Kufa Journal of Engineering
Vol. 17, No. 2, April 2026, P.P. 43-60
Article history: Received 15 March 2024, last revised 27 May 2024, accepted 12 March 2025

RAPID PROTOTYPE OF HUMAN HEAD FOR BIOMEDICAL ENGINEERING BASED ON MEDICAL SCANNED DATA AND ADDITIVE MANUFACTURING

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https://doi.org/10.30572/2018/KJE/170204

ABSTRACT

The rapid developments of additive technology bestirred the interested to application of this technology for different filed. In the biomedical and prosthesis engineering, this technology especially contributes to solve the sophisticated problems from generating the surgical models, and tissue engineering to detect the defected zone of anatomy. In the introduced paper a suggested strategies have been adopted to create a printable model for the human's head depending on the row data from the CT or MRI with DICOM format and the software of medical data processing. The additive manufacturing based on 3D printing technology has been used to produce the 3D physical models of the face parts. Surface roughness for the created models have been measured, which ranged (0.65-1.846) $\mathcal{M}$m for the printed modes, also an image processing technique have been adopted to compare the dimensional accuracy between the prototypes and the DICOM image, where the maximum deviation value was (0.8mm). The adopted strategies were simplified to use by any interested in biomedical domain, and proved a good effectualness to create any suggested human body parts.

KEYWORDS

Additive Manufacturing, Medical Data Processing, Biomedical Engineering.

1. INTRODUCTION

Rapid prototype (RP) is a digital technology which used to produce parts on a layer-by-layer manner based on the additive manufacturing (AM) without subtractive nor formative materials such process of machining, molding, or casting. It's based on a computer aided design (CAD) data. And it gives faster process, better product, and lower cost for design and development process. This technology has widespread applications such as aerospace, automotive, consumer products, electronics, medical modeling, biomedical developments, toys, power tools, and jewelry manufacturing custom Hwaiyu G., and Cmfge, PE (2004). The RP technique permit the inserters to fabricate a tangible prototype of the quickly designs, addition to two-dimensional models. prototypes represent visual aids for communicating ideas with inserters or customers, also it can be used to test various design aspects. RP allow to inspect parts in a very early stage of designing, which decreases the overall product cost. There are a various types technique of RP such as Stereolithography (SLA), Fused Deposition Manufacturing (FDM), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), three-dimensional printing (3D printing) and Multi-jet Manufacturing Vinesh R. and Kiran J. F. (2008). The rapid developments of 3DP technology exposed the researcher to experiment the capability of this technology within the different fields. Regarding of the biomedical domain includes the most advanced fields, such as tissue and bones surgery, organic or tissue fabrication for educational, artificial prosthetics engineering, and many more.The application of AM for biomedical or medical domains can be used to fabricating personalized and sophisticated devices or objects based on patient MRI or CT scans, 3D printing a special prostheses or implants like skull bon implants, orthopedic implant, mandibular prosthesis, spinal disk, maxillofacial, Invisalign braces, hearing aids, dental implants, neuroanatomical models, cartilage tissues, heart valve, bone, and artificial ear. The application of 3DP technology for biomedical engineering has great advances for understanding and developing the patient-specific treatment status. As a result of the recent technological improvement progress, many of invention have been a reality, such as implantations of artificial organic and dosages formation that invented to special status and provide modified active pharmaceutical ingredients (APIs). Depending on the modern technologies of additive manufacturing becomes a powerful engineering tool for corporations and healthily industries and, although there are some bulkheads, they provide a promising treatment for current domains and future Zaisam D., et al (2020) and Al-Duroobi et. al, (2024) discussed applications advantages, and disadvantages of 3DP technologies and its effects for patient-specific medicine, and the using of 3DP in healthcare. The author used an open-source software called Tinker CAD to generate a tablets and a capsules . Yigang Chen, et. al, (2020) discovered the effects of 3D printing technology on medical students understanding of Henle trunk's variation, comparing with 2D images. The 3D printed Henle trunk model was effective teaching aid, which can help student to understand the anatomy of Henle trunk. Mallikarjuna N Nadagouda, et al, (2020) and Al-Bdairy (2025) presented a review for additive manufacturing, using 3D) printing, and their applications in many applications, including the medicine domain for surgical planning and tissue regeneration. The authors also presence the development of materials for biocompatible that's led to increasingly useful in medicine. Sambit Ghadai, et. al, (2020) presented a directly printed for inspect the multi-level models representation of voxel for complex geometries, and data of CT. Where the author concluded that the introduced additive manufacturing algorithm produced produce a better surface finish. Pengwen Wang, et. al, (2021) and Ali M. Al-Bdairy (2020,2021) constructed and developed a helmet by a reversing engineering, and 3D printing technology. It's collected the point cloud data using 3D scanner and the data processed by (Geomagic Studio) and (SolidWorks), it optimizes the production process, reduce the development cycle, and improve efficiency of production. Yongqiang Hao, et. al (2020), investigate the application of 3D printing technology for reconstruction the bone defects of acetabular. It's used radiographic methods, related to interactive medical image control system and surgical experience to determining the volume of defect, stability of prosthesis, and the accuracy of installations, it's proved the ability to reconstruction of bone defects using a 3D printing prosthesis, and it`s able to give good effects in patient status. Chong Wang, et. al, (2020) introduced a review of 3D printing using for bone tissue engineering scaffolds. Also, presented how to apply 3D printing technology for the designing, and fabrication of bone tissue engineering scaffolds with desirable shape, structural, physical, chemical and biological features for enhanced biological performance and for regenerating complex bone tissues. Abid Haleem, et. al, (2019) provided a review for applications of 3D printing in the engineering of bone tissue which can help to treatment a critical defect of bone, involves the scaffold manufacturing with combination of materials and cells.The present paper will be organized as follow, section 2 will be illustrated the adopted work strategies to perform the prototyping of the intended case study of a humane head and the building flowchart of this strategies, the detailed steps of that strategies have been introduced in subsections I, and II, then section 3 illustrate the simulation, generating the tool path, prototyping processes arriving to final prototypes, in sections 4 the results and discussion for intended case study will be presented, finally a conclusion will be illustrated and recorded in section 5.

