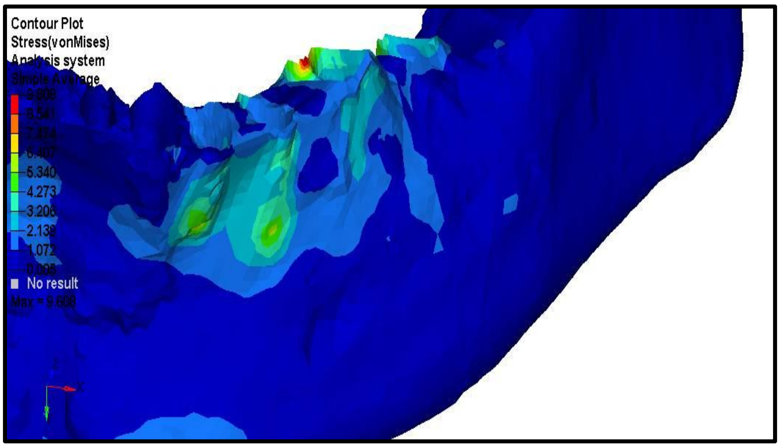


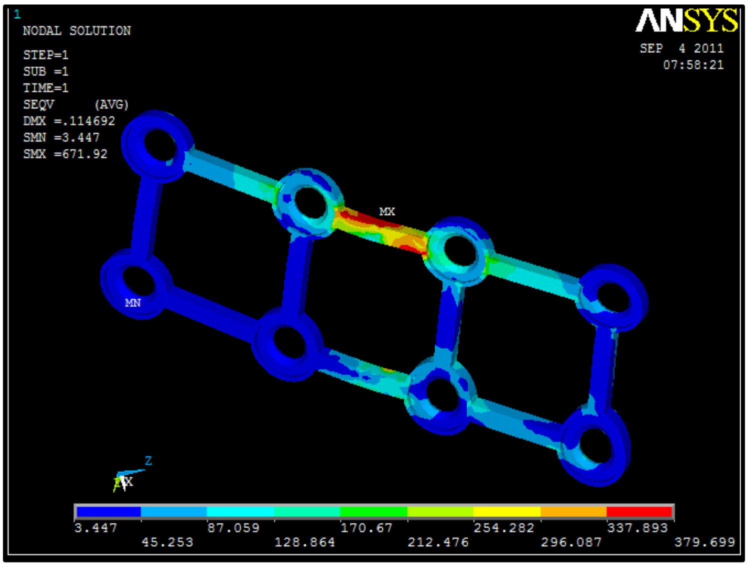
Fig.45

III. <u>VON MISES STRESS IN THE CANCELLOUS BONE :</u>

Maximum stress: 9.608 Mpa

Minimum stress: 0.005 Mpa

1. Max stress is present in the superior region of the cancellous bone.
2. Right side segment in the above image has higher stress and is due to compressive force



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
SEQV      (AVG)
DMX =.114692
SMN =3.447
SMX =671.92
```

Fig.46

IV. VON MISES STRESS ON 3- D PLATE :

Maximum stress: 379.699Mpa

Minimum stress: 3.447 Mpa

- Stress max occurs on the

1. Superior border of the connecting bar between the right medial and the left medial superior holes of the plate.
2. Highest stress region is in the centre bars of the plate, and since the yield strength for titanium is more than 800MPa plate is safe for the applied load

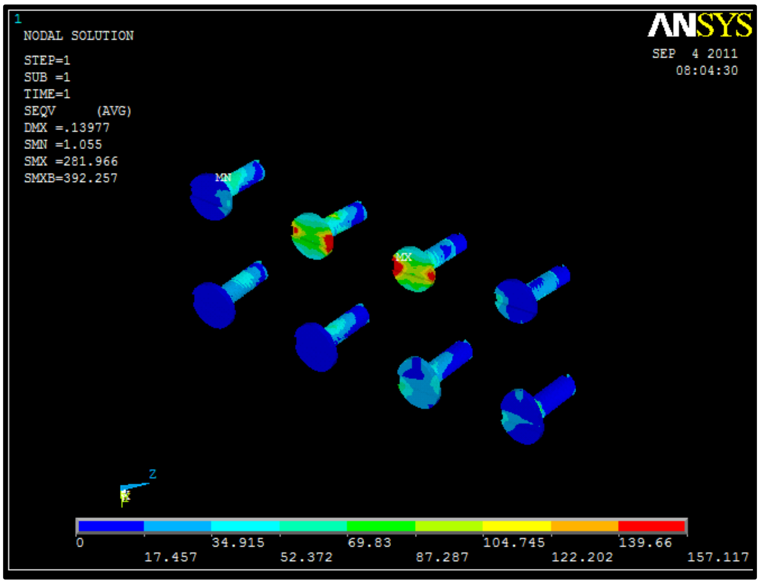


Fig.47

V. <u>VON MISES STRESS ON THE SCREWS :</u>

Maximum stress: 157.117 Mpa

Minimum stress: 0.00 Mpa

- Stress max occurs

1. On the right and left margins of screw head for right medial and left medial screws of upper bar.
2. Highest stress region in the screw is near the neck of the screw, and since the yield strength for titanium is more than 800MPa screws are safe for the applied load

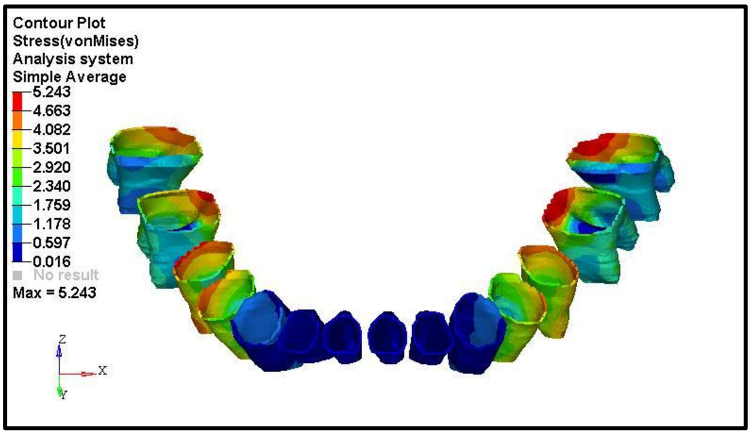


Fig.48

VI. VON MISES STRESS ON THE PERIODONTAL LIGAMENT :

Maximum stress: 5.243Mpa

Minimum stress: 0.016Mpa

Maximum stresses are observed on the posterior PDL’s and also on the upper crest region. Front 6 PDL’s are having minimum stress

MEASUREMENT OF DEFORMATION / MOVEMENT

I. DEFORMATION / MOVEMENT IN FULL MODEL(in mm):

X AXIS :

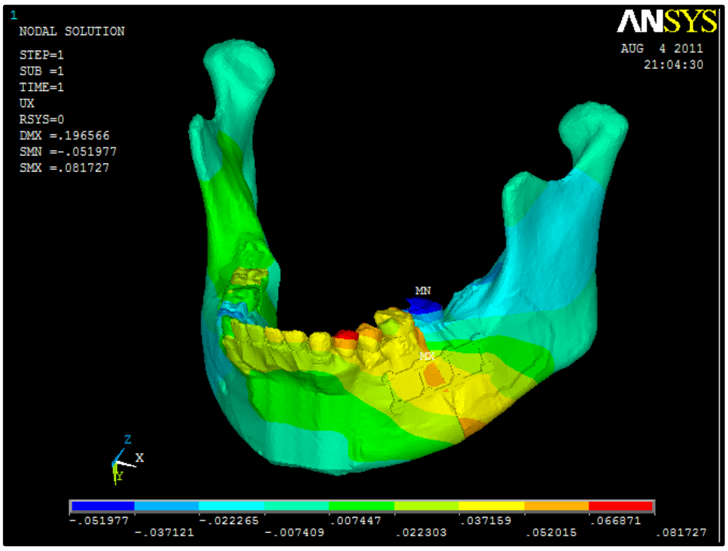


Fig.49

Step = 1
Sub = 1 → linear static analysis
Time = 1
Ux : displacement / movement in x axis
RSYS : resultant coordinate system
SMN : strain minimum
SMX : strain maximum

Maximum displacement / movement mesiodistally: .081727 mm

Minimum displacement / movement mesiodistally: -.051977 mm

Maximum displacement occurs on the cusp tip of 1st premolar on the fractured side.

Y AXIS:

Fig.50

Uy : displacement / movement in y axis

+ve : movement upwards

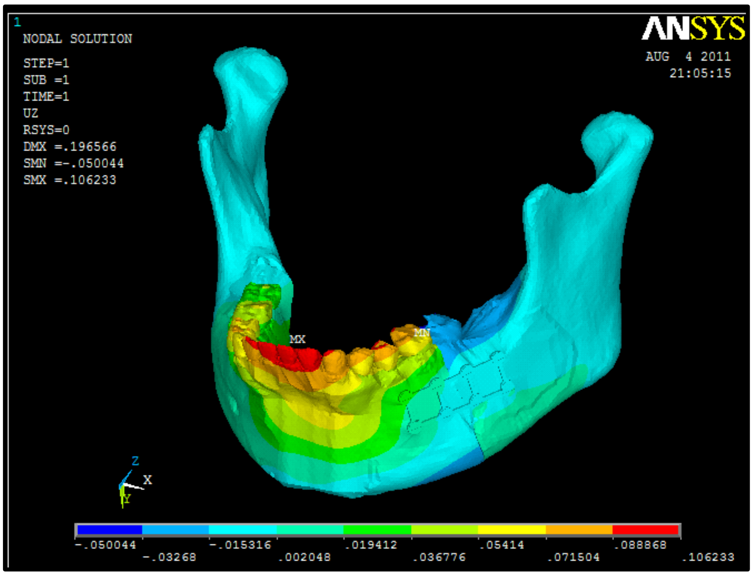
-ve : movement downwards

Maximum displacement / movement vertically: .177222 mm

Minimum displacement / movement vertically: -.001826 mm

Maximum displacement occurs on the distolingual cusp of 1st molar and 2nd molar on the fractured side.

Z AXIS:



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UZ
RSYS=0
DMX =.196566
SMN =-.050044
SMX =.106233
```

