

Surgical Planning in Pan Facial Trauma Using Additive Manufacturing Medical Model-A Case Study

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Abstract

Additive Manufacturing (AM) technology is an engineering technology which has a wide scope in medical field. Of various medical fields, craniofacial and maxillofacial surgery adapted this technology and is making use of it to overcome the shortcomings of traditional procedures. Medical application of AM or Rapid prototyping was started two decades ago and is expanding its frontiers with the advancement in technology and technical expertise by the medical professionals. AM technology is widely being used in maxillofacial surgery for hassle free planning, patient education and execution of the surgical procedure and for precision using medical models. The Current case is of pan facial trauma with multiple facial bones fracture treated by surgical planning on AM medical model to adapt the mini plates to be prior to the surgery. This paper also deals with the importance of AM medical models in complex surgeries for better outcome.

Keywords: Additive manufacturing; 3D printing; Rapid prototyping; Maxillofacial surgery; Pan facial trauma; Adaptation on mini plates

Introduction

Additive Manufacturing is a process that creates parts in an additive by adding layer-by-layer. This technology produces models or prototype parts from source such as Computed Tomography (CT scan), Magnetic Resonance Imaging (MRI), Cone Beam Computed Tomography (CBCT), Computer Aided Designs (CAD) or from any Reverse Engineering techniques [1]. AM technology is used for building physical models and prototype parts from 3D CAD data in various industries such as Automobile, Aerospace, Mechanical, Medical, dental and so on [2,3]. AM applications have generated increased interest in recent years, and many countries are trying to apply AM technique to various fields round the globe. Among which medical field is one of the most benefited industries with this technology? As the medical field requires patient specific medical model, which is unique for each patient and easy to get it using AM technology, it allows user for the mass customization, i.e. X number of parts in a single batch can be produced as X unique parts. In the early stages of AM, it is used in the medical industry for pre planning of complex surgeries [4,5]. The first application of stereolithography in Maxillofacial Surgery was performed by Brix and Lambrecht in 1985 for craniofacial surgery planning, here after the technological advances in hardware and software of AM has been refined and incorporated in craniofacial surgery in recent years [6]. AM medical models are considered an interesting appliance for diagnosis in congenital malformations, craniomaxillofacial defects, pathologies, reconstruction, maxillofacial trauma, orthognathic surgery, facial asymmetry, surgical planning, and in designing custom made prosthesis which helps in professional-patient communication for its ease of availability [7,8]. The virtual image is made into a physical medical model by a technical process called AM. This technique was originally emerged as Rapid Prototyping in mechanical engineering and has found applications in medicine. The word prototyping was first used to describe the act of producing a prototype i.e., a unique product, the first product, or a reference model. In the past, prototypes were handmade by sculpting or casting and their fabrication demanded a long time. With the development of information technology, three-dimensional models can be devised and built based on virtual prototypes. Computers can now be used to create accurately detailed projects that can be accessed from different perspectives in a process known as computer-aided design (CAD). To materialize virtual

objects using CAD, a computer-aided manufactory (CAM) process has been developed. To transform a virtual file into a real object, CAM operates using a machine connected to a computer, similar to a printer or peripheral device [9]. In the present day as per ASTM latest classification there are seven processes available for fabrication of AM medical model [10]. Classification based on the process and raw material used to fabricate the processes, among the seven processes the Material Extrusion process is available easily throughout the globe and it's easy to maintain. The operating and initial cost for these machines are also very less. Due to its ease of availability and cost factor Material Extrusion process is used for fabricating medical models widely. Fused Deposition Modeling falls under the category of Material Extrusion. Models made out of this technique have good strength and these models can be used for functional purpose and this technique also provides the flexibility of printing models with multiple colors, but in most cases each color at a time [11]. The 3D CAD patient data is converted in to Stereo Lithography (stl) file format to accept globally for any AM machine to fabricate physical model [12]. The current case is of pan facial trauma which was treated by AM medical model in mock surgery to finalize sequence of steps to adopt in actual surgery and also to optimize surgery procedure.