2. THE ADOPTED WORK STRATEGIES

Magnetic resonance imaging (MRI) and computed tomography (CT) can be help to give statue of specific imperfections of patient, and these images can further be used to create 3D printing models. The human head skin and bone skull models for adult man was used in the present work which gained by the data of CT scans for the patients through inspection. These CT scans were used to build the standard tessellation language (STL) format file for 3D printing. The procedure of 3D printing a scanned parts is showed in Fig.1, that provides the sequential steps that required for creation of the prototype of the medical data in conjunction with additive manufacturing using the 3D printers.

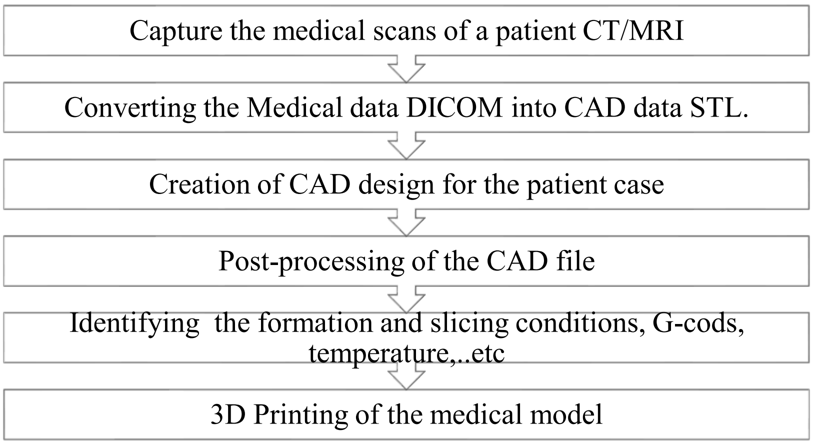


Fig. 1 Steps of medical data manufacturing.

The creation of a 3D printed model for medical data involves several steps, which are: identification of the anatomical target area, converting the medical data of Digital Imaging and Communications in Medicine (DICOM) into CAD data STL, geometric 3D modeling based on medical imaging, post-processing and file editing to make the model suitable for printing, identifying the formation and slicing conditions, G-cods, temperature,..etc., finally creation the physical model of patient body part using the 3D printing technology. In the present work the gathering CT or MRI scans for patients, with the DICOM directory format have been converted into CAD models using 3D processing software, InVesalius 3.1. These data format then exported as an STL. file for 3D printers .

Some of strategies have been adopted in the present work to convert the scanning data of CT or MRI into desired 3D physical model, these strategies involved; importing the medical data strategy, modifying strategy, and rapid prototyping strategy. The flowchart of the introduced strategies in the present work is showed in Fig. 2.

The strategies starting with importing the DICOM format data from CT or MRI devise, then manipulate this data using the open source3d modelling software InVesalius 3.1 to remove the noised data which associated to scanning process, and convert the DICOM into printable data file format with STL. Post-processing for the STL. file has been achieved using Meshmixer software to obtain a smoothed file with format STL without any defects, and processing the mesh to solving the imperfectives that could be cause mistake during 3D printing that lead to getting a defect-free high-quality STL. file of the part from a CT scan. The 3D printing technique was used in the present wok as one of the communally used technics for additive manufacturing.

