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Benefits of Additive Manufacturing Medical Model in Orbital Floor Reconstruction Surgery: A Case Study

*Santosh Kumar Malyala[1], Y Ravi Kumar[1], Aditya Mohan Alwala[2], and Praveen Vasamsetty[2]

[1]Department of Mechanical Engineering, National Institute of Technology Warangal, India
[2]Department of Oral & Maxillofacial Surgery, Panineeya Institute of Dental Science & Research Center, Hyderabad, Telangana, India

Abstract

Additive Manufacturing (AM) is one of the latest manufacturing processes. AM technology provides patient specific customized physical model, which is almost not achievable by any other technique. AM medical models are best suitable for pre-planning of complex medical surgeries such as reconstruction of the orbital floor which has fractured due to severe craniofacial trauma. Orbital floor is formed by a very thin bone which is often fractured during trauma. Among all the injuries of the craniofacial region, orbital fractures account for about 40 percent. The restoration of the orbit to its pre-traumatic volume and anatomy is one of the most delicate and difficult procedure. However this method which involves multiple try-ins, poses a risk of injury to the important structures within the orbit. AM provides the flexibility to bend, adapt/modify the plate prior to the surgery, which saves the intra-operative surgery time. This also avoids the revision of surgery in some cases. For the current study a patient specific preplanning medical model was made at a low cost using Fused Deposition Modeling (FDM). Placing a reconstruction plate/mesh which was pre-adapted on a model reduces operating time, risk of soft tissue trauma, and allows precise plate positioning and restoration of orbital volume. Using the FDM medical model overall surgery time is reduced by 40 minutes.

Keywords

Additive Manufacturing; Orbital floor reconstruction; Fused Deposition Modelling; Medical model; Pre planning Surgery

Introduction

Additive Manufacturing (AM) technology has been started for manufacturing prototypes before 30 years with the name Rapid Prototyping (RP). This technology has evolved from prototypes to fully functional parts in various Industries [1]. The Advantage of this technology is to fabricate any complex geometry easily. AM parts are fabricated with almost zero percent wastage of raw material. As compared to conventional subtractive process, AM process adds material in layers. Addition of material is done till the last layer, where the model is completed [2]. The customized models can be fabricated very easily with this technology, which exactly suits for the medical industry. In medical industry the anatomy differs from patient to patient. The patient specific medical model is obtained using the Computer Tomography (CT) of the patient [3]. The CT data of patient is processed through the medical imaging software, once 3D Computer Aided Design (CAD) model is generated [4]. This data is further used for fabrication of patient specific AM medical model. These AM medical models can be easily fabricated using Fused Deposition Modeling (FDM) technique [5,6]. Since FDM is one of the cost effective processes available in AM. These FDM models also have good mechanical properties. The mock surgeries can be conducted on AM medical model and this information from mock is used for finalizing the steps in the actual surgery [7]. The AM medical model provides flexibility for almost each and every step that is going to be adopted in the actual surgery in advance.

Methodology

The following steps are followed for the current case study, which are shown in (Figure1).

CT data Acquisition and Reconstruction: For the current case study the patient underwent scanning by 128 slice CT scanner, with scan parameters of the tube current as 300mA, tube voltage as 130kV and pitch as 1mm [8,9]. The CT data was reconstructed using the reconstruction parameters of slice thickness as 0.6mm, slice increment as 0.3mm and field of view as 512 X 512 matrix size. These optimized parameters are followed to obtain the best quality of patient's scan data which is used in the later stages. Obtaining quality CT scan data is very important to fabricate AM medical data for replication of patient's anatomy. For the current case patients bone anatomy at orbital portion is the region of interest.

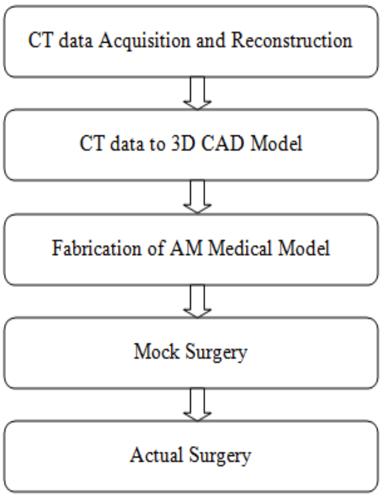

Figure 1: Flow chart of approach.