Case Report

This is a case of 25 year old male, who sustained injuries due to road traffic accident. He was reported with bleeding from mouth and nose and loose teeth in the anterior region of the lower jaw. On clinical examination, the patient was conscious coherent and responding to

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verbal commands. The Glasgow coma scale was 15 on 15. Head injury was clinically ruled out. On examination of face, there was peri-orbital ecchymosis, flattening of nasal bridge, subconjunctival hemorrhage, deranged occlusion, sublingual hemorrhage and avulsed maxillary and mandibular anterior teeth. A provisional diagnosis of pan facial trauma was made and computed tomographic scan (CT scan) was advised. The 3D reconstructed computed tomographic scan Figure 1 revealed, fracture of the fronto-nasal region, fractures on anterior and lateral walls of maxillary sinus on both sides, mandibular parasymphysis fracture on left side, dento alveolar fracture on maxillary and mandibular anterior region. Thus the diagnosis of pan facial trauma was confirmed. The DICOM (Digital Imaging and Communication in Medicine) images obtained from CT scan were processed through MIMICS software. This software converts DICOM data to 3D CAD (Computer Aided Design) data [13]. The CT scan consists of patient complete information i.e. exposed to the scan area. From the complete information the bony information is segregated in the MIMICS software in the initial stage using Hounsfield Units. In the later stage only required region of interest is separated using the edit mask, cut, split tools etc. For the current case injuries or fractures are observed on the region of mandible, maxilla and the nasal regions. After analyzing the fractures data from MIMICS the intensity of the fracture is clearly identified and for the ease of identification each fracture portion is colored differently as shown in (Figure 2). The STL file is processed through the CURA software, which is open source preprocessing software for Fused Deposition Modelling technique AM machine. In this software the layer height, orientation of the medical model, fill density of the medical model and temperature to operate can be defined for fabrication of AM medical model. For the current case Maker Pi M14 machine is used for the fabrication of medical model. The material used is PolyLactic Acid (PLA) with additives is used as a filament. The basic principle of FDM technique is to extrude the filament from the nozzle at desired temperature with required diameter to form the required shape or model. AM medical model was made in different colors and parts according to the displacement of fractures and reduction was done on the model. Proper occlusion was achieved. Once the reduction was satisfactory, necessary miniplates were bent according to the contour of the anatomical structure. Complete planning was done on the medical model and to finalize the size and shape of the mini plate as shown in (Figure 3). The case was operated under general anesthesia and nasotracheal intubation. Standard surgical procedures were followed and the fractures were fixed at fronto-nasal region, naso-maxillary buttress, zygomatico-maxillary buttress on left and right sides with 2.0 mm plates and necessary screws. Mandible was fixed with 2.5 mm and 2.0 mm plates and necessary screws as shown in (Figure 4). The whole procedure took about 2 hours. There was precession in the surgery and the time required has drastically minimized. As the plates were adapted in prior, the reduction was easy and proper. This helped in minimizing the operating time thereby the complications due to prolonged general anesthesia. The patient recovered with no complications. The postoperative radiographs were taken to confirm the placement of the plates and reduction of bones. Figure 5 represents the postoperative Orthopantomogram and Figure 6 is postoperative Para nasal Sinus View.

Discussion

Since many years, surgeons depended on plain X radiographs for the diagnosis and treatment planning. The older diagnostic aids provided a two dimensional image of a three dimensional object. Thus for proper orientation, another radiograph was advised perpendicular to the first radiograph. With the advancements in diagnostic aids, a third dimension was added to the existing radiography [3 dimensional CT Scan]. This was of a great use to the surgeons for both planning and patient education. Thus far, 3-dimensional (3D) reconstructed

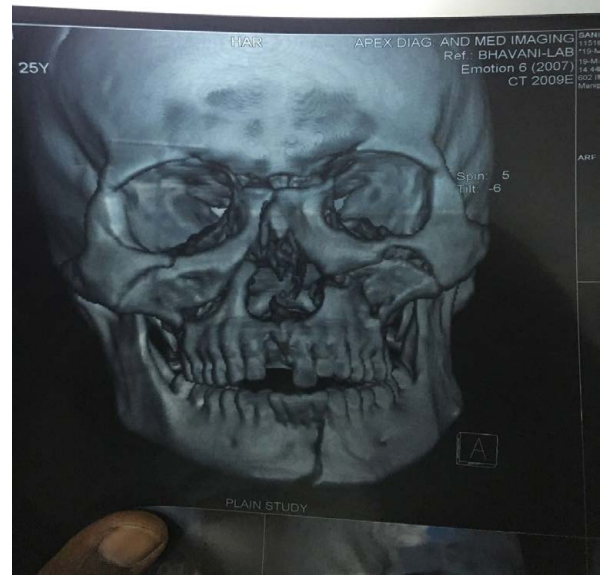


Figure 1: X-ray of the patient.