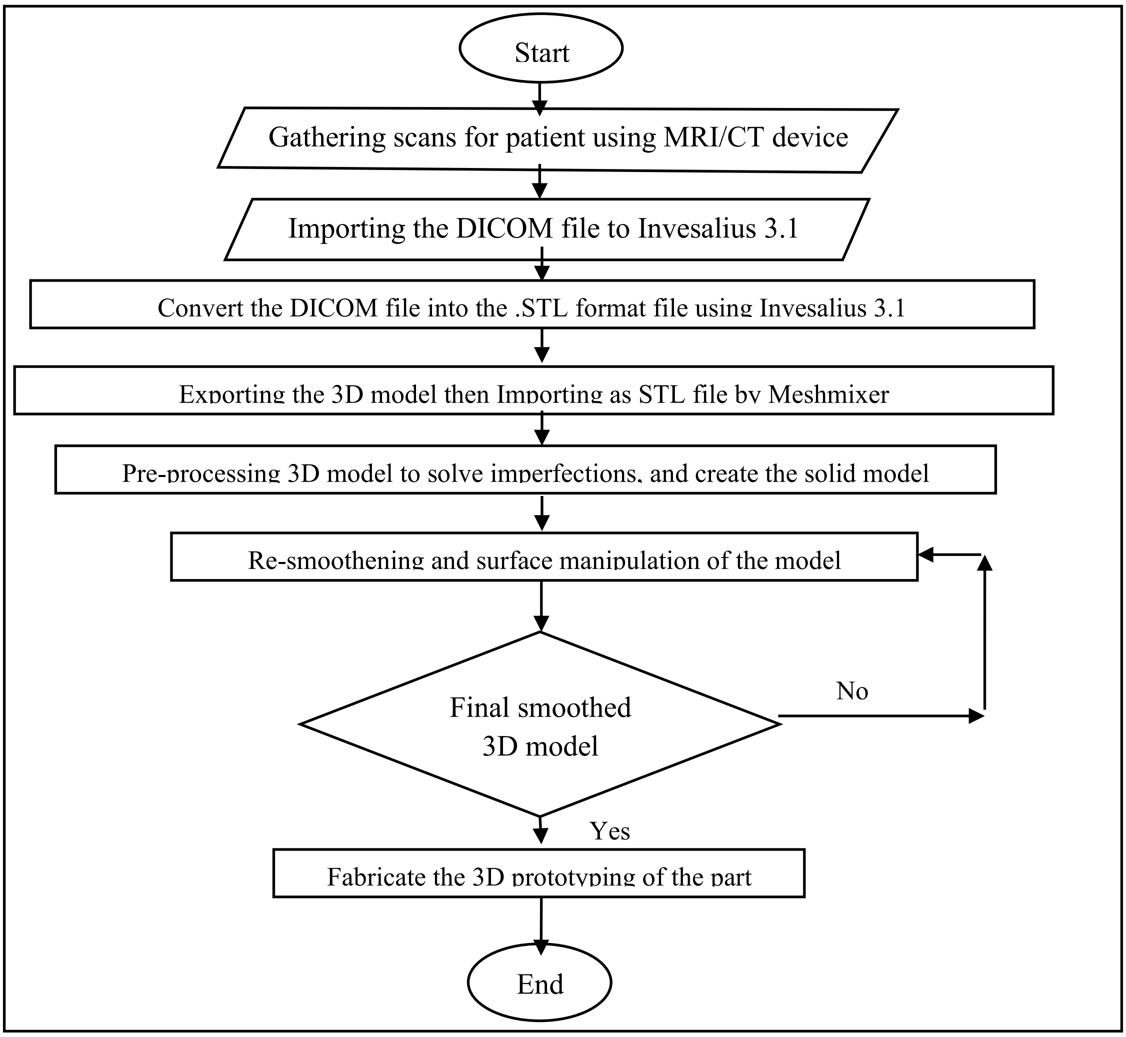


Fig. 2. Flowchart for convert the scanning data of CT or MRI into desired 3D physical model.

2.1. IMPORTING THE MEDICAL DATA STRATEGY

Toshiba Aquilion ONE 320 slice computed tomography (CT) scanner, has been used to performed scanning on patient head. The scanner is fast and can give advanced cardiac imaging and neuroimaging.

A CT case study of the patient that illustrated in Fig.3, which are a set of individual images that taken directly from CT device for a multi slices of the patient head.

All data of image were gathered and stored in DICOM format as shown in fig.3 for head topology of the patient. The DICOM format file then imported in a 3D modelling software called InVesalius 3.1, as shown in Fig.4 to converting the DICOM images into 3D printable format file with stl. extension with three basic steps, where in the first step the DICOM images had been imported into InVesalius 3.1 software and the region of interest had been selected as showing in Fig.5-a, the masks for adult skin and bone have been created and selected in the second step as showing in Fig.5-b, , then the 3D surface of this masks have been generated as showing in Fig 5-c and d in the third step for the head topology and skull respectively.

