ISSN : 0974 - 7435 Volume 8 Issue 6

BioTechnology
An Indian Journal
FULL PAPER

BTAIJ, 8(6), 2013 [843-847]

Establishment of biomechanical model of rigid internal fixation applied in the treatment of mandibular fracture

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ABSTRACT

Purpose:A three dimensional finite element model which covers part of maxillary fracture, four kinds of mandibular fractures and rigid internal fixation is established in this paper, aiming at four parts where mandibular fractures occur frequently in clinical.Methods:CT images of the patients are imported to Mimics medical modeling software for jaw bone reconstruction. Maxilla and mandible structures of cortical bone and cancellous bone are distinguished respectively by adjusting the threshold, and their 3D modelsare established for editing and processing. File data are refined in Geomagic Studio, noise and sharp structures are removed to form Nurbs surface, thus igs files are exported.Files are imported to SIEMENS.PLM.NX.V to be stitched into the materialization model. And then the models are cut and assembled for the final fracture model which covers part of maxillary bone and the mandibular bone. Results:The model established for part of maxillary fracture, four kinds of mandibular fractures at different parts and rigid internal fixationcan accurately reflect the shape and anatomical characteristics of jaw bone, and can provide precise geometric configuration and materials group for the later FEA analysis. Conclusion:Biomechanics analyses are applied between the implant sites of titanium screw and the direction of traction according to different kinds of mandibular fractures with FEA method, the results show that 3D finite element model of part of maxillary fracture, four kinds of mandibular fractures and rigid internal fixation has good geometry and mechanics similarity, which can be used to further explore the optimal implant site of titanium screw and the best traction direction of the rubber band for normal occlusion, to provide biomechanics theory basis for treatment of mandibular fractures by internal fixation with titanium plateand titanium screwbetween jaws.

KEYWORDS

Fractures of the mandible;
Three-dimensional finite-elementanalysis (3D FEA);
Biomechanics.

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INTRODUCTION

In recent years, maxillofacial fractures tend to increase rapidly year by year, combined with more serious injury tolerance and more sophisticated injuries. Generally speaking, the fractural position on the mandible is related to its anatomical structure. The position is on the projecting portion of the body and takes up one third of the lower face and one third of the intermediate face on the both sides, liable to get injured and with a high incidence rate. Therefore, the incidence of mandible fractures is the highest among all the maxillofacial fractures. The medical treatment of mandible fracture has always been highly concentrated by scholars at home and abroad. Among the emerging new treatments and theories, the main point is how to achieve perfect results and reduce the incidence of complications. Some positions on the mandible are structurally and mechanically weak, for example, fractures of the symphysis 0 fractures of mental foramen0fractures of mandibular angle and fractures of condyle are high-incidence areas of fractures. When fractures take place on this position, because the muscle groups that cling to the bone pieces have differenttraction directions, fracture pieces are easily to get displaced and an occlusal disorder will happen, causing facial malformations that bring about some functional barriers to the chewing, swallowing and language.

The implantation site of the titanium screw used in the intermaxillary traction, along with the different traction directions of the rubber band, will make the displacement and direction of each position on the mandible become different, thus having a direct influence on the healing of the fracture. By comparing different implantation sites and intermaxillary traction directions, the research will study and analyze the stress distribution of the mandible and the displacement of the broken ends of fractured bones with the expectation to give some guidanceon clinical applications.

MATERIALS

Specimen selection

Healthy adult men with complete dentition and no oral diseases were selected as the testee. Multislice spiral CTtomography was conducted to their maxillas and mandible. The scanning range starts from the zygomatic bone to the interior border of the mandible, with 384 layers in total and alayer thickness of 0.488mm and layer distance of 0.625mm. The saving format is Dicom. The rigid internal fixation uses the small-sized quadripuntal ordinary titanium plate and small-sized bridging quadripuntaltitanium plate as well as retention screws with the dimension of 2×8mm.

Classification of common mandible fractures

Four most commonly seen mandible fractures are fractures of the symphysis, fractures of mental foramen, fractures of mandibular angle and fractures of condyle neck.

Software and equipment selection

① 3D mechanical drawing software SIEMENS.PLM.NX.V8.0 from Siemens AG, Germany; ② modeling software mimics 15.0 from Materialise Inc., Belgium; ③CAE Finite Element Analytical (FEA) software Ansys workbench 13.0 from ANSYSÿInc., US;④surface reconstruction software Geomagic Studio 2013 from Raindrop Inc.Us; ⑤Dell Precision T7600desktop workstationwith the following configurations: WIN7 UltimateOperatingSystem, 6E5-26434-digit CPU, 16G DDR3 1333MHz memory, NVIDIA Quadro 4000 professional graphic card and 1TB 7200RPMhard disk.