Fig.51

Uz : displacement / movement in z axis

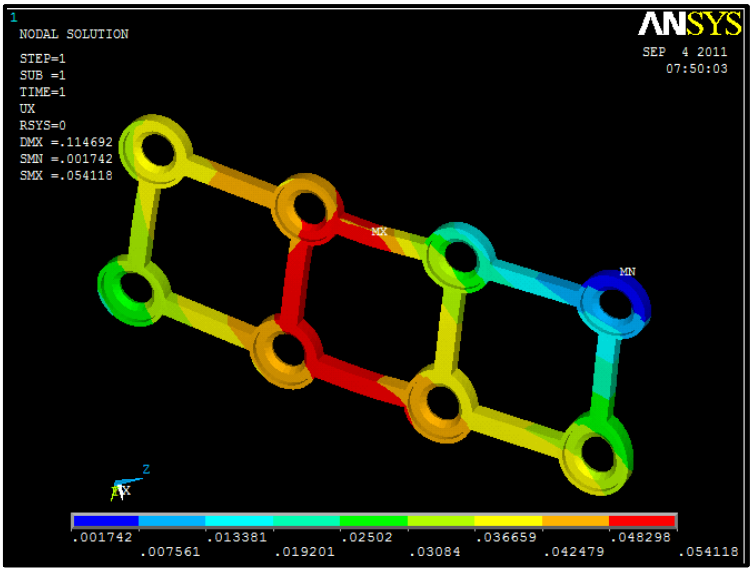
Maximum displacement / movement in buccolingual direction: .106233 mm

Minimum displacement / movement in buccolingual direction: -.050044 mm

Maximum displacement occurs over the incisal edges on the fractured side.

II. DEFORMATION OF 3- D PLATE (in mm) :

X AXIS:



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UX
RSYS=0
DMX =.114692
SMN =.001742
SMX =.054118
```

Fig.52

Maximum mesiodistal deformation: .054118 mm

Minimum mesiodistal deformation: .001742 mm

Maximum deformation is seen over

1. The right medial vertical bar.
2. Half of the horizontal connecting bar between the right medial and left medial upper and lower holes.
3. superomedial aspect of the right medial hole of the lower bar of the plate.
4. inferomedial aspect of the right medial hole of the upper border of the plate.

Y AXIS:

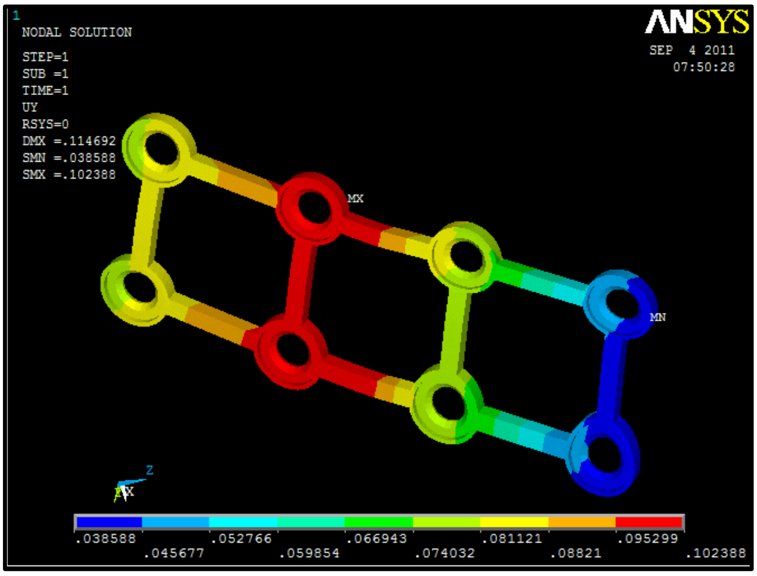


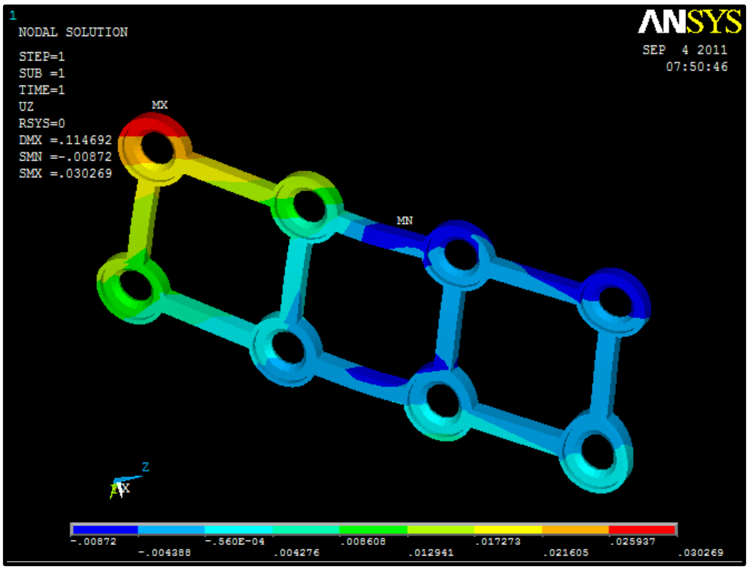
Fig.53

Maximum vertical deformation : .102388 mm

Minimum vertical deformation: .038588 mm

Maximum deformation is seen over the right medial holes of the upper and lower bar of the plate.

Z AXIS:



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UZ
RSYS=0
DMX =.114692
SMN =-.00872
SMX =.030269
```

```
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07:50:46
```

Fig.54

Maximum buccolingual deformation : .030269 mm

Minimum buccolingual deformation : -.00872 mm

Maximum deformation is seen over the superior aspect of the right laeral hole of the upper bar of plate.