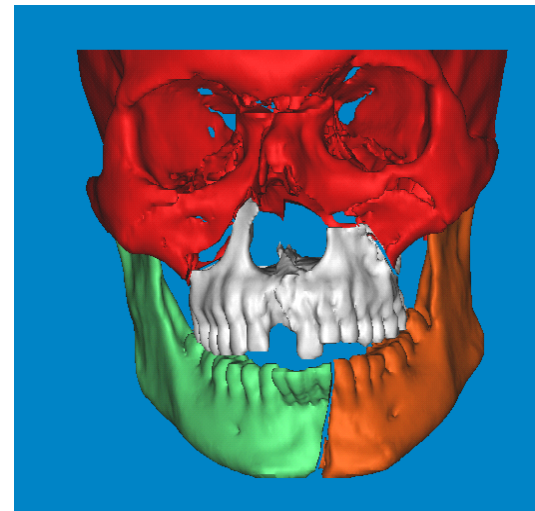


Figure 2: 3D CAD model of the patient.



Figure 3: AM medical model of the patient.



Figure 4: Actual surgery photos after fixing mini plates to patient.



Figure 5: Postoperative orthopantomogram.



Figure 6: Para nasal sinus view.

image derived from computed tomography (CT) data was the best option available for evaluation and treatment of surgical problems in dental and craniomaxillofacial surgery and various other specialties. The major drawback of this modality is that the reconstructed images could not be analyzed comprehensively on various planes and sections as it is only represented as pictures on a screen [14]. In 1987, Brix and Lambrecht used, for the first time, a physical medical model in health care. It was a three-dimensional model manufactured using a computer numerical control (CNC) device, a type of machine that was

the predecessor of rapid prototyping [15]. Medical applications for AM are expanding rapidly and are expected to revolutionize health care [16]. The application of AM medical model in medicine can provide many benefits, including: the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration [17- 20].

Intraoperative bending of plates can be time consuming. Bending the plates on the medical models fabricated using additive manufacturing technologies prior to the surgery reduces operating times. Lethaus et al. [21] have found saving of an average of 40 percent of the reduction of operating time in cases of mandibular reconstruction. Ideal positioning of mandibular segments, time saving by no intraoperative repeated bending and adapting of plates, use of the original surface of the cortical bone as a template for adapting the recon plate, facilitating the preoperative surgical simulation and restoration of centric occlusion of the patient were some of the benefits of virtual surgical planning and construction [22,23]. The authors found similar advantage by using AM medical models. The operating time was reduced significantly and the adaptation of the mini plates was accurate. The pre-determined position also aided in good reduction of the bony segments and reduced the chance of postoperative plate breakage.

Conclusion

The current case of pan facial trauma consists of multiple fractures in the facial region. This kind of multiple fractures is relatively rare. Since there are multiple fractures, the surgery becomes complicated and time taking. As multiple mini plates are to be fixed, the adaptation of mini plate to the patient anatomy is not so easy using conventional CT or X-ray technique, which decreases the outcome. As in this case, multiple fractures and multiple mobile bony fragments make it complicated and time taking. With help of AM medical model, these mini plates are adapted to the patients near normal anatomy before the surgery, which aided in proper manipulation and reduction of fracture fragments and also saved significant amount of surgical time. Comparing with total surgery time of 2 hours 50% of time (1 hour) of surgery time is reduced using AM medical model. The authors suggest that this technique is quite handy and can be applied to other scenarios. The authors conclude that, Additive manufacturing or 3D printing is a good aid in the field of medicine. There is multitude of trends for the usage of 3D printing in the field of Oral and Maxillofacial Surgery. By using these models, the diagnosis, patient education and treatment planning becomes easy while minimizing the operative time and complications. The only drawback of this technology is its cost. With the advancements in technology, we hope that when the cost comes down, the usage could become widespread in the field of Maxillofacial Surgery and medicine.

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