Jurnal Teknologi

Full Paper

PROSTHETIC EAR RECONSTRUCTION APPLYING COMPUTER TOMOGRAPHIC (CT) DATA AND ADDITIVE MANUFACTURING TECHNOLOGIES

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Article history
Received
12 February 2015
Received in revised form
25 April 2015
Accepted
31 May 2015

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Graphical abstract

Abstract

The treatment of auricle defect can be by surgical or prosthetic ear rehabilitation depending on the condition. Current practice by surgeon for prosthetic ear rehabilitation require patient to go for osseointegrated craniofacial implant surgery for retention of the prosthetic ear. Impression technique play a vital role in accurate reproduction of affected and unaffected ears, orientation of the ear during wax try in and fabrication of ear prostheses. Traditionally, the wax pattern was created from the impression taken from patient and the final prosthesis is processed with silicone material. This conventional method has always been time consuming, massive work and caused discomfort to patient. Moreover the accuracy of the final prosthetic sometimes was not satisfied. Improvement in medical imaging technology whereby data from computerized tomography (CT) in 2D format can be converting to 3 dimensional images gave tremendous view for surgeon to visualize the result. A new and impressive advance in the development of additive manufacturing technology is now being able to be applied in medical field. The widespread use of computer-aided design (CAD) combine with computer aided manufacturing (CAM) produced the momentum and desire to translate the 3-D images into physical models. Studies and research have indicated the viability of using medical imaging technology, computer aided design (CAD) and additive manufacturing techniques in prosthetics. This paper proposed a novel method of fabricating the prosthetic ear applying mirror image technique to reconstruct the missing ear, and then fabricate the 3D model of the prosthetic ear using Stereolitography (SLA) technology that will become the master mold to produce the final prosthetic ear. This method eliminates the traditional wax pattern procedure. A clinical study is done onto a patient in HUSM and comparison is made between traditional method vs new approach using computer aided technology. Result showed that there is significant different between traditional and new approach design. The new method also shows time reduction during design and fabrication stage.

Keywords: 3D imaging technique, prosthetic ear, additive manufacturing

1.0 INTRODUCTION

Knowledge of the normal ear morphology is important in the treatment and management of variety of congenital deformities such as hemifacial microsomia, Tessier's facial cleft, microtia, etc. Also, its subtle structures that shows potential signs of age, gender and aesthetic appearance.

Reisberg et. al [1] has reported the importance of ear rehabilitation for facial aesthetic. Previous methods applying hand sculpturing, impression of similar ear for mirror imaging and wax modeling for ear reconstruction. However, these traditional

methods faces a lot of challenges in producing the correct anatomic morphology, as it is time consuming and involved massive laboratory work. Moreover, the impression technique causes deformation and discomfort to the patient. Its also contribute to inaccuracy in producing the prosthetic ear.

Coward et al [2] has utilized a technique using stereo photogrammetric imaging to produce accurate ear prosthesis. Result from this study indicate that stereo photogrammetric showed some significant errors in their result. This could be due to limitation of locating anatomical landmarks especially bony landmarks. Furthermore, another method applying laser scanner have certain disadvantages such as high cost and need proper training [3].

These multi modality imaging techniques play an important role in data capturing. However, not many studies utilized computed tomography scan (CT scan) data for ear reconstructions applying computer reconstruction algorithm. With the marriage of computer imaging technology and advanced manufacturing, recent studies indicate that computer aided design and computer aided manufacturing (CAD/CAM) can overcome the above problems[4,5]. Therefore, the aim of this research is to utilize this technologies of medical imaging and additive manufacturing to custom fabricate ear prosthetic for ear reconstruction and rehabilitation.

2.0 PROBLEM STATEMENT

In the process of making the prosthetic ear, the geometrical dimension of the defective ear is important. The shape, size and position of the defective ear must be balance with the normal one. Current method applied in HUSM totally depends on the artistic skill of the operator. The mirror image technique applied to obtain the reconstructed ear from the normal ear sometimes is not accurate in the sense that errors may occur at any one of many stages during production.