III. DEFORMATION OF SCREWS(in mm) :

X AXIS:

```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UX
RSYS=0
DMX =.13977
SEPC=38.606
SMN =.002575
SMX =.064981
```

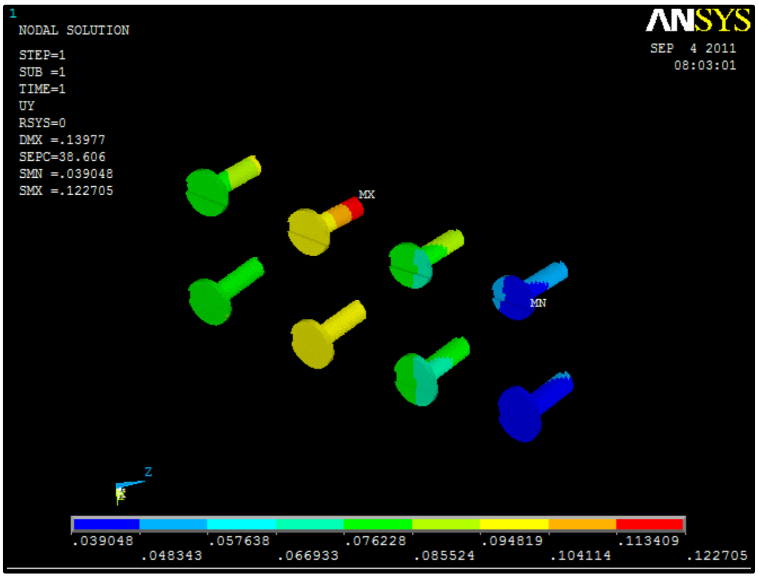
Fig.55

Maximum mesiodistaldeformation: .064981 mm

Minimum mesiodistaldeformation: .002575 mm

Maximum deformation is seen over the apex of the right medial screw of the upper bar of the plate.

Y AXIS:



```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
UY
RSYS=0
DMX =.13977
SEPC=38.606
SMN =.039048
SMX =.122705
```

Fig.56

Maximum vertical deformation: .122705 mm

Minimum vertical deformation: .039048 mm

Maximum deformation is seen over the apex of the right medial screw of the upper bar of the plate.

Z AXIS:

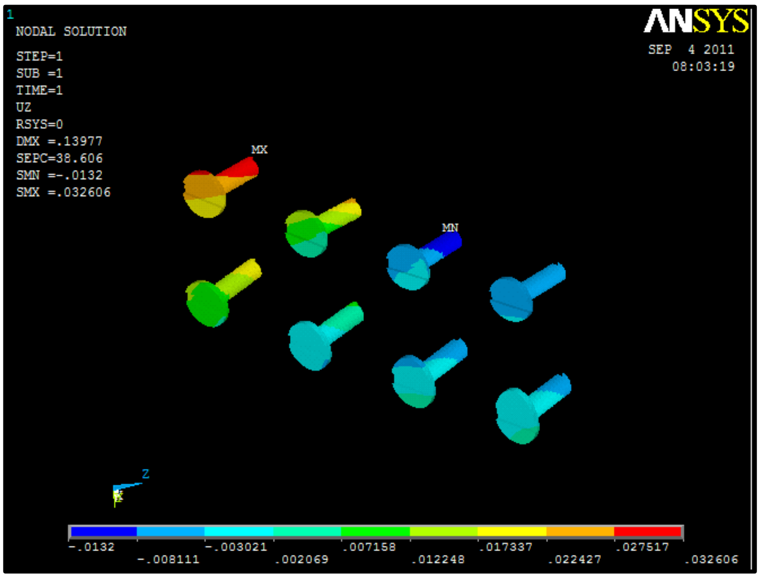


Fig.57

Maximum buccolingual deformation: .032606 mm

Minimum buccolingual deformation: -.0132 mm

Maximum deformation is seen over one fouths of the right lateral screw of the upper bar of the plate.

IV. DEFORMATION IN CORTICAL BONE (in mm) :

X AXIS:

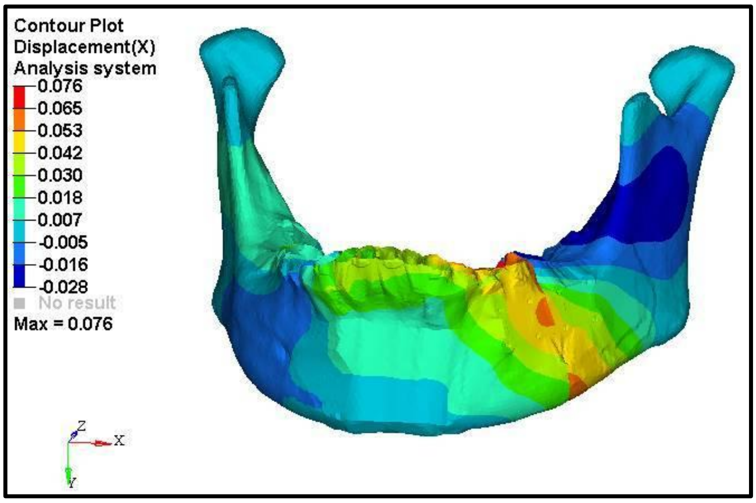


Fig.58

Maximum mesiodistal deformation: 0.076 mm

Minimum mesiodistal deformation: -0.028 mm

Increased deformation is seen over the margin of the fracture line.

Y AXIS:

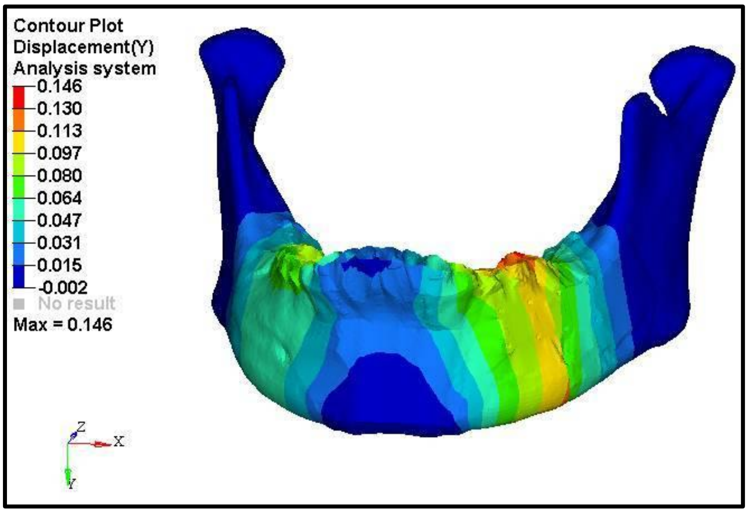


Fig.59

Maximum vertical deformation: 0.146 mm

Minimum vertical deformation: -0.002 mm

Maximum deformation is seen over the lingual aspect of the 2nd molar on the fractured side.

Z AXIS :

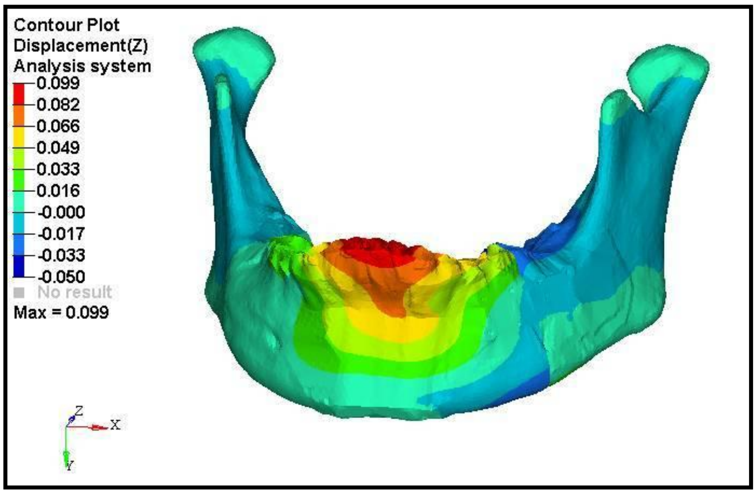


Fig.60

Maximum buccolingual deformation: 0.099 mm

Minimum buccolingual deformation: -0.050 mm

Maximum deformation is seen over the superior aspect of cortical bone in the anterior region.

