Design and Prototyping of Cranial Implants

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Abstract – *The human skull is complex structure and developing an implant based on traditional procedures are limited to develop implant at several occasions. The development of computer aided methods the generation of customized implants made easier and reduced the actual time of procedure. This journal proposes a simplified approach to the customized manufacturing of cranial implants using rapid prototyping. Although, cost-effective is an objective of this research the ultimate goal is saving time as in turn it can save lives which matters the most. A comparison of techniques is also done in this research just to identify how far we have come in implementing the modern technological advancements in the field of healthcare. A detailed analysis of both the composites (Kevlar 29) and the titanium alloys are done on structural and monetary basis.*

Key Words: Cranial implants, Rapid prototyping, Cranioplasty, CT scan, 3D Printing.

1. INTRODUCTION

Cranioplasty is the repair of bone defects or cranial deformities using a bio-compatible material. Substances like precious metals animal bone, autologous bone graft and methyl methacrylate have been used to for repairing the skull defects. Thin sheets of titanium of various thicknesses are used to fit the skull curvature and are attached using screws [1]. Hydroxyapatite cement combining with titanium mesh for repair small holes in the skull. Titanium mesh combined with polyurethane and molded into shape of skull for smaller defects to reduce shock resistance compared to the sheet [2]. Recent advancement of Composite materials in the medical field offer several benefits over traditional metal implants. Due to their low modulus of elasticity and high fatigue strength compared to the metals they better match to bone [3]. There has been tremendous attention in the development of customized cranial implants for the reconstruction of skull defects known as Computer Assisted Cranioplasty (CAC) [4]. CAC implants provide a variety of advantages over the conventional manual repair technique. They reduce in theater time and allow a variety of materials to be used for repairs.The steps involed in developing an implant are as follows. CT scan data processing

1. Voume Rendering from CT scan
2. Creating and editing mesh
3. Creating implant in CAD
4. Generating G codes for printing
5. Printing implant

2. MATERIALS

Acrylic resin, titanium sheet/mesh and hydroxyapatite have all been employed. Each of these materials have different physical and biological properties. Pure titanium (Ti CP) and Ti-6Al-4V are the common titanium base implant used commercially. As they remain inert when implemented into human bodies these classified as biomaterials [1]. Kevlar 29 has the highest specific strength of any current reinforcement, due to its high strength and extremely low density. Although Kevlar 29 is expensive compared to glass fiber, its use may be justified in applications where weight savings are essential, like in the fields of aerospace and medicine. The key advantage of this type of composites is its high specific stiffness and elevated capacity to absorb energy [5].The material properties of Titanium and Kevlar are summarized in the Tables 1,2.

Table-1: Mechanical Properties of Ti CP (ASTM F 67 and Ti6A14V alloy (ASTM F 136) [1]

Property	Grade 1	Grade 2	Grade 3	Grade 4	Ti6A14V
Tensile Strength (MPa)	240	345	450	550	860
Yield Strength (MPa)	170	275	380	485	795
Elongation	24 %	20 %	18 %	15 %	10 %

Table -2: Mechanical Properties of Kevlar-29[5]

E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	υ_{12} (-)	υ_{13} (-)
18.5	18.5	6.0	0.77	5.43	5.43	0.25	0.33
υ_{23} (-)	X_{IT} (MPa)	X_{2T} (MPa)	Z_R (MPa)	S_L (MPa)	S_T (MPa)	P (kg/m^3)	
0.33	555	555	34.5	77	898	1230	

3. METHODOLOGY

3.1. CT Scan data processing

This paper is focussed on converting a CT scan data into 3D printable file. The major software used is **3D Slicer** which is used in medical field for processing CT or MRI scan data and convert them into 3D model which then can be used for various observations. With the help of 216 CT axial slices that are 0.8 mm thick of a patient with cranial deformation is obtained and analysed in this paper. Using 3D slicer software, the 2D image (Fig-1) are concatenated to represent 3D object (Fig-2).
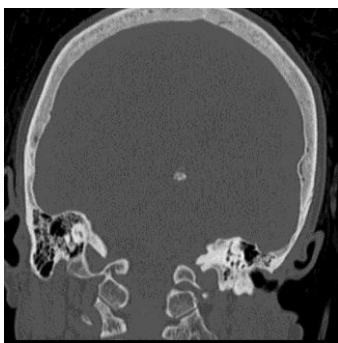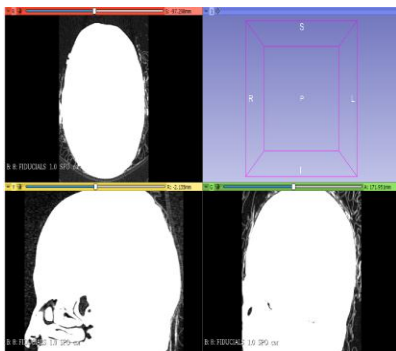

Fig -1: CT scan of Skull cross section

Fig -2: CT Scan DICOM images imported as a single 2D image in 3D Slicer software

3.2 Voume Rendering

The next procedure is to volume render the DICOM images combined to form the skull in three dimensional shape. The process is done in the 3D slicer software. Firstly, render the 3D image by using volume rendering option in the 3D Slicer software; Change the contrast to CT – Bone to detect only the skull shape(bone). Next step is to set the threshold range for detecting the bone in the skull and extract only useful information. This is done in Edit Segment module and the threshold range in this case is set to 100 – 3075 to get the bone data in perfect shape (Fig-3). Remove the speckles in the image by using Islands effect in Edit Module.
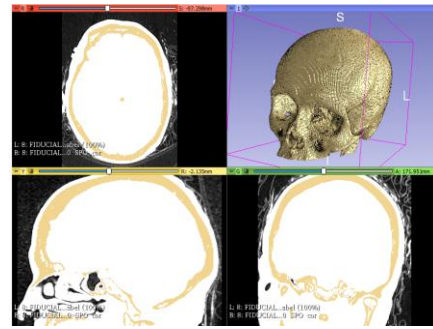