3.0 OBJECTIVE OF THE STUDY

Reconstruction of an aesthetically pleasing auricle that perfectly fit on to the patient by implementing the advanced technology of CAD/CAM and additive manufacturing.

4.0 REVIEW OF THE CONVENTIONAL METHOD OF PRODUCING PROSTHETIC EAR

The prosthetic ear fabrication performed by a maxillofacial technologist or anaplastologist in a laboratory. The conventional method of fabricating ear prosthesis relies on the artistry and availability of the anaplastologist [5]. Several of these procedures are time consuming and require the patient to be present for an extended period of time. Basically, the conventional method of fabricating the ear prosthesis involves:

1. Making impression to duplicate affected area and replicate the unaffected area to determine the correct geometry and position of the prosthesis
2. Creating a clay or wax sculpture of the future prosthesis
3. Silicone injection with the color in to the working mold to get the prosthesis
4. Finishing – trim the prosthetic to obtain final end product and also recoloring if applicable. [6]

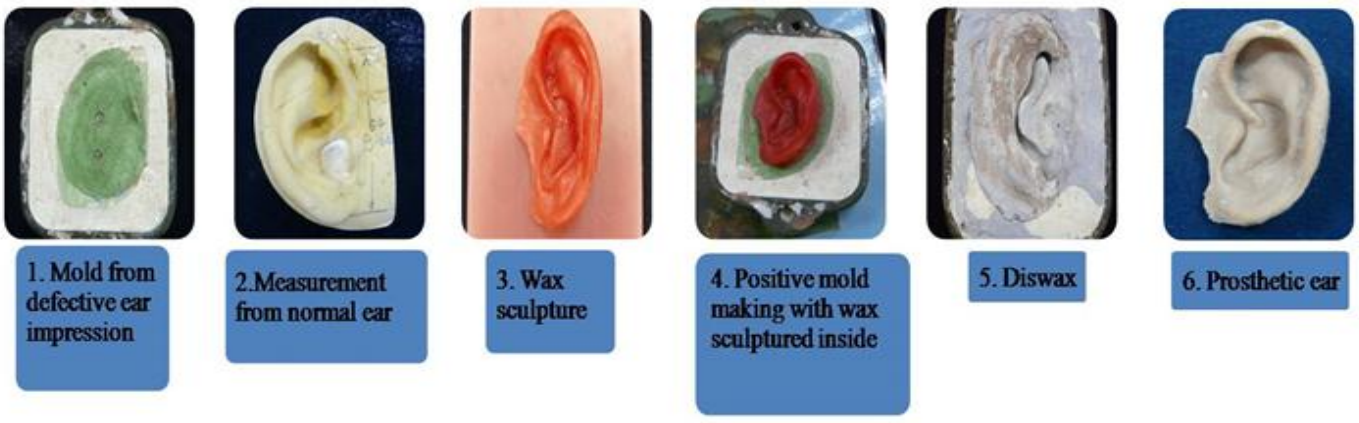


Figure 1 Block diagram of the processes of the system

5.0 CAD/CAM AND ADDITIVE MANUFACTURING FOR PROSTHETIC EAR FABRICATION

Recently, additive manufacturing technology has been introduced in the biomedical field for fabrication of models to ease surgical planning and simulation in implantology, neurosurgery and orthopaedics, as well as for the fabrication of maxillofacial prostheses[7]. Additive manufacturing is a techique that represent a set of additive technologies based on the construction of physical three-dimensional structures, layer by layer, based on its respective digital models. This technology can produce complex shapes such as cavities usually present in human anatomy.