V. DEFORMATION IN CANCELLOUS BONE(in mm):

X AXIS:

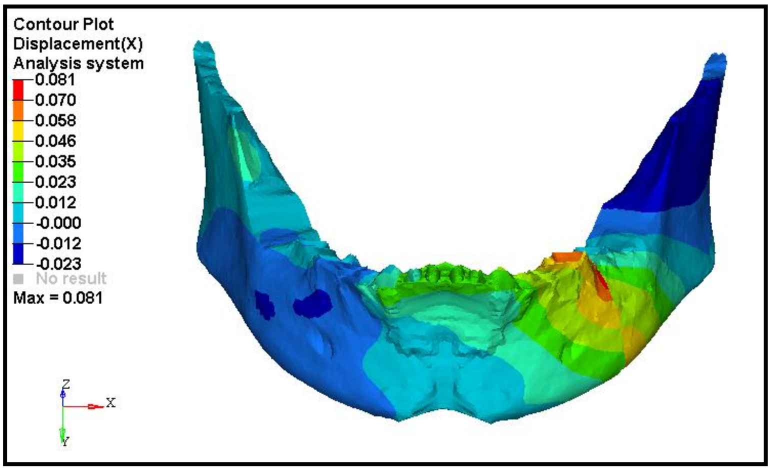


Fig.61

Maximum mesiodistal deformation: 0.081mm

Minimum mesiodistal deformation : -0.023mm

YAXIS :

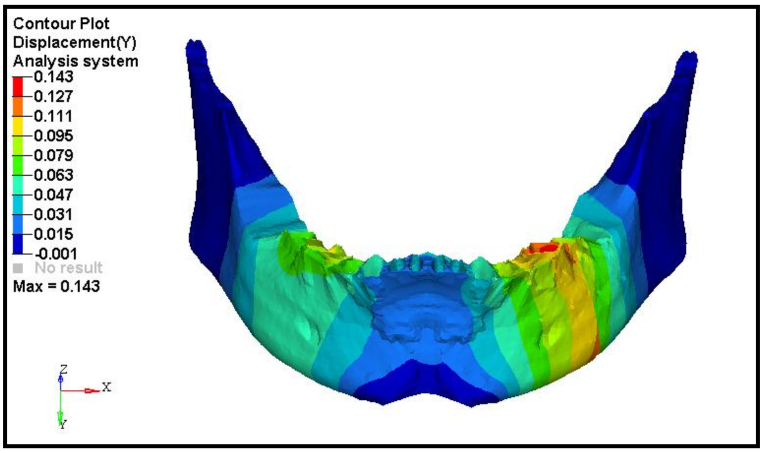


Fig.62

Maximum vertical deformation: 0.143 mm

Minimum vertical deformation: -0.001 mm

Z AXIS:

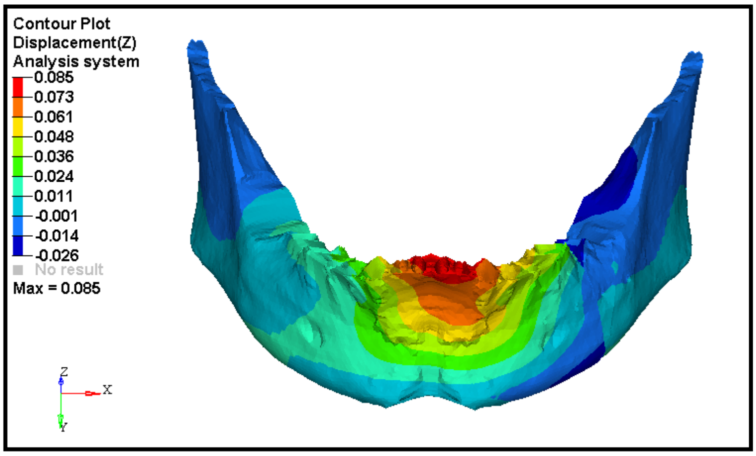


Fig.63

Maximum buccolingual deformation: 0.085 mm

Minimum buccolingual deformation: -0.026 mm

VI. DEFORMATION IN PERIODONTAL LIGAMENT(in mm):

X AXIS:

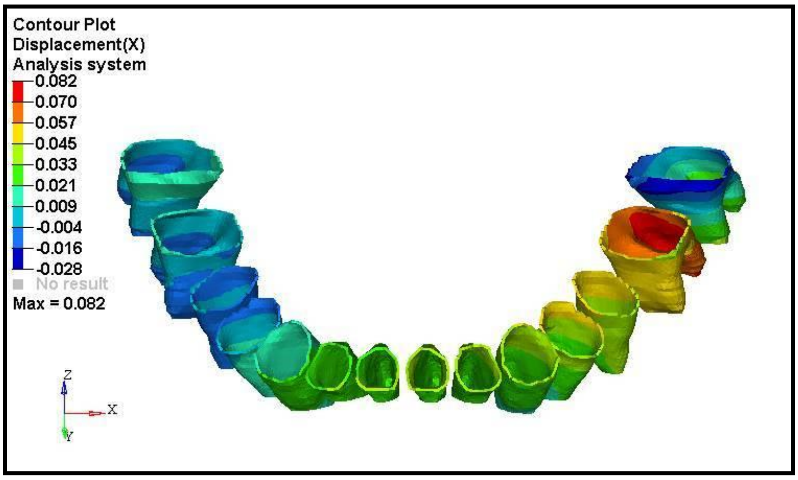


Fig.64

Maximum mesiodistal deformation : 0.082mm

Minimum mesiodistal deformation : -0.028 mm

YAXIS:

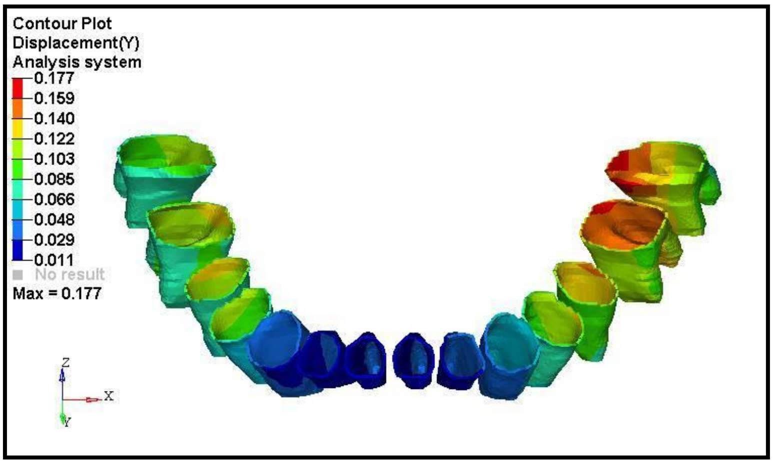


Fig.65

Maximum vertical deformation: 0.177 mm

Minimum vertical deformation: 0.011 mm

Z AXIS:

