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BIOMODELLING OF CRANIO-MAXILLOFACIAL IMPLANT APPLYING OPEN SOURCE SOFTWARE

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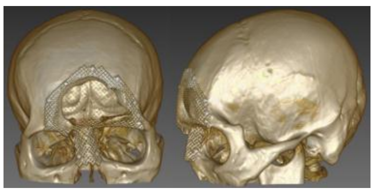
Graphical abstract



Abstract

Advances in craniofacial medical imaging has allowed the 3D reconstruction of anatomical structures for medical applications, including the design of patient specific implants based on computer-aided design and computer-aided manufacturing (CAD/CAM) platforms. This technology has provided new possibilities to visualize complex medical data through generation of 3–dimensional (3D) physical models via additive manufacturing that can be eventually utilised to assist in diagnosis, surgical planning, implant design, and patient management. Although the study on the construction of cranio-maxillofacial implant based on computer modelling and advanced biomaterial are growing rapidly from other parts of the world, however, in Malaysia is scanty, especially with open source application. For this reason, it leads us to embark in a study to produce a potential locally cranio-maxillofacial implant with equivalent standard as compared to the commercially available product applying open source software. As part of four sub-projects of USM Research University Team (RUT) project, the authors had investigated and applied open source software to perform image processing of CT data, to segment the region of interest of anatomical structures, to create virtual 3D models, and finally to convert the virtual 3D models to a format that compatible for additive manufacturing platform. Further research is ongoing to investigate on designing the cranio-maxillofacial implant using open source CAD software using suitable biomaterial.

Keywords: Cranio-maxillofacial implant; 3D model; biomodelling; computer-aided design; additive manufacturing

1.0 INTRODUCTION

A cranio-maxillofacial (CMF) disorder is any type of abnormality of the head or face. The causes range from birth defects to accidents, infection, cerebral decompression or tumours[1]. According to the report by Malaysian Institute of Road Safety Research (MIROS), 2012 Annual report [2], the number of road accidents in Malaysia has increased year by year, from 279,711 in 2002 to 462,423 in 2012. Furthermore, vehicle registration has also increased from 12 milion in 2002 to 22.7 million in 2012. Although no specific study has been conducted on coherent relation between on the road vehicle quantity and accident cases, common causes of CMF bone fractures are motor vehicle accidents (MVA) including motorcycle, automobile, bicycle and pedestrian hit [3]. Studies conducted by Pohchi et al[4] on maxillofacial fracture at Hospital Universiti Sains Malaysia (HUSM) also gain similar result.

Our society places a high regards on physical and facial beauty. And no matter how loving, intelligent or courageous a person may become, most will look no further than the face. Patients with CMF abnormalities normally have facial distortion. Apart from that, they may also suffer from other disabilities such as speech, vision, eating, breathing, and even brain dysfunction. Therefore, the impact of CMF disorder often causes its victim to lead a life of isolation and rejection. Reconstruction of CMF and include skull deformities with CMF implants has been performed successfully by using digital computer design and additive manufacturing [5].

For these reasons, there are significant needs to improvise the CMF treatment for these unfortunate patients in Malaysia. In this regards, the Research University Team (RUT) project aimed at biomodelling and fabrication of CMF implants applying open source applications.

2.0 RUT RESEARCH PROJECT

The RUT project titled "Biomodelling for cranio-maxillofacial reconstruction: aesthetical and functional patient specific biomaterial implants and prostheses" was approved by USM in February 2013. This four years project consist of four main sub-projects such as (i) Biomodelling for cranio-maxillofacial reconstruction, (ii) Synthesis of new biomaterial composite for implants and prostheses, (iii) Fabrication of patient specific implants and prostheses, and (iv) Prosthetic rehabilitation of patients with CMF defects.