Fig -3: CT scan data after volume rendering the DICOM file

3.3 Creating and editing mesh using Meshmixer:

Some of the features of the mesh that are not properly formed in the STL format obtained by the 3D Slicer software can be edited and repaired by using some of the mesh editing software like Mesh mixer and MeshLab (Fig-4 & Fig-5). Mesh editors are excellent tools when it comes to editing files like STL formats. To reduce the complexity and the time of the printing the bottom part of the skull is removed. When the bottom part is sliced the model is opened and transferred to shell objects which are unable to print. These software helps in generating the mesh elements from the existing surfaces and again forms a printable model. These can help in controlling the element size by preserving the geometric details of the object

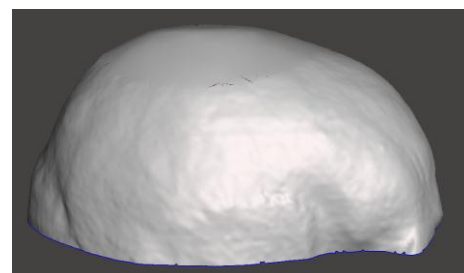**Fig -4:** *Skull image before refined mesh with striations and distortions*

Fig -5: Skull image after refining mesh using Meshmixer

3.4 Editing using FreeCAD:

The biggest challenge in this project is to create an implant on the 3D skull which has no surface features on it. For this the best software available is FreeCAD from which we created the implant by using the spline srfaces with the help of projected points and some surface deformations like holes just to represent in the printed skull.
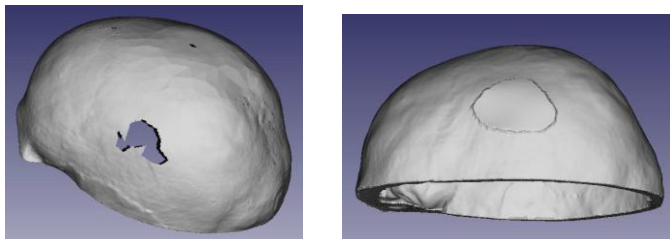

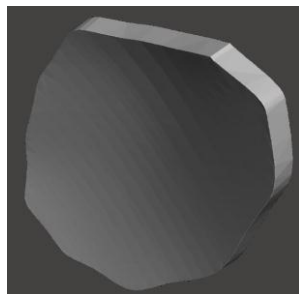**Fig -6:** Skull with a hole model & skull patched up with implant

Fig -7: Implant made on a deformed skull to be 3D printed

3.5 Creating G-code for 3D printing:

Both the implant and the skull ready for 3D printing after the processing done using FreeCAD software can be converted into G-code (which is compatible format for 3D printing machine) with the help of comerical softwares like Fusion360 etc... The code can be anlysed or checked for the printing compactibility with the help of specifed machine software then the model is sent for the printing.

4. RESULTS and DISCUSSION

The main results obtained from Abaqus are by defining the constraint parameters for different materials like Titanium and Kevlar-29. The analysis is done in the Abaqus software applying the boundary conditions fixing the surface on the skull side and applying an impact load of 2000N (table 4). Obtain the maximum stress induced by calculating the von mises stress.
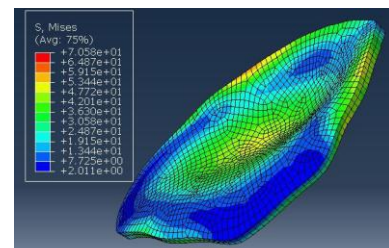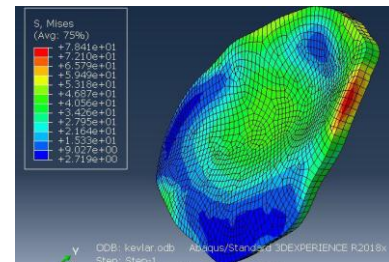

Fig -8: *Titanium Alloy Stress analysis*

Fig -9: *Kevlar-29 Stress analysis*

Table -4: *The peak force for fracture at different regions of head [6]*

Impact area	Force (kN)
Frontal	4.2
	5.5
	4.0
	6.2
	4.7
Lateral	3.6
	2.0
	5.2
Occipital	12.5

The maximum stress levels are ranging form70MPa to 80MPa in both Titanium alloy and Kevlar-29.

4.1 3D Printed Prototype

Both the skull and implant prototypes are made using PLA material whose images are mentioned in the Fig. 10. The results provide an insight into the concept of Cranioplasty and Rapid prototyping.

Fig -10 : *3D printed image of Skull with separately made implant glued to the surface*

5. CONCLUSION

This work focusses on comparing different materials for making cranial implants especially Titanium alloy and Kevlar and its advantages. And also, it is proven that Kevlar can be used as a substitute for metal implants due to its advantages. However, we do not have a single material that has more strength and excellent biocompatibility. There exists several techiques in developing the cranioplasty implant. With the use of advanced CAD techniques to create implants that anatomically correct contours has progressed rapidly over recent times. Prototypes of skull and implants are made to show general concept of Cranioplasty. Cranial implants made from a range of materials can be designed and constructed to an accuracy of ±1 mm. This ensures excellent and ease of fit and reduce surgical time.

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