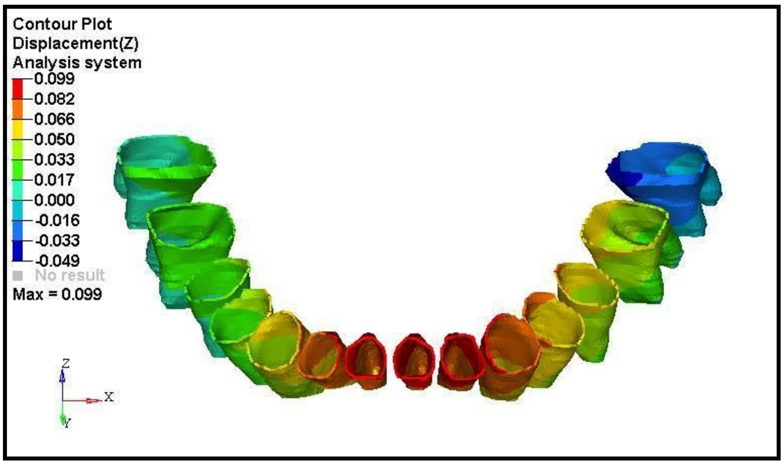


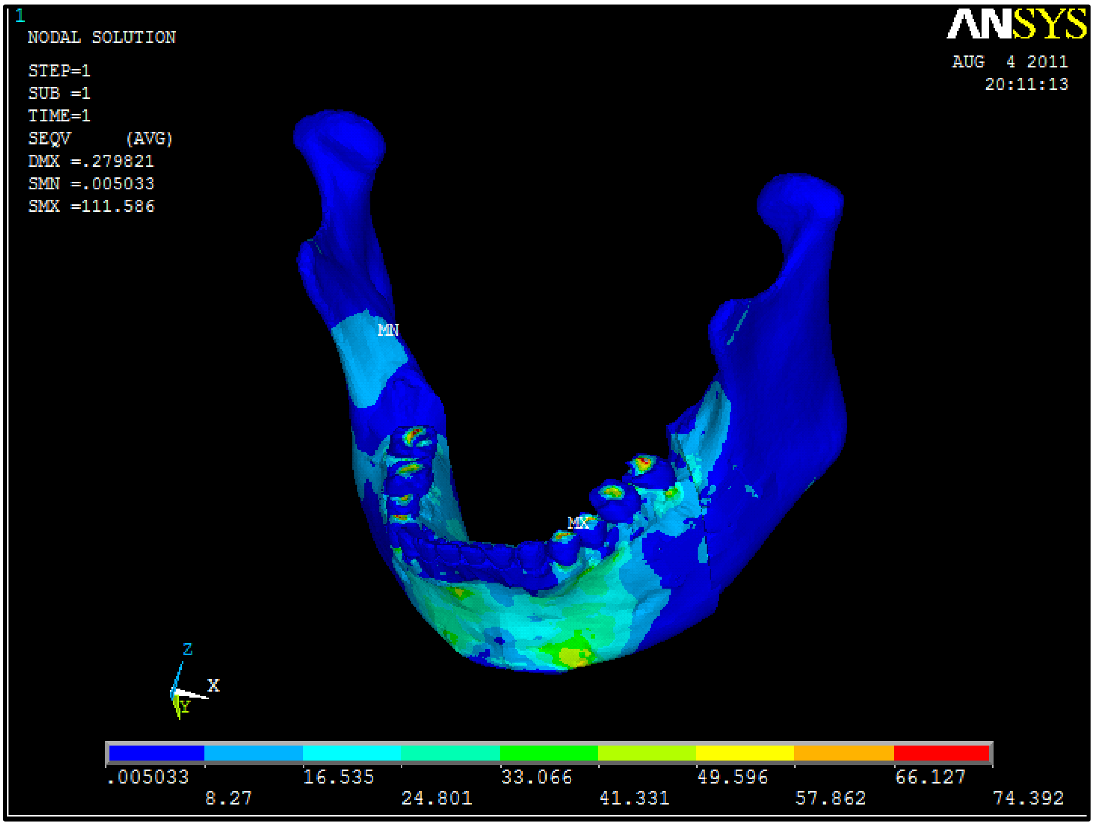
Fig. 66

Maximum buccolingual deformation: 0.099 mm

Minimum buccolingual deformation: -0.049 mm

DESIGN NO 3 - FRACTURE LINE DISTAL TO MANDIBULAR 2ND MOLAR, NOT STABILIZED WITH 3- D MINIPLATE

EVALUATION OF VON MISSES STRESS (IN MPA) :