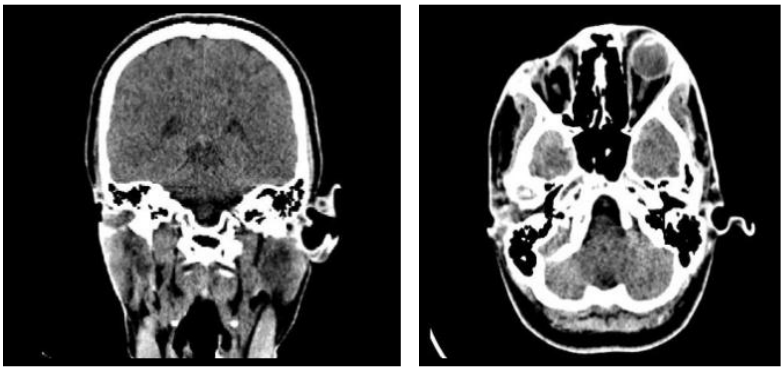
Currently, there are various numbers of additive manufacturing technologies available in the market, based on special sintering, layering or deposition methods. Some of the famous technologies are Stereolitographic (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), 3D Printing. Among of these technologies, SLA is the leading technology with over 500 SLA machine installed worldwide [8]. It's developed by 3-D Systems Inc, of Valencia, CA. The SLA 7000 system is two times faster, on average, than the next fastest solid imaging system from 3D systems. Its system's 0.0254 mm layer thickness yields a smooth finish that result in far less post-processing time.

The study conducted by Jiao et al. reported that fabrication of ear prostheses using CAD/CAM was advantageous because a highly qualified technician is not necessary to sculpture an ear in wax [4]. The procedure can be carried out in a computer and patient can visualize the result at the screen before fabrication. Subburaj et al. also demonstrated the method of fabricating the auricular prosthesis using CAD/CAM and rapid prototyping technologies [9]. The result showed that the computer aided method gave a higher level of accuracy in terms of shape, size and position of the prosthesis, and significantly shorter lead time compared to conventional technique.

6.0 CLINICAL REPORT

The first stage in the fabrication of the prosthetic ear is to capture the data of the ear digitally. There are various techniques to capture the data either mechanical scanning devices or optical scanning devices. In this research, data was captured using medical imaging technique. The study was done onto a 15 years old girl who had traumatic incident that caused 90% of her face was damaged due to acid. She totally lost her right ear in the incident. Doctor planned to do facial reconstruction to help her facing her trauma. One of the plan was to reconstruct her right ear. She had undergone CT scan procedure after the incident.

As for this case, the data is retrieved from CT scan images (see Figure 2). Data captured using CT scan gave stack of images in 2 dimensional (2D) form. All these images need to be converted to 3 dimensional (3D) images for further designing the ear.



(a) (b)

Figure 2 mages of CT scan taken from PACS server in axial (right) and coronal (left) view

The 2D images from the CT is then transfer into the medical imaging software, MIMICS (Materialise, Leuven, Belgium) for 3D image conversion (Fig 3). The image processing and editing is required where any noise from the CT scan process can be erased. Thresholding of the required soft tissue can produce 3-dimensional image for the specific area of interest.

To design the prosthetic ear, mirror image technique is apply in the MIMICS software. The mid-line of face is use as the axis of symmetry, and the image of normal ear is extract, mirror and place on the deficient side Figure 4. From here we can predict the outcome of the prosthetic ear. It is very important to make sure that the position of the new prosthetic ear is align with the normal ear. Once the design is finalize, another CAD software is used for further smoothing the prosthetic ear.

