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Evaluation of Zygomatic Complex Fractures Based on Three Point Fixation Technique using Additive Manufacturing

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ABSTRACT

Zygomatic bone in the facial skeleton occupies a prominent anteriolateral position in the midface. In recent years Additive Manufacturing also popularly known as 3D Printing is a technological boon where objects can be produced physically in 3 Dimensional format and is playing a vital role in biomedical field especially for complex surgeries.The aim of this paper is to evaluate zygomatic complex fractures based on three point fixation technique using additive manufacturing process. The methodology involves collecting CT scan data of a patient having zygomatic complex fracture.The CT scan data is taken before operation and after operation is performed.Once the 3D physical model is printed then the dimensions of fixed landmarks are measured, thereby comparing the Unfractured side to Fractured side before operation and Fractured side after operation. By adapting this methodology, it is possible to evaluate i.e. calculate the percentage of the Zygomatic Bone restored after Operation.

Keywords: Additive Manufacturing, Zygomatic Fracture, Three point fixation, Fixed landmarks

I. INTRODUCTION

Additive Manufacturing (AM) also known as 3D printing, refers to manufacturing a three-dimensional object by adding successive layers of material under computer control to create Objects of any shape or geometry from digital CAD model. AM has application in diversified fields like in aerospace, defence, automobile, jewelery, architecture, archeology, biomedical etc. In biomedical field Additive Manufacturing can be used for planning complex surgeries, developing implants, building prototype models of medical devices and many more.

Zygoma bone is the strong buttress of lateral midface lying between Zygomatic process of Frontal bone and Maxilla. The cause for Zygomatic bone fracture is usually a direct blow to the malar eminence of the cheek during assault. Fig.1 illustrates representation of zygoma in the facial skull.Zygoma bone plays a vital role in restoring the malar prominence prominence of the facial skeleton. The zygoma fracture is generally fixed by using three point fixation technique. Three point fixation means three miniplates are used to align the bone properly.This technique is widely used in Zygoma surgeries

This paper presents the application of additive manufacturing in evaluating the percentage of restotaration of zygomatic complex fractures by comparing before and after operation.

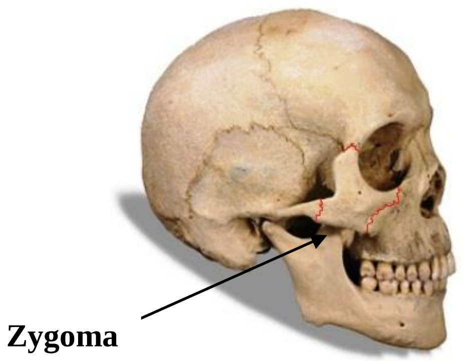

Figure 1. Representation of Zygoma [10]

II. LITERATURE REVIEW

Olszewski Raphael et.al [1] in their work evaluates the Three Dimensional RP models use in CMF surgery. Peter shih Chang et.al[2] describes how stereolithography can be used to produce physical models of the craniofacial skeleton from three dimensional computed tomography data. Elista G.Deliverska et.al [3] illustrates the complications that can occur in case of zygoma fracture and to draw the attention of the clinicians to need of accurate diagnosis and early treatment of the associated with zygoma fractures. Ludmila Novakova Marcincinova et.al [4] integrates the appropriate use of basic and advanced materials used for fused deposition modeling. Paulo Norberto Hasse et.al [5] in their study evaluates clinically and radiographically,unilateral zygomatic fractures treated through internal rigid fixation with miniplates and screws of 1.5 mm.Shams Uddin et.al [6] explains incidence of tripod fracture. Krishna et.al [9] describes Finite Element analysis across the fracture line of a mandible fixed with conventional and locking micro plate.

III. PROBLEM DEFINITION

The main aim of this work is to evaluate zygomatic complex fracture based on three point fixation technique using additive manufacturing. The evaluation is done by 3D printing the fractured skull before operation and fractured skull after operation.Finally the difference in dimensions between 3D CAD Model of the Skull and actual 3D printed skull is calculated.

IV. RESEARCH METHODOLOGY

The following research methodology has been adopted for solving the problem described in the earlier section. The various steps involved are:

- ✓ Collection of patient’s CT Scan data from SVS Institue of Dental Sciences,Mahabubnagar.
- ✓ Modelling by importing CT Scan data in ITK SNAP software.
- ✓ 3D Printing of the fractured skull before operation and after operation.
- ✓ Measuring the dimensions of fixed landmarks on 3D Printed skulls and calculation of % restoration in 3D Printed Skull
- ✓ Measuring Dimensions of Fixed Landmarks in 3D CAD Model using Radiant DICOM Viewer
- ✓ Comparing percentage restoration between 3D printed kull and 3D CAD Model.