This research project involves a multidisciplinary team with expertise from different background such as Oral & Maxillofacial Surgeons, Neurosurgeons, Prosthodontists, Biomaterial Engineers and Scientists, Mechanical Engineers, Mathematicians, Computer Scientists, Community Health Expert, Economist, and Dental Technologist. The researchers are from different Schools in Universiti Sains Malaysia (USM) and from other public universities such as Universiti Teknologi Malaysia (UTM), Universiti Teknologi Tun Hussein Onn (UTHM), and Universiti Teknologi Mara (UiTM). This research also involves international linkages such as University Hasselt, Belgium, Maastricht University, The Netherlands, Lincoln University, New Zealand, and London Metropolitan University, United Kingdom. This study has obtained approval from the Human Research Ethics Committee USM (HREC), reference number USMKK/PPP/JEPeM [259.3.(2)] dated 15th January 2013.

3.0 MATERIALS AND METHODS

3.1 Data Acquisition

The whole system is setup by connecting the PI camera module to the CSI port on the Raspberry PI board via ribbon cable while the LCD screen is connected to the board via HDMI cable. The wireless keyboard and mouse is connected to the board using wireless USB adapter. This is only needed when manipulation of code is required. The power is supplied to the board by connecting a micro USB to USB cable to a wall socket USB adapter or power bank.

3.2 Image Processing

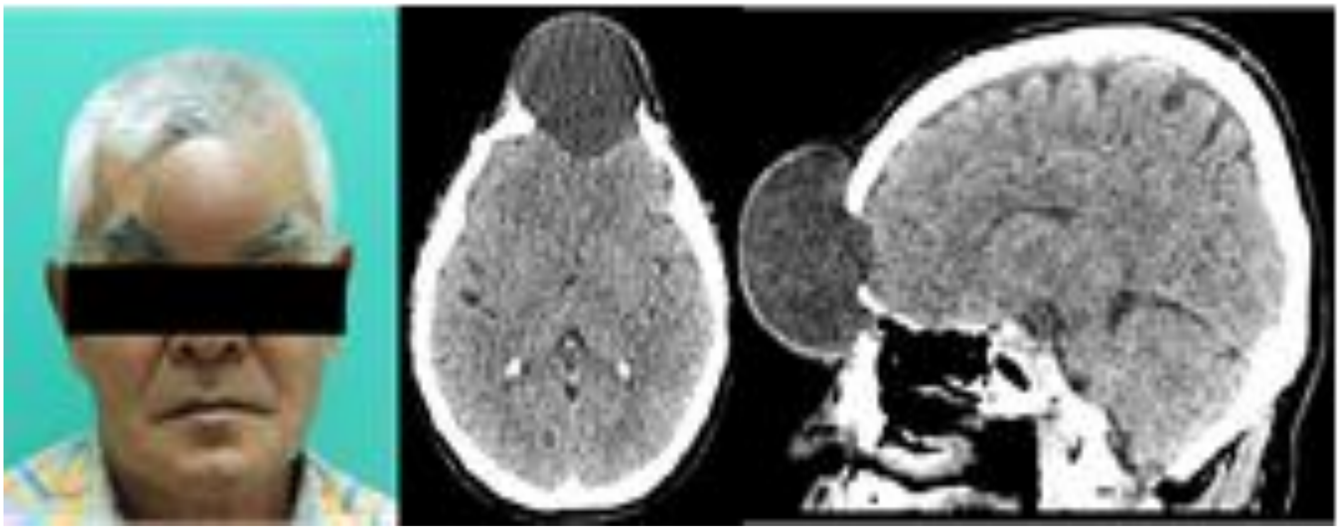
The patient's CT data was processed using the open source Medical Imaging Interaction Toolkit (MITK) software [6], developed by German Cancer Research Centre, Germany. The software offers interactive segmentation and volume visualization of CT images. The use of open source MITK can reduce the cost of relying on commercial software where the ability to process and produce 3D model of the skull was comparable. At the same time, School of Mathematics, USM has studied and produced some algorithms in processing the CT images for patients with cranial defects which later could be used within the MITK framework.

One example of the MITK application is for a 59-years-old male patient attending HUSM with a complaint of swelling on his forehead. CT scanned was taken and the features were suggestive of huge frontal sinus mucocele with local mass effect. There was a well-defined lesion arising from the frontal sinus region and the lesion seems to have capsule around it and not connected to the frontal subarachnoid space. The images of the patient and the CT data are shown in Figure 1.