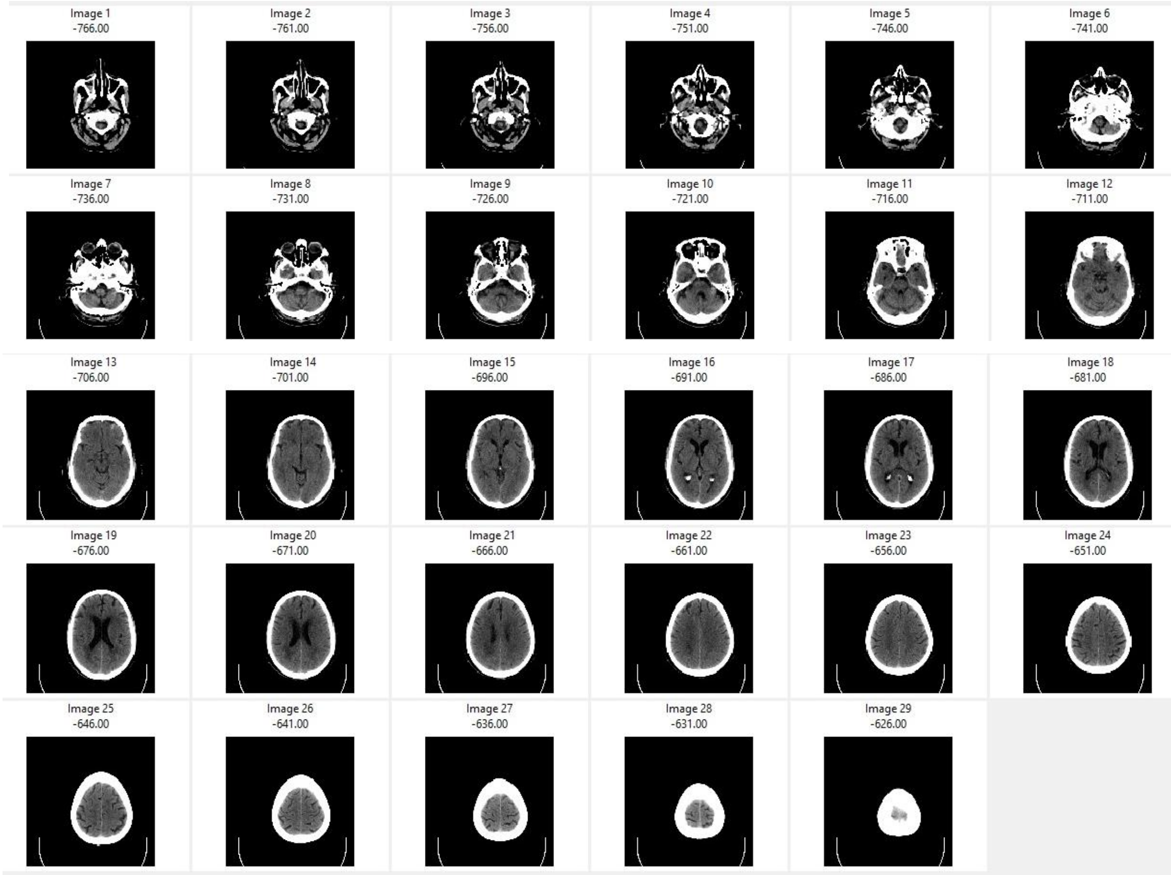


Fig. 3. CT Case study

Fig. 4. DICOM file for Head topology of the patient

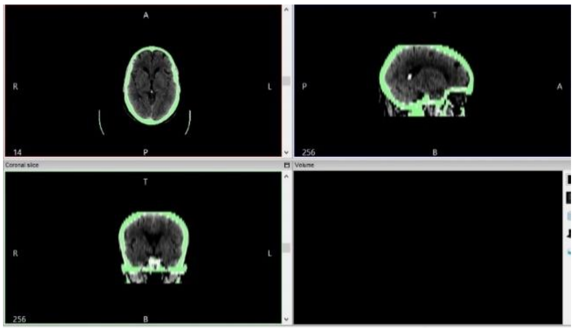


Fig. 5-a. Importing CT Case study for InVesalius software

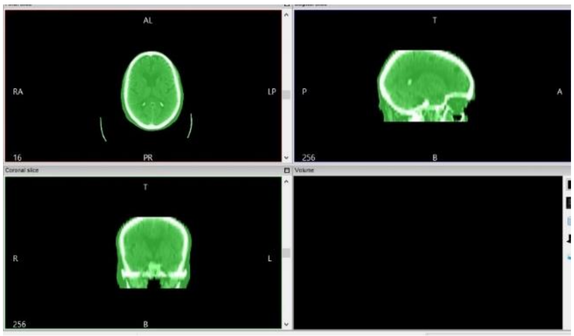


Fig.5-b. Creation of mask for the patient head

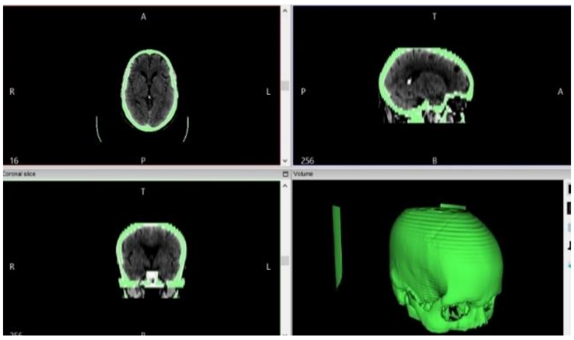


Fig. 5-d. The 3D surface of bone mask of the patient skull bone

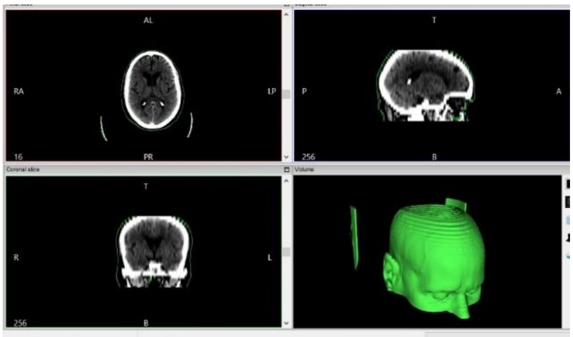


Fig.5-c. The 3D surface of skin mask of the patient head

2.2. Post-processing of .STL file using Meshmixer

Meshmixer software used to import the STL. file that constructed using the InVesalius 3.1, then processed the 3D model to get a smoother 3D surface model. Due to the disconnected mesh patches that generated in modeling software, it is necessary to clean that 3D model from such defects to obtain a perfect mesh of the object.