A. Collection of CT Scan Data

The 2D images of Computer Tomography (CT) scanned data of a 22 years old male patient is collected from SVS Institute of Dental Sciences college, Mahabubnagar, Telangana State in the Digital Imaging and Communications in Medicine (DICOM) format as shown in Figure 2.

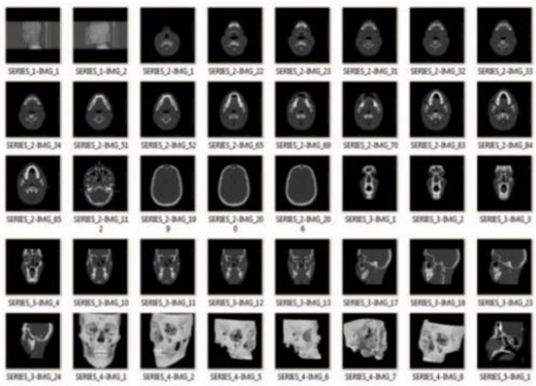

Figure 2. CT Scan Data of the Patient in DICOM format

B. Conversion of 2D Scan Data into 3D CAD Model

The DICOM images were then imported into a medical imaging software ITK SNAP, which is used for the visualization and segmentation of CT scan images. The images were converted into three views coronal, axial and sagittal as shown in the Figure 3.

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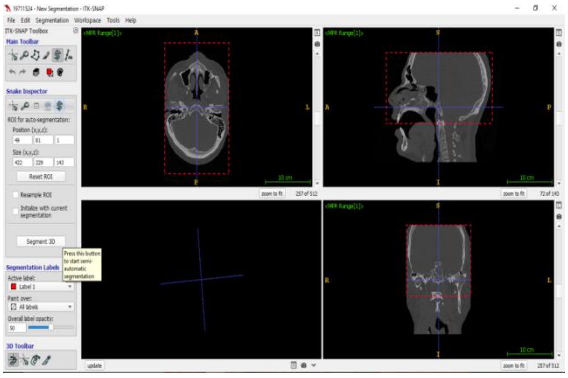


Figure 3. Coronal, axial and sagittal views of CT scandata in ITK SNAP Software

The first step of converting 2D data into a 3D CAD model is segmentation. In segmentation, the initial step is choosing the correct Threshold value. Thresholding classifies all the pixels within the Hounsfield range as the same color or a mask. The lower threshold value allows segmentation of soft tissue, whereas a higher threshold value segments bone. In this case, the lowest and highest threshold values selected for the bone are 310 and 3075. The 2D scanning data was converted into a 3D model as shown in the Figure 4

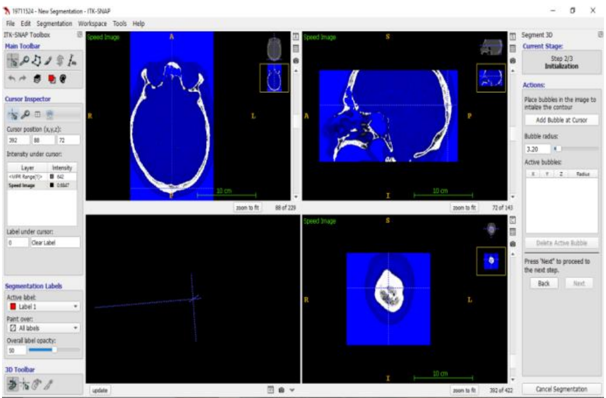


Figure 4. Conversion of 2D data into 3D model

The zygoma bone is selected as region of interest and 3D CAD model generated is shown in Fig.4.

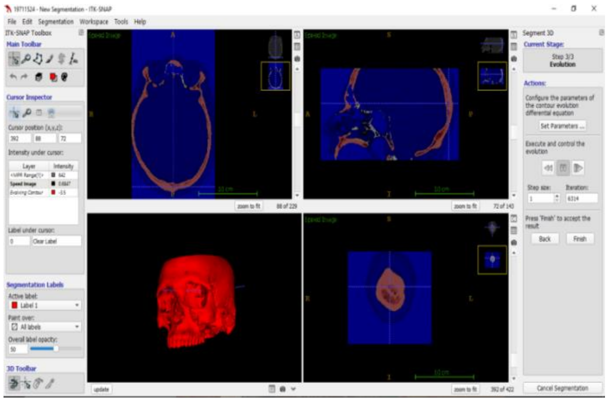
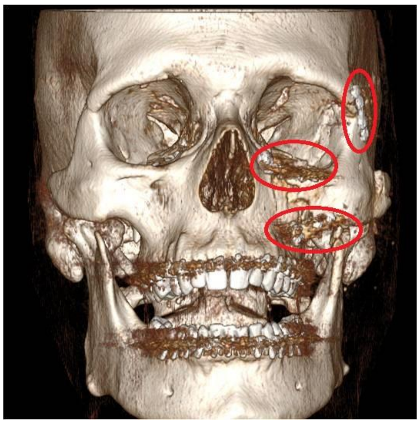


