The Benefit of 3D Printing in Medical Field: Example Frontal Defect Reconstruction

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Abstract

This study describes a methodology to design a custom-made cranial prosthesis for a patient who suffered injuries from road traffic accident. Computer based cranial defect reconstruction techniques is developed. The design approach was based on the 3D reconstruction of the skull of the patient, obtained by a CT scan. Then a reverse engineering (RE) method is used to reconstruct the defect prosthesis computer-aided design (CAD) model. Once the prosthesis CAD design was completed, the 3D models the skull and the prosthesis were transported into Rapid Prototyping (RP) machine to fabricate the physical model. Finally, the RP model is directly used to produce the biomaterial calcium phosphate cement (CPC) prosthesis. The prosthesis was successfully implanted and a satisfactory result was obtained by using this design method.

Keywords: Tomography; Designed prosthesis; Computer-aided reconstruction; 3D printing

Introduction

The medical imaging such as Computerized Tomography (CT) is an important tool to diagnose the defect and advances in computer software algorithms has allowed the 3D reconstruction of anatomical structures for several medical applications, including the design of custom-made prosthesis. Several studies have reported the use of CAD and advance manufacturing platforms such as computer aided manufacturing/computer numerical control (CAM/CNC), 3D printing and Rapid Tooling (RT) in the production of customized prosthesis and surgical resection template [1-16].

This paper presents a clinical cases study of frontal reconstruction using CT/RE/3D printing, with skull template to design the prosthesis geometry. The results demonstrate that the use of 3D printing to produce the custom made prostheses reduces the possibility of errors during surgery, and perfect fit of the prosthesis was obtained, as result the surgical time was reduced.

Case Study: Cranial Defect

3D image reconstructions

A patient with frontal injury from traffic accident was admitted to hospital for defect reconstruction. It was decided to use calcium phosphate cement (CPC) as the cranioplasty prosthesis through a rapid prototyping stereo lithographic technique. A CT scan was performed using standard craniofacial CT Scanning Protocol; the CT raw data in the form of DICOM files was transferred into Mimics software to convert a set of 2D CT images into a 3D volumetric image, at this time, the craniofacial osseous structures and the defect area were clearly demonstrated (Figure 1). After the 3D volumetric reconstruction using medical imaging software, a STL file of the entire skull was generated and exported into stereo lithography machine to produce a life-size physical skull model (Figure 2a), with this stereo lithography skull model, the cranial defect was clearly shown and evaluated. For prosthesis geometry modeling, a point cloud data of the 3D volumetric image was generated and transferred into Geomagics Studio 6.0 (Raindrop Geomagic, Inc., Research Triangle Park, NC) to design the prosthesis CAD model (Figure 2b).

Image based prosthesis design

Once a 3D reconstruction of the skull was obtained, a point cloud data of the skull 3D volumetric image is imported into reverse engineering software (Geomagic Studio 6-Raindrop Geomagic, Inc., Research Triangle Park, NC) to design the prosthesis CAD model. In reverse engineering environment, the points cloud data are denoised and wrapped as polygonal surfaces as shown in Figure 2c.

Using the information acquired from imaging diagnostics and 3D printing skull models, the extent of the necessary resection, including a margin of safety, is determined before surgery, and the implant custom made prosthesis is designed to cover the resulting bone after defect resection This is done as follows:

First, the approximate area of defect is identified on the 3D volumetric image in reverse engineering environment, then cut out to remove the defect area feature (image data). Next, the design of prosthesis geometry for this case is based on another intact cranial data. A sound Individuals skull use as reference skull template is chosen from the CT database, then the reference skull template 3D image is positioned such that it matches the orientation of the target skull (patient skull), then superimposed on the target skull image. Next, the individual sound skull 3D image data is scaled to better fit with the target skull (patient skull), when the reference template is well fitted to the target skull, the shape of the reference template that match the defect area is used to cover the defect on the target skull as well as to build the prosthesis for final craniofacial reconstruction.