Through MeshMixer it can be analysis the 3D mesh before 3D printing for identifying the imperfections that could cause mistakes through 3D printing, the 3D mesh models for the head skin and the skull are shown in Fig.6 and Fig.7 respectively.

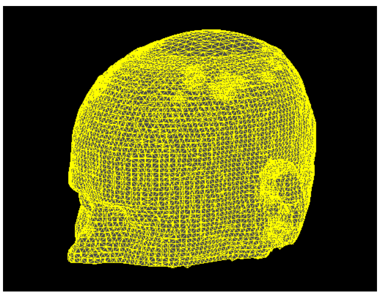


Fig. 6. 3D mesh models for the head skin of the patient

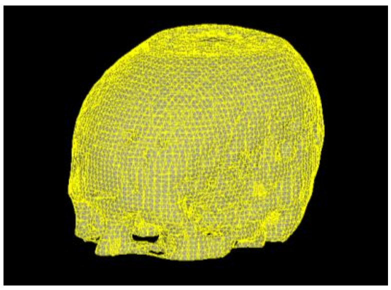


Fig.7. 3D mesh models for the bon skull of the patient

Finally obtain a defect-free and high-quality .STL file for the part based on CT scan. In the present work a 3D printable file have been constructed for the outer topology of the head skin and the skull that show in Fig.8 and Fig.9 respectively, that have been exported as STL. file format after removing the noised data of scanning process.

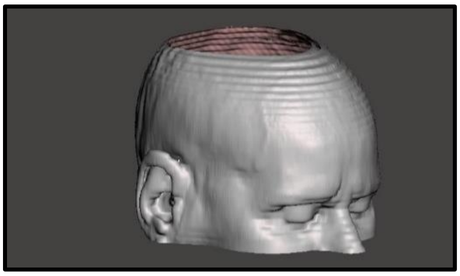


Fig. 8. 3D printable model for Head skin of the patient

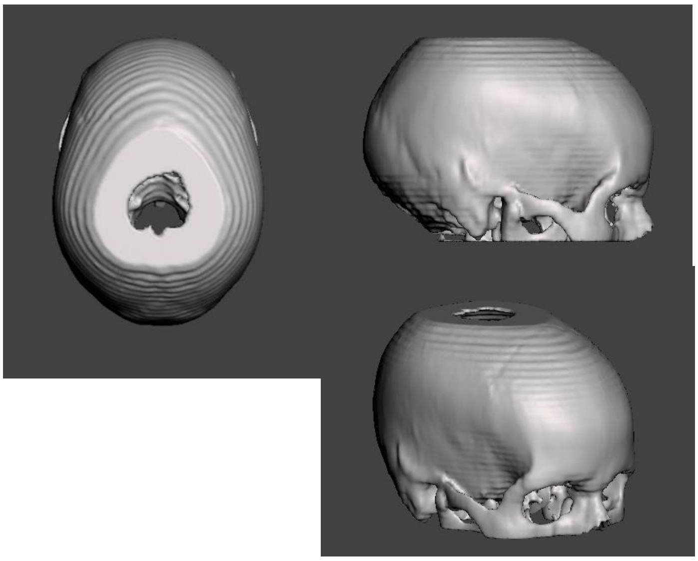
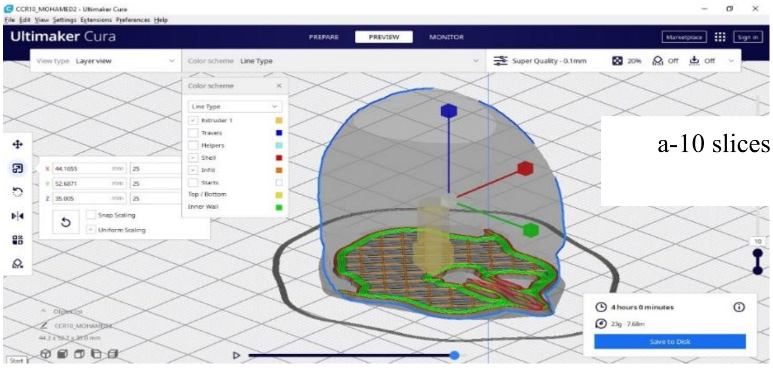