Figure 5. 3D model of the skull

Figure 6 illustrates patients's postoperative image where three miniplates are fixed at three different points on the zygoma bone, hence known as three point fixation technique. The three points are highlighted with red colour where the miniplates are fixed. in the surgery.



C. 3D Printing of the Skull using FDM Process

Two skulls are 3D Printed,the first one is before Operation and second one is after Operation.The Printer used is FlashForge Finder. Since the maximum Build volume of this Flashforge Finder 3D printer is 140 mm × 140 mm × 140 mm.But actual dimensions of the skull is 137.08 mm×196.30 mm×144.63 mm. So the skull is printed by scaling down the STL file to 50% of actual STL File. Fig. 6 illsutrates the STL file format of 50 % scaled down model of patient's preoperative skull in flash forge finder software.

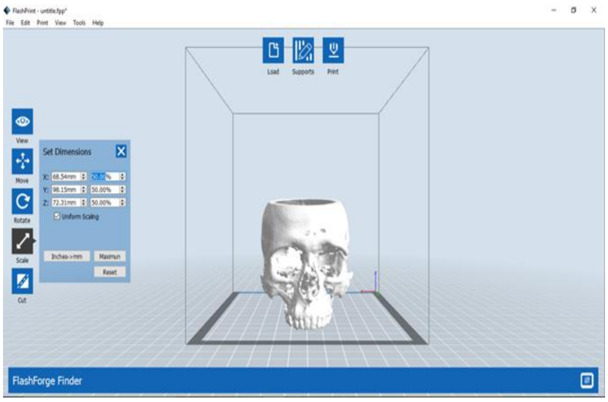


Figure 6. Patient's Preoperative 50% Scaled down STL file

Figure 7 illsutrates the sacled down 3D Printed Model of patient's preoperative skull. The total build time for printing scaled down model of skull before and after operation are 10.5 hours and 11.5 hours respectively.

Figure 7. 3D printed sacled down model of Patients skull before operative.

D. Measuring Dimensions of Fixed Landmarks on 3D Printed skull

The fixed landmarks considered for measuring dimensions on the skull for zygomatic fractures are Inion(In), Porion(Po), AnteriorNasalspine(ANS), Zygomatic prominence(ZyP) and Anterior alveolus(AAI). The above landmarks are fixed globally. Figure 8 below shows the fixed landmarks on the skull considered for measuring dimensions [2].

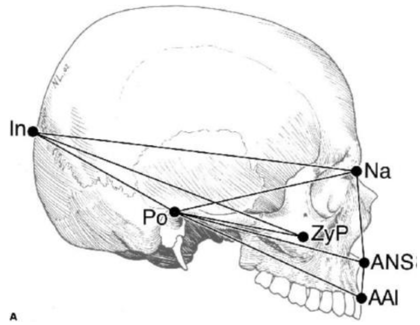


Figure 8. Fixed landmarks on the skull for measuring Dimensions [2].

Figure 9 below illustrates the distance measured between Inion-Porion on 3D printed scaled down model of the unfractured side of the skull using digital vernier callipers.

Figure 9. Distance measured between Inion-Porion of the Unfractured side of the skull using digital vernier callipers

Similarly the distance between all the other landmarks are measured. Table 1 below illustrates distance between Fixed Landmarks of Unfractured side of the 3D printed skull.

Table 1. Distance Between Fixed Landmarks Of Unfractured Side Of The 3d Printed Skull

Landmarks	Dist. Between Land marks of Unfractured side of the scaled down model of the 3D printed skull in mm	After Scaling up by a factor of 2 in mm.
In-Po	59.6	119.2
In-ZyP	91.0	182.0
Po-AAI	59.7	119.4
Po-ANS	58.5	117.0
Po-ZyP	38.6	77.2

Figure 10 illustrates the dimensions measured between the Inion and Porion landmarks on the 3D printed scaled down model of the fractured side of the skull before operation using vernier calipers.