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
SEQV      (AVG)
DMX =.279821
SMN =.005033
SMX =111.586
```

Fig. 66

I. VON MISES STRESS IN THE FULL MODEL :

Maximum stress: 74.392 Mpa

Minimum stress: .005033 Mpa

Here the distal fragment slides downwards when the fracture is not stabilizd with plate and the loads are applied.

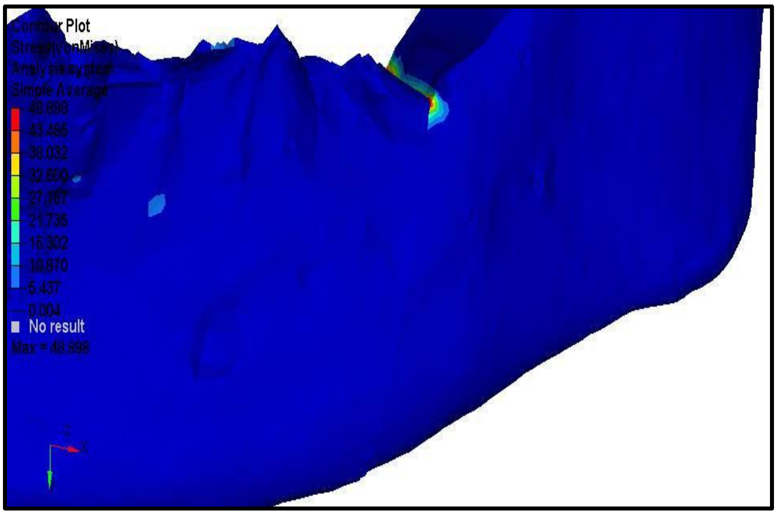


Fig.67

II. VON MISES STRESS IN THE CANCELLOUS BONE :

Maximum stress: 48.898Mpa

Minimum stress : 0.004Mpa

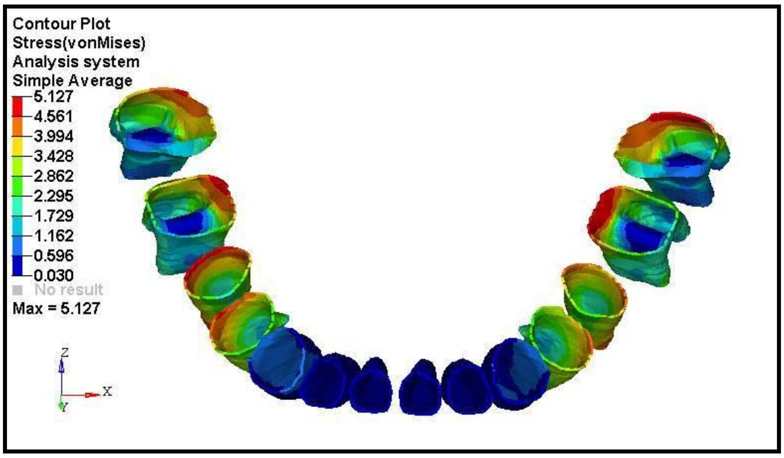


Fig. 68

III. VON MISES STRESS ON THE PERIODONTAL LIGAMENT :

Maximum stress: 5.127Mpa

Minimum stress: 0.030Mpa

MEASUREMENT OF DEFORMATION / MOVEMENT

I. DEFORMATION / MOVEMENT IN FULL MODEL (in mm) :

X AXIS:

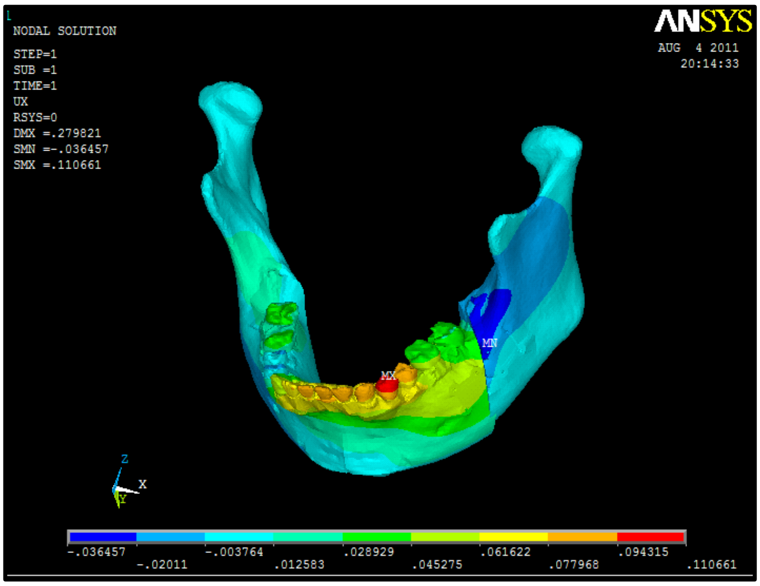


Fig.69

Step = 1

Sub = 1 → linear static analysis

Time = 1

Ux : displacement / movement in x axis

RSYS : resultant coordinate system

SMN : strain minimum

SMX : strain maximum

Maximum displacement / movement mesiodistally: .110661 mm

Minimum displacement / movement mesiodistally: -.036457 mm

Maximum displacement occurs on half of the crown of 1st premolar on the fractured side.

Y AXIS :

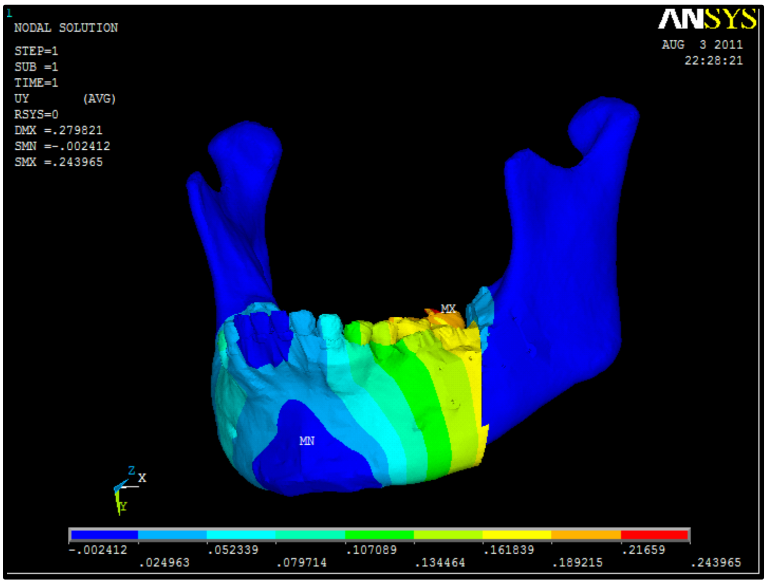


Fig. 70

Uy : displacement / movement in y axis

+ve : movement upwards

-ve : movement downwards

Maximum displacement / movement vertically: .243965 mm