Fig. 9. 3D printable model for skull bone of the patient

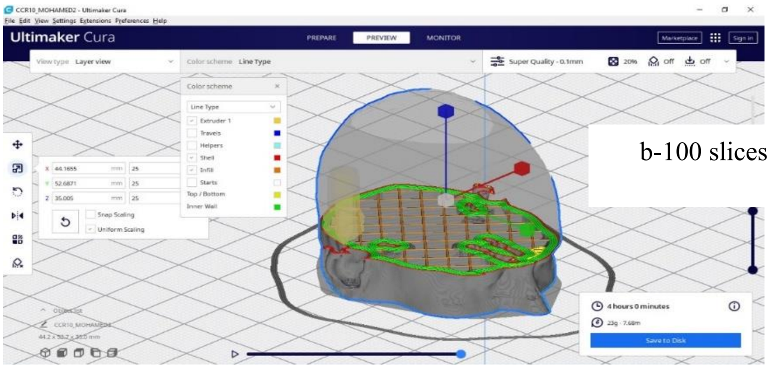
2.3. PROTOTYPING OF 3D-PRINTED MODEL

The G-Code for the desired surface object have been generated and inserted into the 3D printer. In the present work the slicing operation had been done for CAD models. Addition to that, it can be getting a physical 3D representation of medical data directly from CT or MRI scans by the introduced procedure. The 3D printer used for this study is Ender 3. Cura 4.13 for 3DP simulation software was used to slicing the STL. file and testing the formation conditions which involve; temperature, travels speed, adhesion used, support used, fill pattern, ..., etc., and generation the G-cods for 3DP process. Figs.10,11 represent the simulated 3D model for the head skin topology and skull bone case studies respectively.

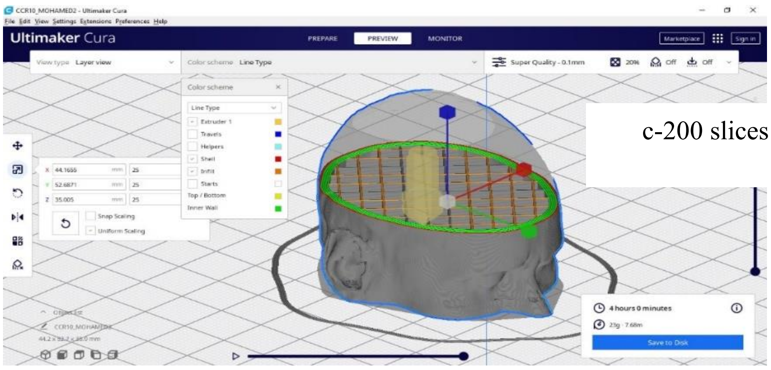
The 3D physical model of the patient part has been fabricated using 3D printing technology based on Ender 3 printing machine will be used as the additive manufacturing to fabricate the 3D prototyping of the part. In the present work, PolyLactic Acid (PLA) based filament with the 3D printing conditions that listed in Table 1.was used for fabricate the 3D prototyping of the adopted parts in the present study.



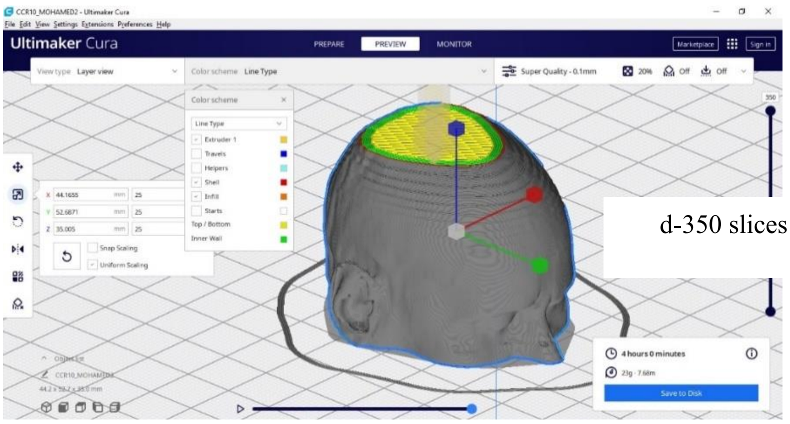
a-10 slices (each slice is 0.1mm)



b-100 slices (each slice is 0.1mm)