All the data surrounding defect are removed from the reference skull template image leaving only the defect area feature which will be

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used to generate the prosthesis geometry, and the part of the prosthesis which is used to close the defect area is derived from the reference skull template. Because the precise and individual fit results from determining the implant margins by the borders of the defect, the prosthesis margins that contact the defect surrounding bone is derived from the patient skull nonaffected neighboring contours. Thus, the defect area surface and margin area surfaces of the prosthesis are connected, and a three-dimensional geometry results (Figure 2d). The prosthesis was fabricated in a Rapid Prototyping (RP) machine using stereolithography. Finally, the prosthesis SLA pattern is directly used to produce the biomaterial calcium phosphate cement (CPC) prosthesis (Figure 2e).

The patient underwent frontal bone resection and reconstruction using the customized biomaterial CPC prosthesis. The customized CPC prosthesis for frontal bone defect repair was then successfully implanted into the bone defect area at the correct position during surgery, and the surgery time was significantly reduced by using the 3D printing technique in the fabrication of the prosthesis and surgical template. Figure 3 show the patient photos before and after surgery operation.
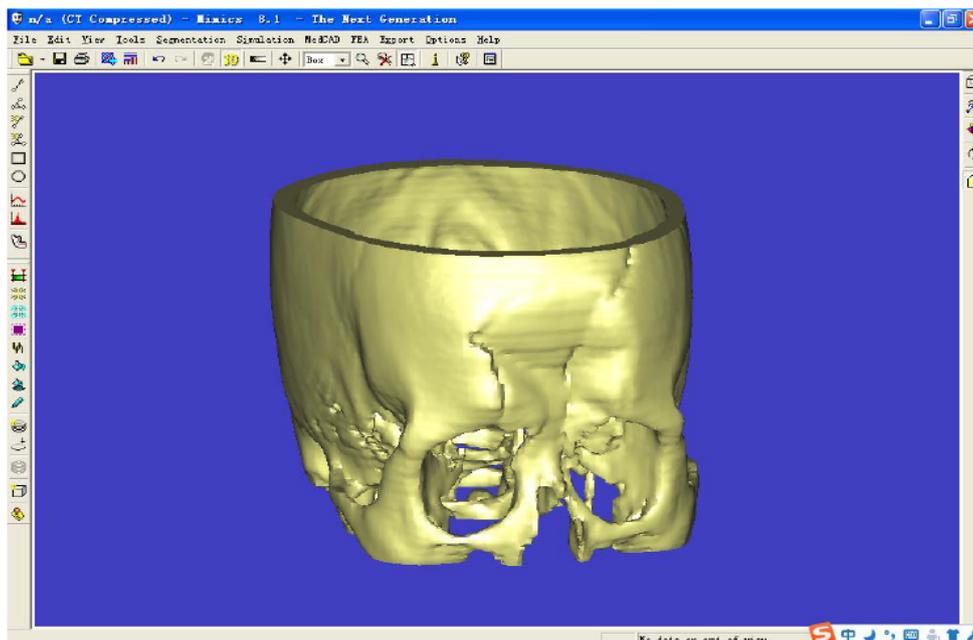
Figure 1: 3D reconstruction of the skull from DICOM data.
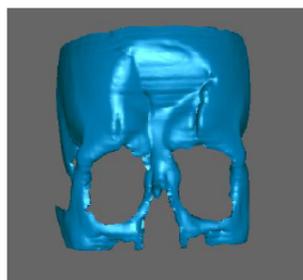
a) 3D volumetric image transferred into Geomagics software
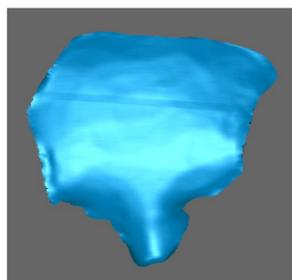
b) CAD prosthesis

c) SLA skull model

d) SLA prosthesis model

e) CPC prosthesis

Figure 2: Customized prosthesis modelling.

Figure 3: Patient photos before and after surgery operation.

Conclusion

This paper presents a clinical cases study of frontal reconstruction using CT/RE/3D printing, with a reference skull template to design the prosthesis geometry. Three-dimensional reformatted images and 3D printing were used in the evaluation of the defects, custom prosthesis design, surgery planning and reconstruction of cranial defect. The 3D printing skull model of the patient has allowed a clear visualization of the defect area and enable to better assess the localization of bone resection contour. Moreover, the combination of 3-D imaging, physical models and reference skull template have allows the design and production of precise fit prosthesis; the operation time was reduced as well as a satisfactory result was obtained by using this design method.

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