The hard tissue was segmented from the soft tissue by using the "Threshold" function in the software. A threshold value of 226 Hounsfield Unit (HU) was chosen to segment the hard tissue similar to HU that used in the commercial Mimics Software, Version 17 (Materialise, Leuven, Belgium). The virtual 3D model was visualized after the segmentation process. Finally, the segmented CT data was converted into stereolithography (STL) format, a triangular representation of a 3D surface geometry which is widely used for rapid prototyping and computer-aided manufacturing.

3.3 Additive Manufacturing

The preoperative model of the skull was printed using Stratasys Objet30 Scholar 3D Printer (Stratasys, Eden Prairie, United States) stationed in Craniofacial Medical Imaging Lab, School of Dental Sciences, USM. This 3D printer is using PolyJet 3D printing technology, an additive manufacturing method that patented by Stratasys. The PolyJet 3D printing is similar to inkjet printing where the 3D printer jet layers of curable liquid photopolymer onto a build tray. The Objet30 3D printer jetted and instantly uv-cured tiny droplets of liquid photopolymer. Fine layers accumulated on the build tray to create a precise 3D model of the skull. The printing process and printed 3D model is shown in Figure 2.



(a) (b)

Figure 1 (a) Huge swelling on the patient's forehead and (b) CT data of the patient showing the lesion