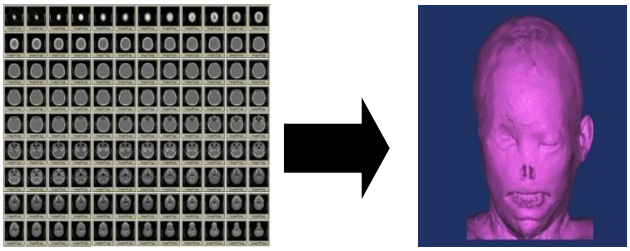


Figure 3 Data conversion from CT images to 3D image with deficiency

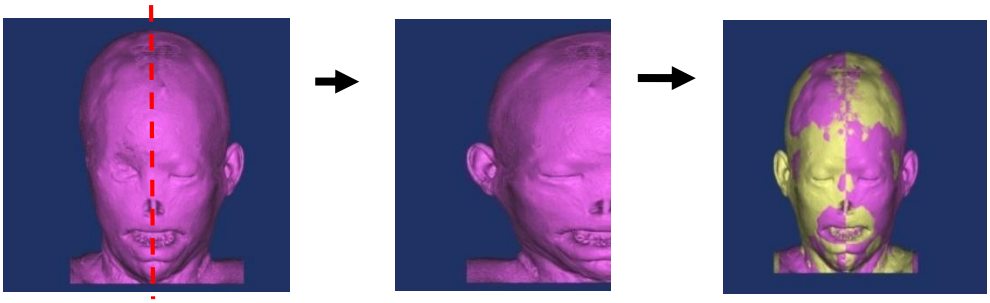


Figure 4 Design process of the prosthetic ear applying mirror image technique

The GeoMAGIC software was used to prepare the part before it go for fabrication. This process will highlight on the respective area of interest (Figure 5). The new profile of the prosthetic ear was cut and then the thickness was given (Figure 6). Command such as surface smoothening, data reduction and blocking of undercuts were apply at this stage. This process is essential to prepare the part for additive manufacturing fabrication.

Figure 5 Highlight the area of interest

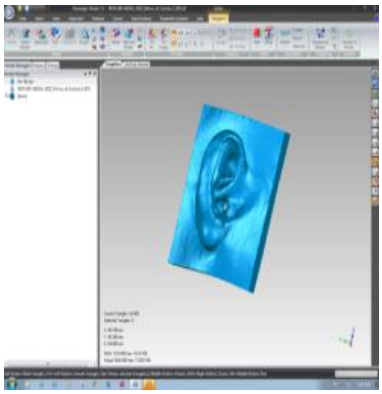


Figure 6 Virtual design of using CAD software

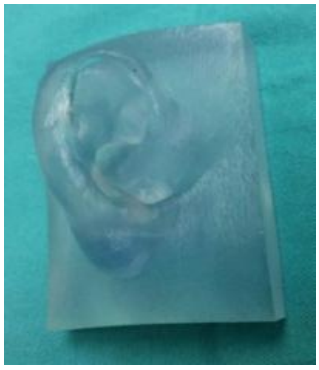


Figure 7 3-D model obtained from SLA.

Once the design has been finalized, the part is then sent to the additive manufacturing machine for fabrication. The final design was converted to STL format which is composed of a series of triangles and is widely adopted in the CAD/CAM field. As for this study, Stereolitography (SLA) technology was applied to fabricate the prosthetic ear. This method generally used UV (ultraviolet) light to cure resin to form the desired shape. The prosthesis that came out from this machine will then be used as the master mold to fabricate the final prosthetic ear (Figure 7).

7.0 RESULT AND DISCUSSION

Instead of using the traditional method to obtain the profile of the prosthetic ear, the advanced technology of medical imaging using computer tomography (CT scan) can be used to collect 3

dimensional anatomic data. Using medical imaging software to convert the slices of images obtained from the CT, 3D model of the required area can easily generated. The advantage of using CT is that, data captured can show the anatomy of ear external and internally. With these data, doctor can easily diagnose and plan for implant surgery if necessary. Furthermore, with this computer generated procedure, the hassle of using hydrocolloid impression that lead to discomfort to patient was eliminated.

The new design of the prosthetic ear using mirror image technique using CAD software show that there is significant different compared to the design obtained with traditionally hand sculptured technique (Figure 8). Ear measurement comparison was done for a few standard ear parameters to show the different compared to the normal ear of the left side (Figure 9). Percentage error was calculated with respect to normal ear measurement and shown in Table 1.