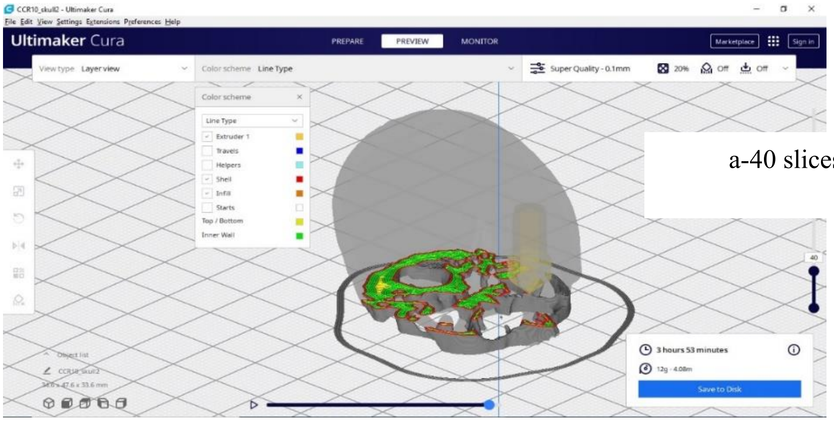


c-200 slices (each slice is 0.1mm)

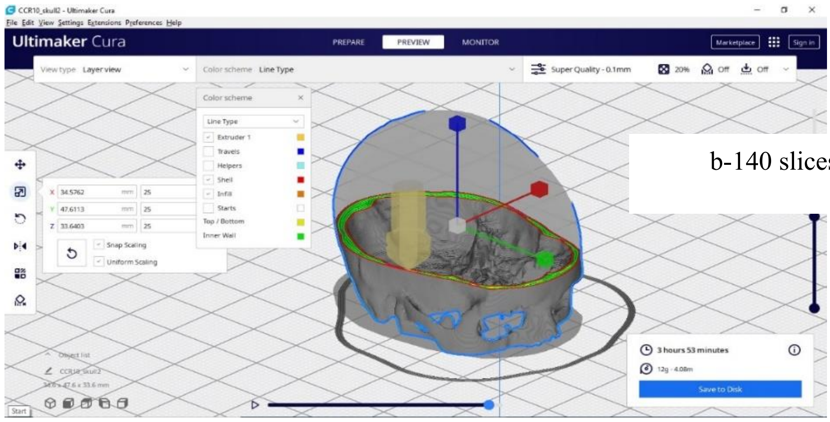


d-350 slices (each slice is 0.1mm)

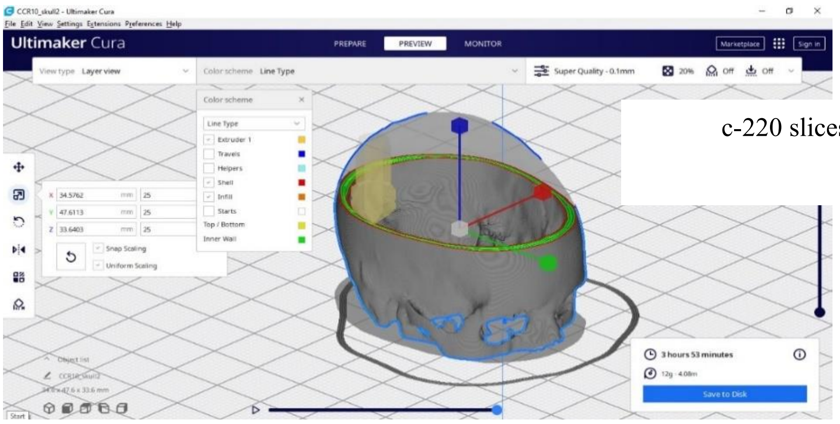
Fig. 10. 3D simulated model for Head topology using Cura.



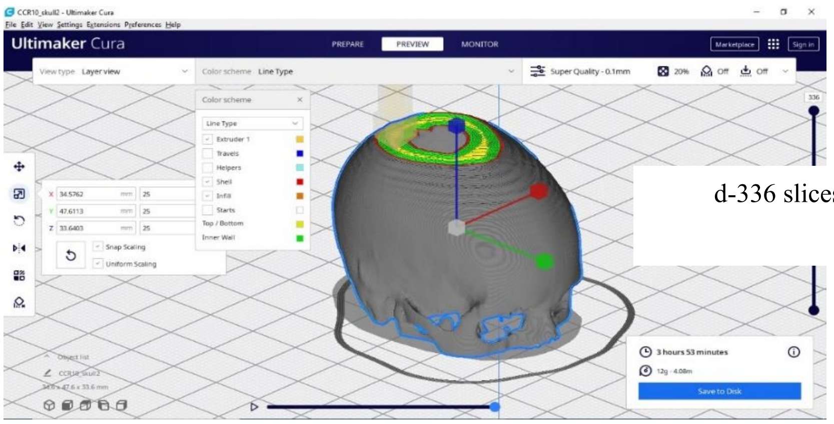
a-40 slices (each slice is 0.1mm)



b-140 slices (each slice is 0.1mm)



c-220 slices (each slice is 0.1mm)



d-336 slices (each slice is 0.1mm)

Fig. 11 3D simulated model for skull bon using Cura.

Table 1. Material parameters used in 3DP process

No.	Parameter	Value
1	Filaments diameter	1.75 mm
2	Printing temperature	220 C°
3	Plate temperature	40 C°
4	Print speed	40 mm/sec
5	Infill density	25%
6	Material used	PLA
7	Adhesion used	Yes
8	Layer height	0.1mm

3. RESULTS AND DISCUSSIONS

The application of AM for biomedical or medical domains can be used to, generating a models and devices for medical domain with complected and special topography based on tomography (CT) of patient or magnetic resonance imaging (MRI) scans. 3D printing of such objects including special implants and prosthetics for mandibular, skull, orthopedic, maxillofacial, spinal disk, hearing aids, dental, neuroanatomical models, tissues, bone, and so others.