METHODS TO BUILD A 3D FINITE ELEMENT ANALYTICAL (FEA) MODEL

How to build the FEA models of rigid internal fixation used in the four types of mandible fractures on different positions

Save the CT data in Dicom format and import it to mimics 15.0. Select the reconstruction area by using the Thresholdof the software; then use the Image Editing function to add or delete the image border and make the reconstructed image clearer; use the Region Growing function to give an image segmentation to the selected image and reconstruct images with different structures, including the reconstruction of maxillary bone and mandible as well as the teeth thereon; finally, use the 3D Calculation function to complete the reconstruction and clearly reappear the structures of the maxillary bone and mandible which include the whole dentition. Save the model in STL format and import it to Geomagic Studio 2013. Process the 3D model with a fine trimming and create a NURBS curved plane and export as igs document. Import the curved plane to SIEMENS.PLM.NX.V8.0 to create a physical model. Then cut and assemble the model to make some date preparation to the 3D Finite Element Analysis later and save it in Parasolid format.

Assumed conditions of 3D finite element analysis

①To imitate the biomechanical features in curing the mandible fixation, the study processed the mandible model toseparate the mandible on the high incidence area. The shape of the fracture line was assumed to be a straightline. ②The tooth and alveolar boneare assumed to have a bonded contact relationship and have no relative motion. The maxillary and mandibular tooth have a "No Separation" contact relationship and a slight slippage is acceptable. ③It is assumed that there is no friction between the fracture slots, which have a "No Separation" contact relationship and a slight slippage is acceptable. ④The titanium plate, screw and mandible have a bonded contact relationship and the latter two are permanently connected.

Among the various clinical ways of curing the mandible fractures, the study chose the widely-used technology of rigid internal fixation, in which pure titanium was used. (Figure 1-6)Two titanium plates were placed at the fracture line with an interval of 2mm. The upper titanium plate was symmetrically placed at the fracture line to protect the tooth root from been damaged.[1]

RESULTS

Combined with CT scanning technology, software such as mimics 15.0 is applied to establish the three-dimensional finite element model of part of the maxillary and four kinds of mandibularfracture rigid internal fixation. This model has high simulation, and its geometry and biological properties are close to the entity. The establishment of this 3D model is fast and accurate, and the modeling procedure is simple with shorter time. On the model, different number of titanium screws, different implanted loci and the direction of traction rubber band can be continued to establish. The whole model has 578875nodes and 361107 units. (Figure 1-6)