***Corresponding author:** Santosh Kumar Malyala, Department of mechanical Engineering, National Institute of Technology Warangal, India, 506004, Tel: +91 9963343361; E-mail: msantoshpdd@gmail.com

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CT data to 3D CAD Model

The patient's native CT scan data is in the form of Digital Imaging and Communications in Medicine (DICOM) format. The medical software's are capable of obtaining the 3D Computer Aided Design (CAD) model from the DICOM data [10,11]. For the current case study, Materialize MIMICS 18.0 software is used to generate a patient specific medical model. In the current case study, the patient's orbital region is segregated from the complete skull data, using the operations of edit mask, cut and split etc. The threshold value of 225 to 1025 is used to filter the patent's bony data from the complete scan set of complete scan data. The patient's 3D CAD model from the MIMICS is show in the (Figure 2a).

Fabrication of AM Medical Model

Although there are several options or techniques of fabricating the 3D model, the only primary requirement to fabricate the AM medical model is to store the data in stereolithography (STL) file format. For the current case study STL file of patient specific model is obtained from MIMICS software. Flashforge finder printer is used to fabricate the patient specific AM medical model, which works on the principle of Fused Deposition Modeling (FDM) process [12]. Flashprint is the preprocessing software used to set the parameters for AM medical model. The printing parameters used for fabrication of AM medical model are layer thickness of 0.06mm, fill density of 100% and printing temperature of 210^{0}C. The poly lactic acid (PLA) filament is used as raw material for fabricating the AM medical model as shown in (Figure 2b).

Case Description

This is a 26 year old male who sustained multiple injuries on the face due to road traffic accident. There was subconjunctival hemorrhage (bleeding underneath the conjunctiva of the eye), periorbital ecchymosis bilaterally (purple discoloration of the skin around the eye due to the extravasation of blood into the subcutaneous tissues); there was loss of sensation over left infraorbital region and also mild degree of lowering of interpupillary line. The ocular movement was restricted in upward gaze and the patient also had diplopia of left eye. The vision and the ocular reflexes were unaltered. Coronal CT scan of skull revealed a breach in the floor of the left orbit along with herniation of periorbital soft tissue into the maxillary sinus. The diagnosis of "blow out fracture - left orbit" was established. Intraoperatively, the orbital floor was approached through subciliary incision under general anesthesia. Forced duction test was performed and was positive [This test is to evaluate whether the restricted movement of the eye is due to muscle entrapment and mechanical restriction due to fracture or due to neurological disorder]. The herniated intra-orbital contents including inferior rectus muscle and fat was disengaged from the bony defect and the orbital floor was reconstructed with a 1.5mm titanium mesh.

Mock Surgery

The DICOM images were collected from the CT scan and a virtual model was reconstructed. The model was printed into a physical model by additive manufacturing. A 1.5 mm Titanium mesh was adapted onto the orbital floor after reduction of the fracture site on left side. The preformed titanium mesh which was shaped to duplicate the orbital anatomy by covering the defect of the orbital floor was placed carefully under the orbital contents. The titanium mesh is adapted on the model during the mock surgery as shown in (Figure 3). The appropriate size of the screws required was selected using this model and also placement of the screws was planned over it. The mesh was placed over the defect and fixed with titanium mini screws, 3 in number. On the infraorbital rim.. It was found to be advantageous to use the FDM model as the manipulation of the mesh was very minimal during surgery. This titanium mesh is used directly over the patient during the actual surgery.