Figure 10. Distance measured between Inion-Porion of the fractured side of the skull before operation using digital vernier callipers

Similarly the distance between all the other landmarks are measured. Table 2 below illustrates distance between Fixed Landmarks of fractured side of the 3D printed skull before operation

Table 2. Distance Between Fixed Landmarks Of Fractured Side Of 3d Printed Skull Before Operation

Landmarks	Dist. Between Land marks of fractured side of the scaled down model of the 3D Printed skull before operation in mm	After Scaling up by a factor of 2 in mm.
In-Po	58.8	117.6
In-ZyP	88.8	177.6
Po-AAI	61.0	122.0
Po-ANS	60.1	120.2
Po-ZyP	38.1	76.2

Figure 11 illustrates the dimensions measured between the Inion and Porion landmarks on the 3D printed scaled down model of the fractured side of the skull after operation using vernier calipers

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Figure 11. Distance measured between Inion-Porion of the fractured side of the skull after operation using digital vernier calipers

Similarly Table 3 illsutrates the distance measured between the fixed landmarks of fractured side of the 3D Printed Skull after operation.

Table 3. Distance Between Fixed Landmarks Of Fractured Side Of 3d Printed Skull After Operation

Landmarks	Dist. Between Land marks of fractured side of the scaled down model of the 3D Printed skull after operation in mm	After Scaling up by a factor of 2 in mm.
In-Po	60.2	120.4
In-ZyP	90.1	180.2
Po-AAI	61.3	122.6
Po-ANS	60.4	120.8
Po-ZyP	38.8	77.6

Table 4 illsutrates the comparison of distances between unfractured side and fractured side of the skull before operation. Note in all the tables starting from Table 4 to Table 13 only numerical difference in values is considered without signs [2].

Table 4. Comparison Of Distances Between Unfractured Side And Fractured Side Of The Skull Before Operation

Landmarks	Unfractured Skull in (mm) Un	Fractured skull Before Operation (mm) Bn	% Difference between Unfractured & fractured side of skull before operation
In-Po	119.2	117.6	1.3
In-ZyP	182.0	117.6	2.4

Po-AAI	119.4	122.0	2.1
Po-ANS	117.0	120.2	2.7
Po-ZyP	77.2	76.2	1.3

% of Difference in dimensions between Unfractured side of skull and Fractured skull before operation for for Inion-Porion =(Un-Bn)/Un*100 = {(119.2 – 117.6) / 119.2} * 100 = 1.3 % .

Table 5 illsutrates the comparison of distances between unfractured side and fractured side of the skull after operation.

Table 5. Comparison Between Unfractured Side Of The Skull And Fractured Side Of The Skull After Operation.

Landmarks	Unfractured Skull in (mm) Un	Fractured skull After Operation (mm) Bn	% Difference between Unfractured & fractured side of skull after operation
In-Po	119.2	120.4	1.0
In-ZyP	182.0	180.2	0.9
Po-AAI	119.4	122.6	2.0
Po-ANS	117.0	120.8	3.2
Po-ZyP	77.2	77.6	1.03

% Difference between Unfractured skull and fractured skull after operation for Inion-Porion =(Un-An)/Un* 100 =(120.4-119.2)/119.2*100=1.0

Table 6. Calculation Of Percentage Of Restoration

Landmarks	Difference of value of (Unfractured skull-Fractured skull before Operation) DUB (mm)	Difference of value of (Unfractured skull-Fractured skull after Operation) DUA (mm)	% Restored
In-Po	1.6	1.2	25.00
In-ZyP	4.4	1.8	59.09
Po-AAI	2.6	3.2	23.00
Po-ANS	3.2	3.8	18.75
Po-ZyP	1.0	0.4	60.00

% Restored=(DUB-DUA)/DUB*100 =

% Restored for Inion-Porion =

(1.6-1.2)/1.6*100 = 25.00

E. Measuring Dimensions of Fixed Landmarks in 3D CAD Model.

The dimensions of the fixed landmarks in 3D CAD model is measured using Radiant DICOM Viewer software. Intially unfractured side is measured then Before and after Operation of fractured side of the skull and After Operation. Figure 12 below illustrates measuring of the distance between Inion-Porion of unfarctured skull in 3D CAD Model.

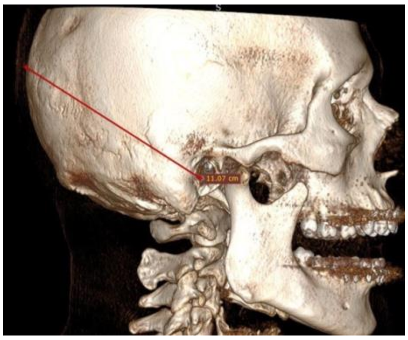

Figure 12. Distance between Inion-Porion OF Unfractured side of the skull

Table 7 to 12 illsutrates the distance between the fixed land marks of unfractured, fractured skull before operation, fractured skull after operation and calculation of percentage of restoration respectively.