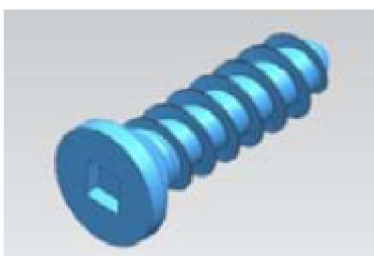

Figure 1: Screw

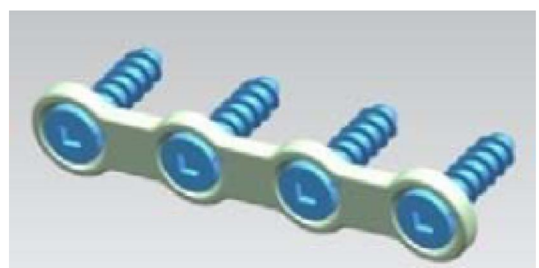

Figure 2 : Miniplate

Figure 3 : Fractures of the symphysis

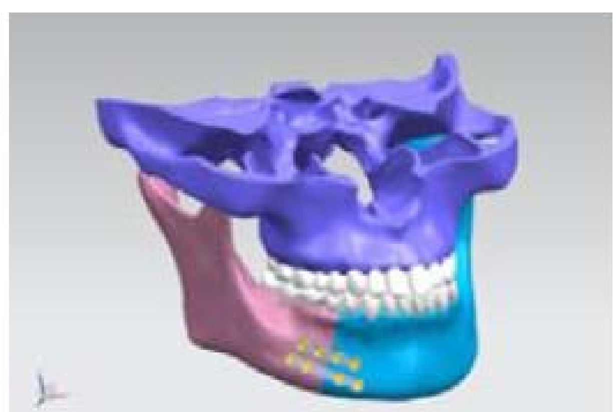

Figure 4 : Fractures of mental foramen

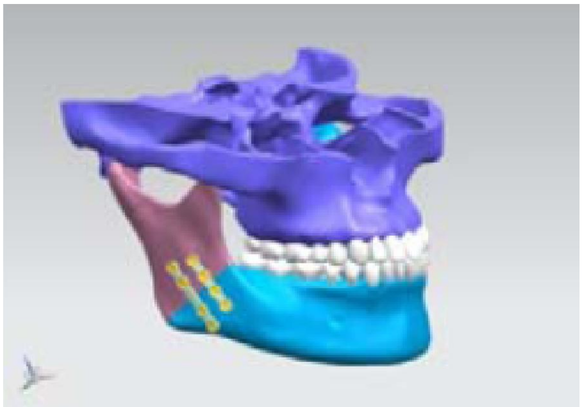

Figure 5 : Fractures of mandibular angle

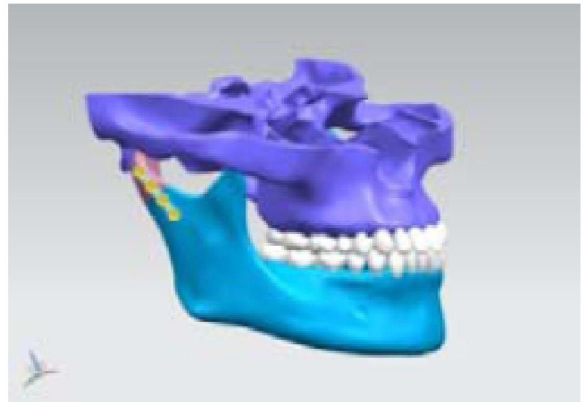

Figure 6 : Fractures of condyle

TABLE 1 : per The characteristics of various materials tested.[2,3,4,5]

Material	Elastic Modulus(MPa)	Poisson's ratio
Cancellous bone	$1.37\times10_4$	0.30
Cortical bone	$7.93\times10_3$	0.30
Teech	$2.0\times10_4$	0.30
Miniplate	$2\times10_5$	0.30
Sutura	1	0.30

DISCUSSION

In 1973, Thresher applied Finite Element Method (FEM) to the dentistry for the first time, which has become an effective analytical tool in the researching area of oral cavity biomechanics and provided theoretical basis to the treatment of oral diseases and optimal designs of medical instruments**[6]**. 3D Finite Element Analytical (FEA) method has been increasingly and widely adopted because of its incomparable superiority. 3D FEA method is a numerical method in mechanics analysis and is also common in the biomechanics area. The method divides the continuouselastomerinto many finite units and replaces the original elastomer with the combination and finally gets the property of the whole elastomer after studying that of each unit. The methodcan simply imitate the irregular complex structure and substances formed by different materials and divide them into smaller and simpler elements and grid (discretely divide the continuous body) them, therefore, it is suitable for the mechanical research of a variety of problems[7]. The discretely divided finite units will be used to replace the original object and provide with a property analysis of its physical field; ultimately the physical property of the whole model will be obtained with the property of the unit[8].

When studying the biomechanical traits of the mandible fractures, the material mechanics features and the loading manner of the imitated model played a vital role in the accuracy of the analytical results. The biggest advantage of the experiment is the accurate reconstructed model, which derives from the concrete shapes of the CT-scanned maxillas and mandibles.[9, 10] The model can be rotated freely and observed from different positions and angles. Besides, the model can imitate the fractures on different jaw positions and the fixed pattern of different fracture lines. Complex fracture fixation can be imitated through the modeling.[11]

The treatments of mandible fracture include manual reduction and traction replacements. Stable environment helps to better healing the mandible fractures. AO/ ASIFfundamental principles hold that the stable fixation is the precondition of healing the broken ends of fractured bones and fulfilling early functional activities[9]. The new technology of Rigid Internal Fixation (RIF) has developed in recent 20 years and has been widely used in the treatment of mandible fractures, featured with good results, convenience and reduced fixing time. The most frequently applied method to recover and maintain the occlusal relationship is intermaxillary traction, which uses the traction titanium screws between the maxilla and mandible to fix the traction. Compared with arch barsplintfixation, intermaxillary fixation titanium screwhas the advantages of reduced operation time, convenience, less injuries to gingival papillaandoral mucosa and easily maintained oral hygiene.

Currently, in the clinical applications at home and abroad, the implantation site of intermaxillary traction titanium screws and the intermaxillary traction direction are decided based on the doctors' clinical experience. The treatment of mandible fractures aims to recover the chewing function and the appearance. The recovery intents to return back to the occlusal relationship before the patient get injured. The model can imitate any implantation site of intermaxillary traction titanium screws and can adjust the rubber band to any traction direction. The displacement and direction of each position on the mandible under different fractural situations can be observed at any time. The mandible fractural position, the implantation site of intermaxillary traction titanium screws and the intermaxillary traction direction under different situation can be biomechanically analyzed in the model. The model helps provide some intuitive biomechanical basis to observing the dental displacement and the fixation of maxilla and mandible as well as the application of the intermaxillary traction titanium screws in the intermaxillary traction fixation.

The study shows us a reconstructed model, in which themaxillas and mandibles of some regular young males were selected as the sample. Therefore, the study may give some referential value to the treatment of mandible factures of young men, but may be not necessarily suitable for other age groups. The mandible stress of elderly patients, in particular, willmake some changes due to the changes on cortical bone and sponge bone and alveolar boneresorption caused by tooth defect or agomphiasis. In this case, an individualized sampling model should be created to make some biomechanical analysis[12, 13].

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