Minimum displacement / movement vertically: -.002412 mm

Margins of the distal fragment containing the teeth moves vertically downward than theproximal fragment and the lower border of both sides are not in continuity.

Z AXIS :

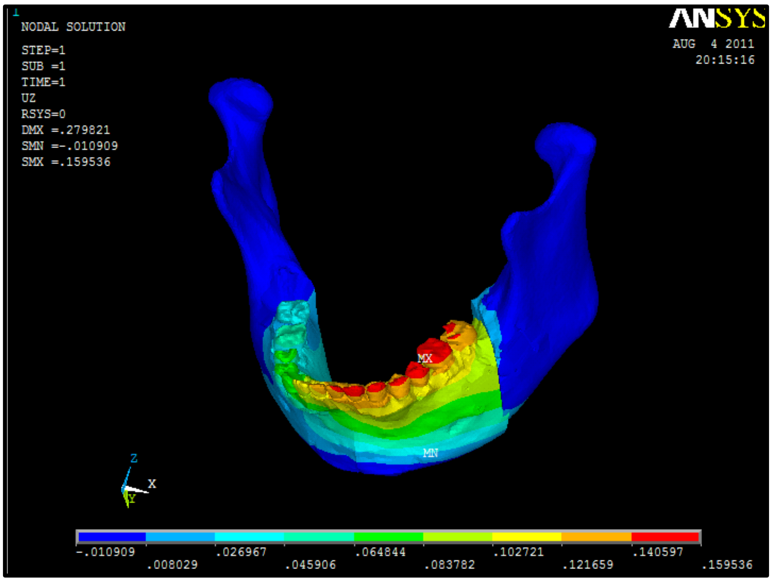


Fig. 71

Uz : displacement / movement in z axis

Maximum displacement / movement in buccolingual direction: .159536 mm

Minimum displacement / movement in buccolingual direction: -.010909 mm

- Maximum displacement is seen towards the incisal edges and cusp tips of premolars and molars on the fractured side.
- The resultis a buccolingual torque of the distal fragment.

II. DEFORMATION IN CORTICAL BONE (in mm) :

X AXIS :

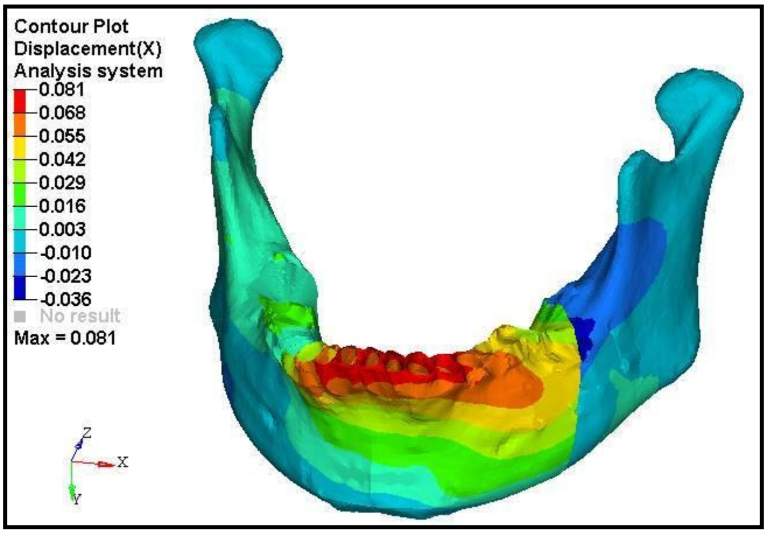


Fig. 72

Maximum mesiodistal deformation: 0.081 mm

Minimum mesiodistal deformation: -0.036 mm

- Maximum deformation is seen at the crestal region of alveolar bone near the CEJ of mandibular anterior anterior teeth.

Y AXIS:

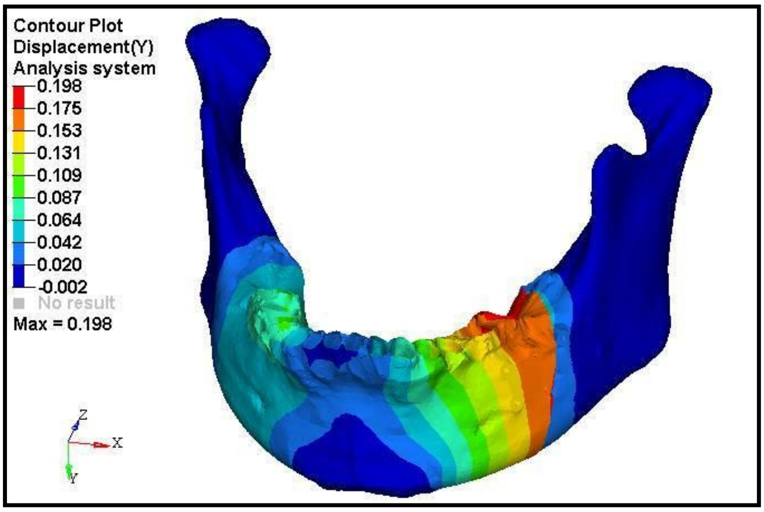


Fig.73

Maximum vertical deformation: 0.198mm

Minimum vertical deformation: -0.002 mm

Maximum deformation is seen over the lingual aspect of the 2nd molar on the fractured side.

Z AXIS:

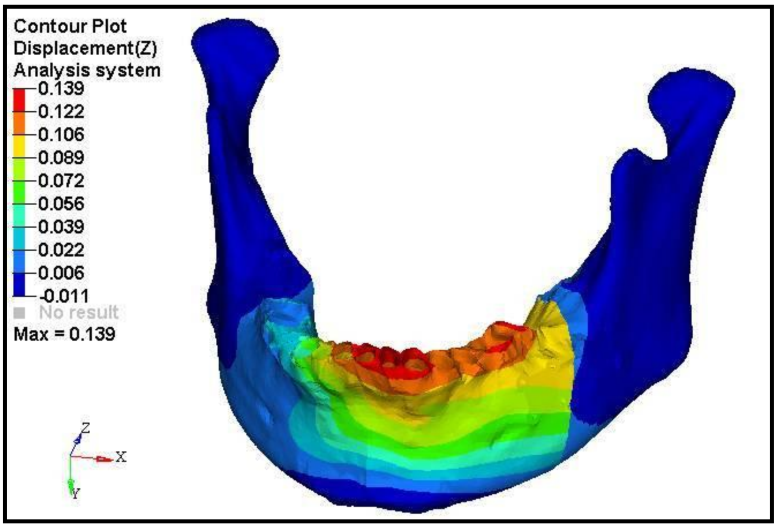


Fig. 74

Maximum buccolingual deformation: 0.139 mm

Minimum buccolingual deformation: -0.011 mm

III. DEFORMATION IN CANCELLOUS BONE(in mm):