Table 7. Distance Between Fixed Landmarks Of Unfractured Side Of The Skull

Landmarks	Unfractured Side of the Skull (mm)
In-Po	110.7
In-ZyP	171.3
Po-AAI	109.8
Po-ANS	109.9
Po-ZyP	75.6

Table 8. Distance Between Fixed Landmarks Of Fractured Side Of The Skull Before Operation

Landmarks	Fractured side of the Skull Before Operation in mm
In-Po	96.4
In-ZyP	151.1
Po-AAI	121.5
Po-ANS	120.9
Po-ZyP	75.1

Table 9. Distance Between Fixed Landmarks Of Fractured Side Of The Skull After Operation

Landmarks	Fractured side of the Skull After Operation in mm
In-Po	99.4
In-ZyP	160.5
Po-AAI	117.3
Po-ANS	117.9
Po-ZyP	74.2

Table 10. Comparison Between Unfractured Side Of The Skull And Fractured Side Of The Skull Before Operation

Landmarks	Unfractu -red Skull in mm Un	Fractured skull before Operation in mm Bn	% Difference b/w Unfractured & Before operation
In-Po	110.7	96.4	12.91
In-ZyP	171.3	151.1	11.79
Po-AAI	109.8	121.5	10.65
Po-ANS	109.9	120.9	10.00
Po-ZyP	75.6	75.1	0.66

% Difference Between Unfractured Skull &Fractured Side Of Skull Before Operation =(Un-Bn) / Un * 100

% Difference Between Unfractured Skull And Fractured Skull Before Operation For Inion-Porion = (110.7-96.4) / 110.7 * 100=12.91

Table 11. Comparison Between Unfractured Side Of The Skull & Fractured Side Of The Skull After Operation

Landmarks	Unfracture skull in mm Un	After Operation (mm) An	% Difference b/w Unfractured &After operation
In-Po	110.7	99.4	10.20
In-ZyP	171.3	160.5	6.30
Po-AAI	109.8	117.3	6.83
Po-ANS	109.9	117.9	7.27
Po-ZyP	75.6	74.2	1.85

% Difference between Unfractured skull and fractured skull after operation =(Un-An)/Un*100

% Difference between Unfractured skull &fractured skull after operation for Inion-Porion =(110.7-99.4)/110.7*100=10.20

Table 12. Calculation Of Percentage Restoration In 3d Cad Model

Landmarks	Difference value (Unfractured skull- Fractured skull before Operation) DUB (mm)	Difference value (Unfractured skull- Fractured skull after Operation) DUA (mm)	% Restored
In-Po	14.3	11.3	20.97
In-ZyP	20.2	10.8	46.53
Po-AAI	11.7	7.5	35.89
Po-ANS	11	8	27.27
Po-ZyP	0.5	1.4	64.28

% Restored=(Dub-Dua)/Dub*100

% Restored For Inion-Porion = (14.3-11.3)/14.3*100 = 20.97

Table 13. Difference In % Restored From 3d Printed Skull And 3d Cad Model

Landmarks	%restored 3D Printed Skull (P)	%restored 3D CAD Model (C)	% Difference b/w (P) & (C)
In-Po	25.00	20.97	16.12
In-ZyP	59.09	46.53	21.25

Po-AAI	23.00	35.89	56.04
Po-ANS	18.75	27.27	45.44
Po-ZyP	60.00	64.28	7.13

V. CONCLUSIONS

- ✓ Following are the conclusions drawn from 3D CAD Model and 3D Printed model of unfractured and fractured skulls before and after operation.
- ✓ The amount of restoration of zygoma bone calculated from 3D CAD model before and after operation for Inion-Zygomaticprominence and Porion-Zygomaticprominence were found to be 46.53% and 64.28% (See Table 12). These landmarks are only considred because they are the prominent landmarks for evaluating zygomatic restoration.
- ✓ Similarly the amount of restoration of zygoma bone calculated from 3D Printed skull before and after operation for Inion-Zygomaticprominence 59.09% and Porion-Zygomaticprominence was found to be 60% (See Table 6).
- ✓ It is very difficult to identify land marks in software so the dimensions measured may not be accurate, while from 3D Printed model it is easy to take. It was found that by comparing percentage restored from 3D printed skull and 3D CAD model, Inion-Zygomaticprominence landmark has percentage difference which is in Table 13 i.e. 21.25% and Porion-Zygomaticprominence landmark has percentage difference of about 7.13 %.

VI. ACKNOWLEDGEMENTS

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