Figure 8 3D model of Prosthetic ear from SLA (right) and wax pattern (left) by the maxillofacial technician

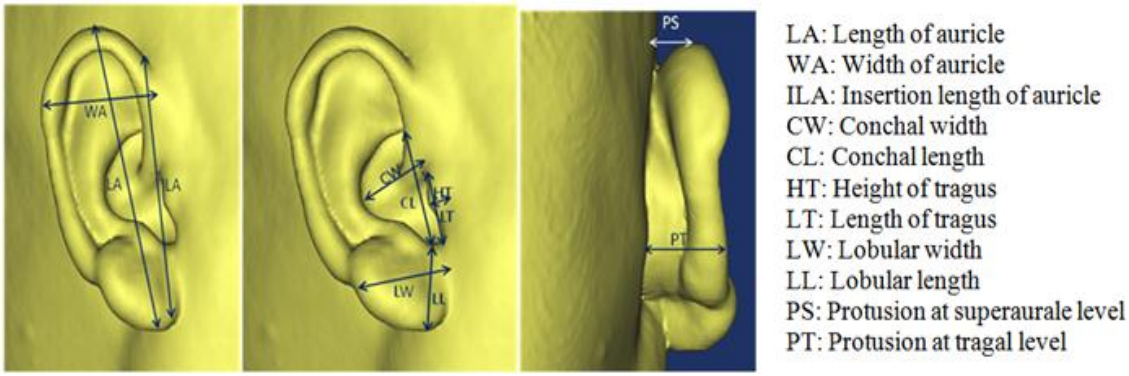


Figure 9 Standard Morphological measurement of the ear

In term of time taken to design and fabricate the prosthetic ear with the new approach using computer aided technology, the crucial stage as reported by the technician is to sculptured the new design of the prosthetic ear. It takes almost one week to finish the design. Mirror technique using CAD software only takes a few minutes. 3D image editing takes only a few hours depending on the outcome from the CT scan. Preparing the design for additive manufacturing fabrication takes 3 to 4 hours accordingly. And the fabrication of the final design that acts as the master mold for the prosthetic ear takes 3 to 4 hours. There is a definite time savings when the computer aided approach is employed based on a single clinical trial. However more case studies need to be performed to validate the time saving. The digital images and mold design can be preserved. This is important for future reconstruction if necessary as human ear growth accordingly.

Despite the advantages elaborate above, there are some limitations that need to be considered while developing the technique using computer aided approach. Definitely the equipment required for initial set up to establish the procedures are high. The mirror imaging technique can only be applied to the case with unilateral missing ear. For bilateral missing case, the design technique may change. The anthropometric knowledge is highly important to determine the correct position of the prosthetic ear with respect to facial harmonist.

Table 1 Comparative study between two methods with respect to normal

Measurement (Refer Fig 9)	Normal Ear	Traditional Method		Additive Manufacturing	
		Traditional	Percentage Error	SLA	Percentage Error
LA	50.55	49.31	2.45	49.6	1.88
WA	27.53	22.11	19.69	26.73	2.91
LL	15.98	17.34	8.51	19.31	20.84
LW	14.08	22.02	56.39	14.18	0.71
ILA	45.32	42.42	6.40	44.31	2.23
LT	10.22	6.84	33.07	11.11	8.71
HT	3.83	0.91	76.24	4.28	11.75
CL	18.36	16.11	12.25	17.58	4.25
CW	14.64	9.84	32.79	13.43	8.27
PS	10.31	14.57	41.32	10.73	4.07
PT	24.9	21.39	14.10	23.91	3.98

8.0 CONCLUSION

This paper describes the overall process of fabricating the prosthetic ear by implementing the advanced technology of medical imaging technique of CT scan to capture the ear profile in 3D digital image, computer aided technology to design the prosthetic ear and also utilize the beauty of additive manufacturing technology to custom fabricate the prosthetic ear cast. This procedure is time saving and eliminate the dependency on skill technician to wax sculpture the prosthetic ear.

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