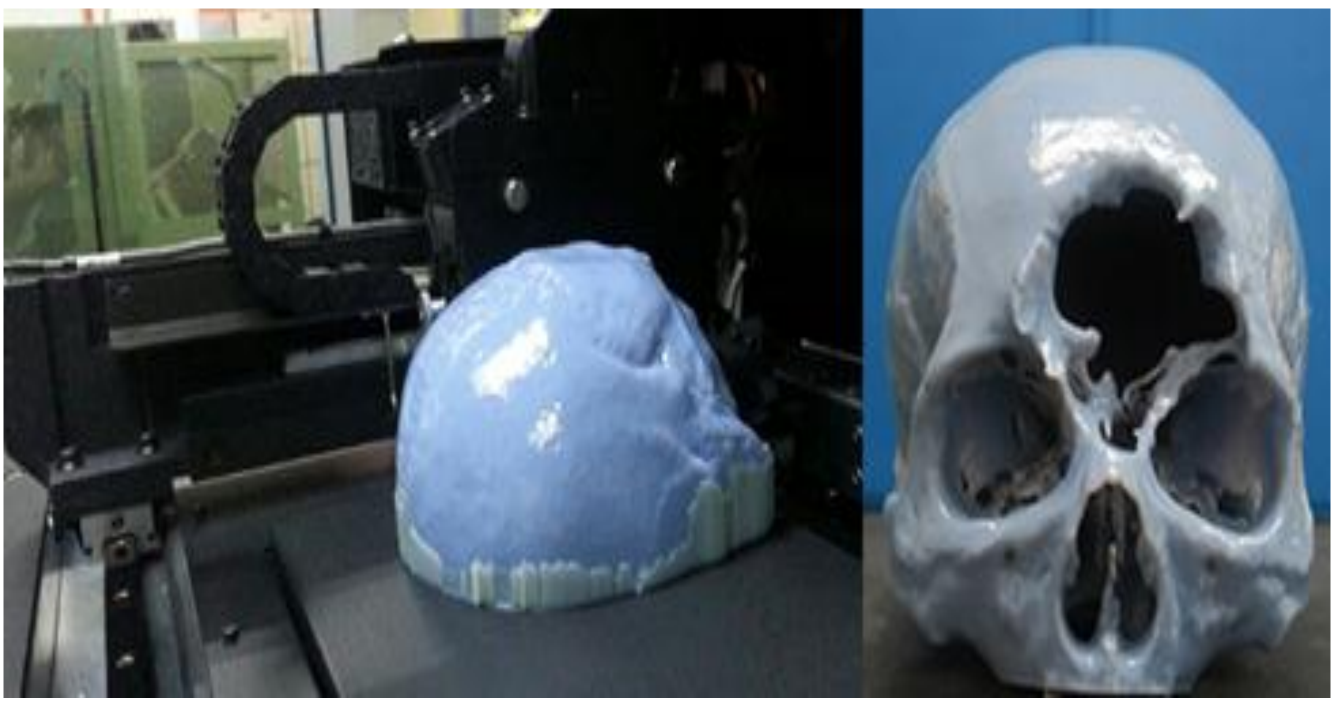


Figure 2 The printing process and the 3D model of the skull

3.4 Clinical Applicationn

The 3D model produced was used for pre-operative planning between the Neurosurgeon and Maxillofacial Surgeon. It was also used as reference during the operation day as shown in Figure 3. The titanium mesh implant was successfully inserted by the Maxillofacial Surgeon after the Neurosurgeon resected the mass.

4.0 RESULTS

The open source software was successfully applied to perform image processing of CT data, to segment the region of interest of anatomical structures, to create virtual 3D models, and finally to convert the virtual 3D models to a format that compatible for additive manufacturing platform. The physical 3D model was successfully printed for clinical application.

The post-operative CT scan was taken after 7 days. The CT scan images clearly showed the craniolasty covering the defected skull. The virtual 3D model of the skull provided the clinician the clear view of the defect and the titanium mesh implant covering the defect. The post-operative virtual 3D model showing the titanium mesh implant is shown in Figure 4.

Figure 3 Pre-operative planning and discussion in the operation theatre using 3D Model (left) and insertion of titanium mesh implant to cover the defected skull perioperatively (right)

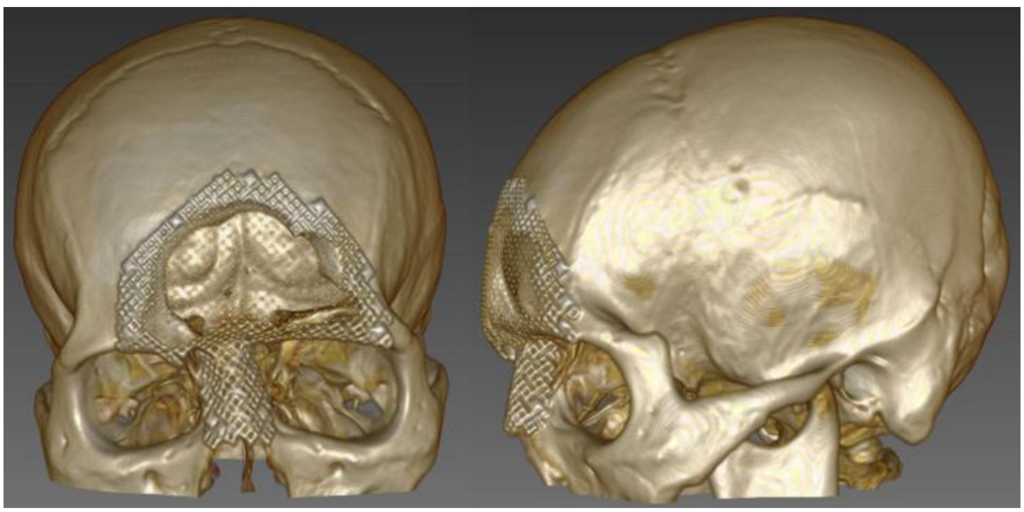


Figure 4 Virtual 3D model showing the titanium mesh implant

5.0 DISCUSSION

The virtual 3D model of the skull was created using open source software from the CT data. This 3D CT imaging provided a more accurate assessment of CMF defects and asymmetry [7]. The virtual 3D model was then converted to STL format for fabrication using additive manufacturing. The physical 3D model was then used for pre-operative planning and discussion by the Neurosurgeons and Maxillofacial Surgeons. The 3D modelling enables the exact fit of the implant to the surrounding tissues. This reduces duration of surgery due to preoperative planning of correct geometrical and anatomical details [8]. The titanium mesh implant was used to cover the skull defect and successfully inserted to patient. The use of 3D reconstruction and 3D model reduces the possibility of errors during surgery, improves fit and provides better implant stability [9]. The patient will be further reviewed after 6 months of operation.

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