Actual Surgery

The case was operated under general anesthesia. Under all aseptic conditions under nasotracheal intubation, 2% lignocaine with 1:80,000 adrenaline was injected in the infraorbital region. A subciliary incision was placed and blunt dissection was carried out to reach the fracture site in the infraorbital rim, the orbital contents were elevated carefully using a blunt instrument. Fracture was reduced and the pre-adapted and trimmed titanium mesh prepared during the mock surgery is directly placed towards the orbital floor and the contents of the orbit are released onto the mesh as shown in (Figure 4). Care is taken not to endanger any vital structures while placing the titanium mesh. Three 1.5 X 6mm screws were used to secure the mesh to the infraorbital rim. Closure is done in layers. The medical model saved surgical time of 40 minutes also minimizing the patient's morbidity.

Discussion

Any signs of diplopia (double vision), enophthalmos greater than 2mm, extensive fracture of the floor of the orbit greater than 50% and progressive numbness in the region supplied by the second branch of trigeminal nerve indicate the requirement for correction of orbital floor fracture. Also an untreated orbital floor fracture may cause an occulo-cardiac reflex. Determination of the important anatomical structures or landmarks during the reconstruction of the orbital floor and medial wall of the orbit was very difficult before the advent of 3D models. These models have given an extra hand to the surgeon in bypassing the need for adapting or shaping the mesh/plate intra-operatively, which would require multiple try-ins on the patient, thus increasing the risk

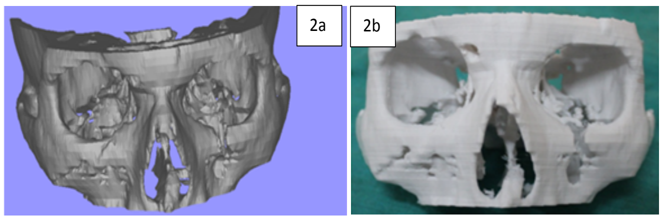

Figure 2: a) Patient's 3d cad image b) Patient's AM medical model.

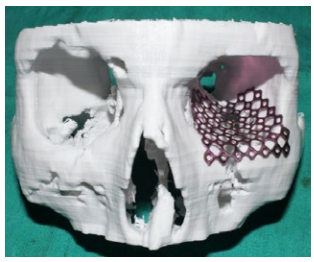

Figure 3: Mock surgery on AM medical model.

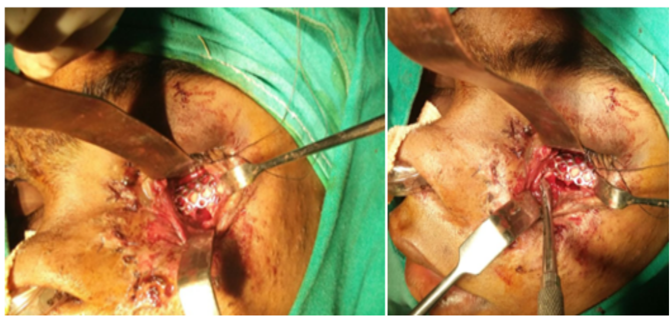

Figure 4: Actual surgery images.

of trauma to the important structures within the orbit. Pre-adapting the mesh/plate over 3D model would facilitate immediate placement of this mesh/plate with high precession and accuracy by reproducing the contours of the orbital walls without further corrections or manipulations and minimizing the risk of trauma to vital structures. In the current case, titanium orbital plate was placed almost immediately with minimal or no further manipulation and no revision surgery was necessary after evaluating implant position with the medical model.

Conclusion

Merging the use of additive manufacturing to the field of surgery has produced models which replicate patient's bony anatomy, where the surgeon can perform pre-operative planning surgery on these models. Throughout the centuries, surgeons have been trying to make changes in the field of maxillofacial surgery in understanding complex anatomical details of the maxillofacial region for the benefit of patients. For the current case study, AM medical model of the patient is fabricated using easily available low cost FDM machine, which reduced the cost of preplanning medical model. The other advantage of the medical model is adapting or bending of mesh plate prior to the surgery. With the exact fit of the orbital mesh plate, surgery time is reduced by 40 minutes. The reduced surgery time improved the safety of the patient. The accuracy of the FDM model can be further improved using specific algorithms.

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Conflict of Interest

The authors report no conflict of interest.

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