X AXIS

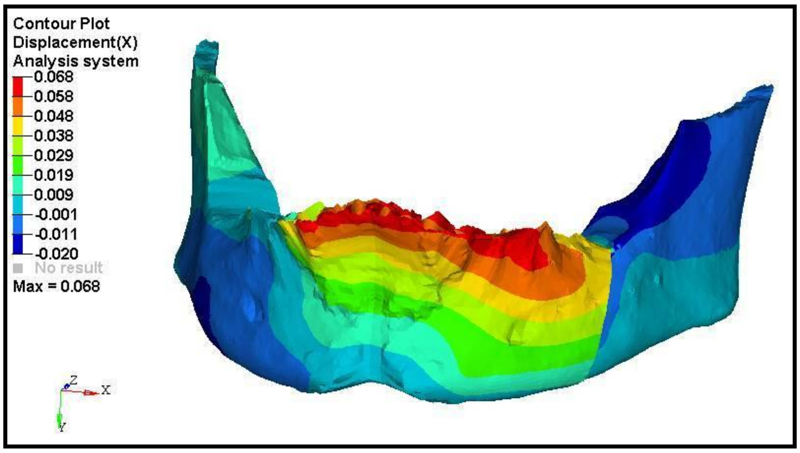


Fig. 75

Maximum mesiodistal deformation: 0.068 mm

Minimum mesiodistal deformation: -0.020 mm

YAXIS :

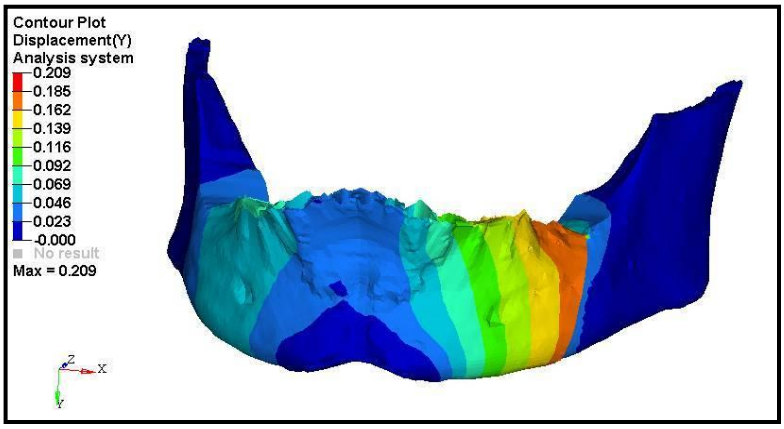


Fig.76

Maximum vertical deformation: 0.209 mm

Minimum vertical deformation: -0.000 mm

Z AXIS:

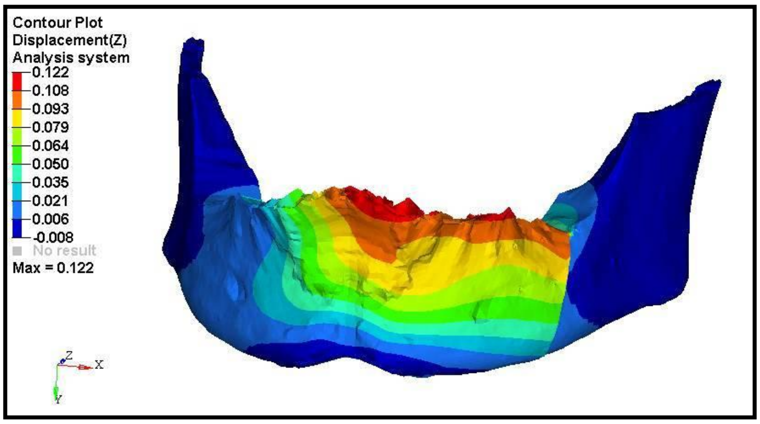


Fig.77

Maximum buccolingual deformation: 0.122 mm

Minimum buccolingual deformation: -0.008 mm

IV. DEFORMATION IN PERIODONTAL LIGAMENT(in mm) :

X AXIS:

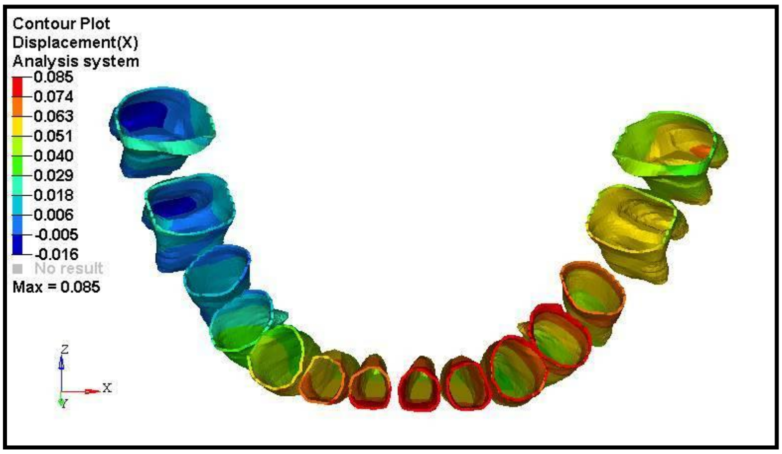


Fig.78

Maximum mesiodistaldeformation : 0.085 mm

Minimum mesiodistaldeformation : -0.016 mm

YAXIS :

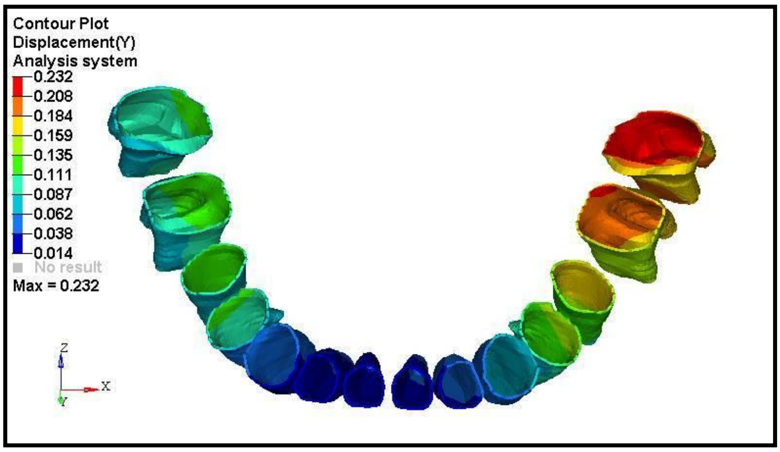


Fig.79

Maximum vertical deformation : 0.232 mm

Minimum vertical deformation : 0.014 mm

Z AXIS:

Fig.80

Maximum buccolingual deformation: 0.139mm

Minimum buccolingual deformation: 0.003 mm

PATIENT NO 1

PRE OPERATIVE RADIOGRAPHS:

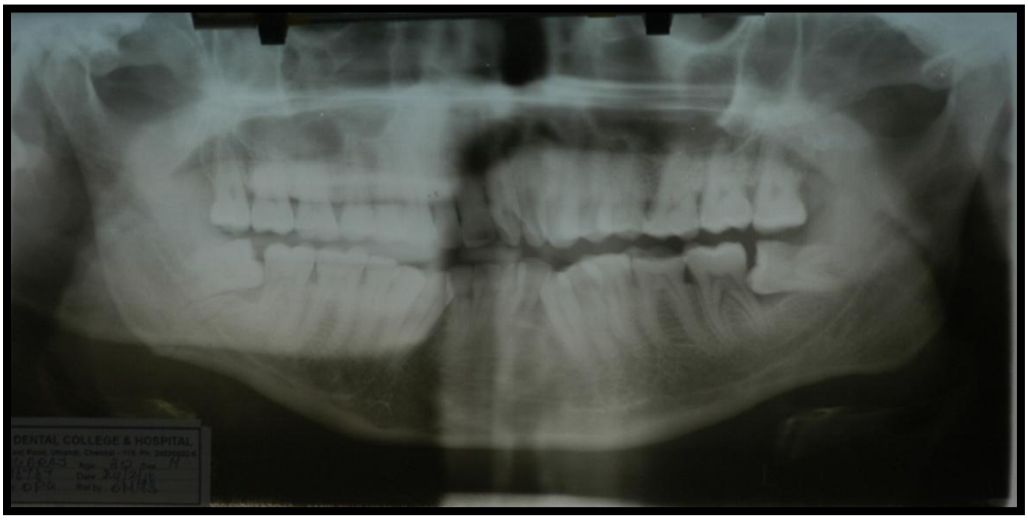


Fig.13: PRE OP ORTHOPANTOMOGRAM

Fig .14: PRE OP PA 10^o

POST OPERATIVE RADIOGRAPHS:

Fig.17: POST OP ORTHOPANTOMOGRAM

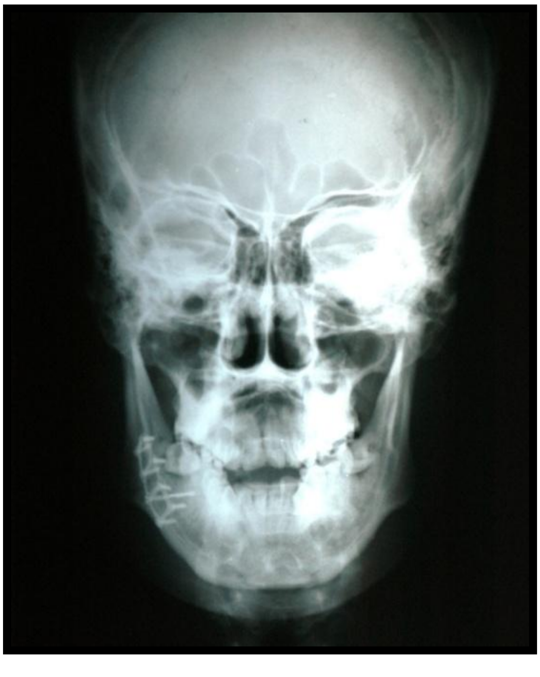


Fig .18: POST OP PA 10°

INTRAOPERATIVE PHOTOGRAPHS

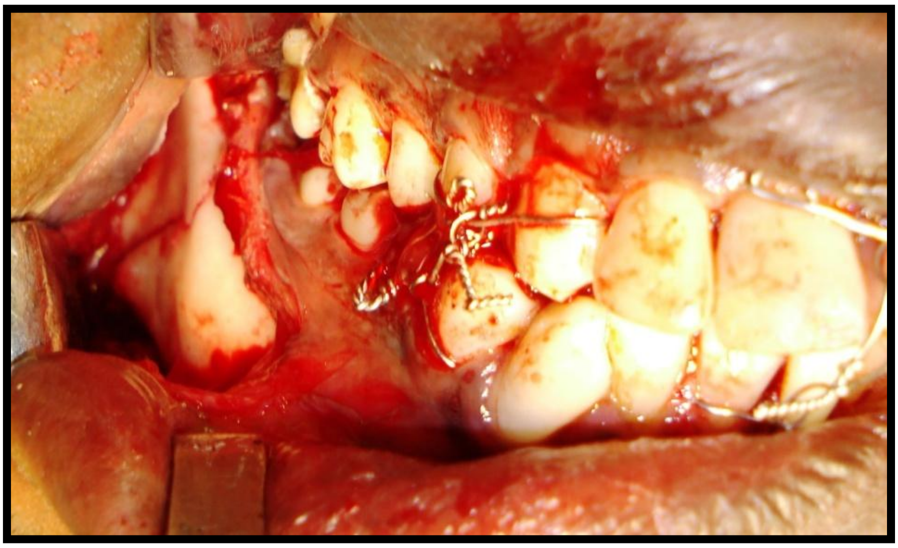


Fig.15: EXPOSURE OF THE FRACTURE SITE

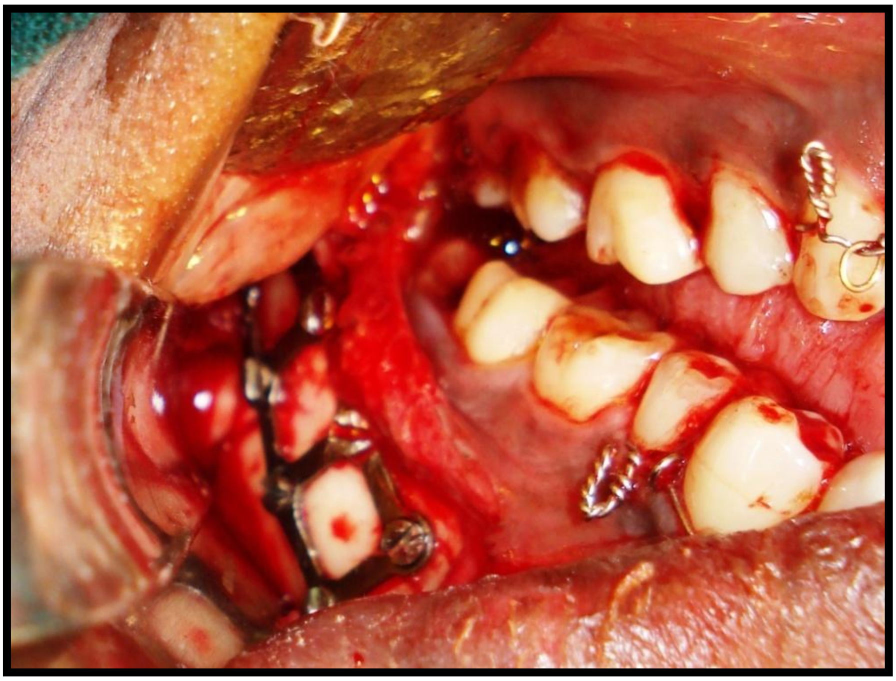


Fig.16: STABILIZATION WITH 3- DIMENSIONAL MINIPLATE