The status application of 3D printing technology for biomedical engineering contributed to advices and understanding the patient-treatment status. Also, developing a various innovation, such as a successful implantation for artificial organ and dosage forms that aides to enhance the patient status and improve pharmaceutical components. Finally, it can be adopting AM technology as a powerful tool for underlying barriers and providing offers therapies for current and future medicine statuses.

This research gives the methodology to create a 3D prototype based on CT/MRI scan data that used to get a 3D CAD model in form of (STL. file) model. Addition to above mentioned, the adopting methodology can used be to the develop the patient treatment status, based on what will be decide for pre-planning procedures of surgeries operation or implantation process. Patient's parts data were gathered from CT/MRI data can be processed using a software for slicing such as; 3D slicer, Blender and MeshMixer. The next sub sections presents an illustration of printed models using 3D printing process for the skull bone and skin mask of patient's face. For mor validation of the introduced methodology, surface finish of the fabricated models have been examined and measured, also, the image processing technique had been adopted to make a dimensional comparison of the fabricated prototypes and the Sliced model from DICOM file.

3.1. 3D PRINTING RESULTS

The geometry of human head skin is very complected, and the fabrication process using the classical manufacturing processes is very difficult. But, using 3D printing technique make a facility in cost and time domain for fabrication a precisely models for each patient's anatomy.

The 3D printing has various applications related to the human head such as; medical models, prosthetics and implants, dental and orthodontic, hearing aids, reconstructive surgery, research and education, cosmetic enhancements, and neurological studies anatomical studies. Fig. 12 shows the 3D printed model of human head skin.

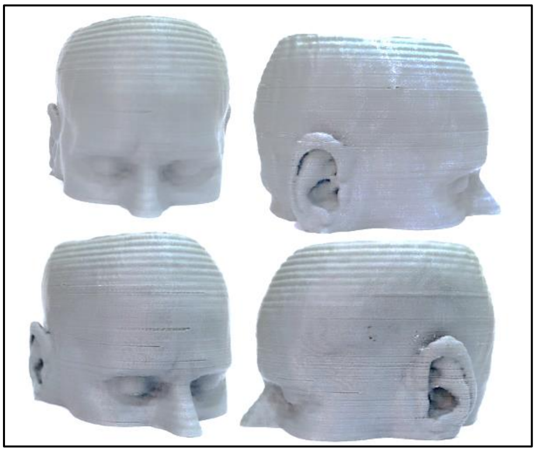


Fig. 12. Prototype of Head topology.

The skull bon geometry is one of the most sophisticated surfaces of anatomy. The models of skull known as cranial 3D printing, it can be use in various fields such as; surgical planning, custom implants, reconstruction after trauma, craniofacial surgery training, research, education and development domain, aesthetic reconstruction, and treatment of craniofacial birth defects. The 3D prototype model of skull bone that adopted in the present work has been generated starting from conversation the MRI/CT scan data into 3D model, then fabricated using the 3D printing technology as Additive Manufacturing process. Fig. 13 shows the 3D printed model of the skull bone.

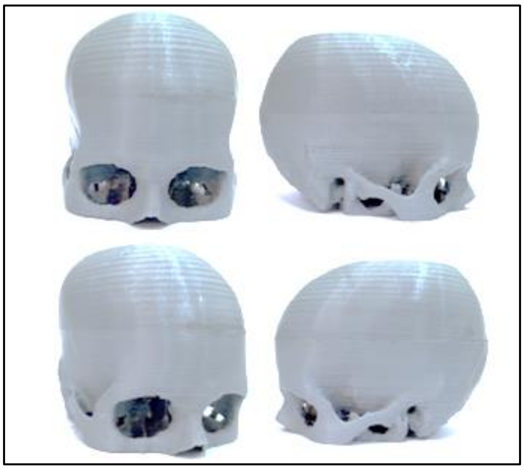


Fig. 13. Prototype of skull bon.

3.2. SURFACE ROUGHNESS RESULTS

The surface roughness had been measured for the fabricated models using 3D printing process. Fig. 14 present the Elcometer 7062 MarSurf PS10 Surface Roughness Tester device, that used in accordance with ASTM to surface roughness measurement domain. The measurements have been achieved for more than one side of the fabricated models, which mentioned in Figs 12, 13. The surface roughness values taken as the average for five measured, so; the average surface roughness was (1.846) ℳm for the skin head topology prototype, while was (0.65) ℳm for the skull bon prototype.

Fig. 14. The used electrometer device.

3.3. Image Process and Dimension Accuracy Results

Image processing technique has been used to conclude the dimensional accuracy for the studied case studies, Fig. 15 present the introduced procedure for this domain using Matlab program.

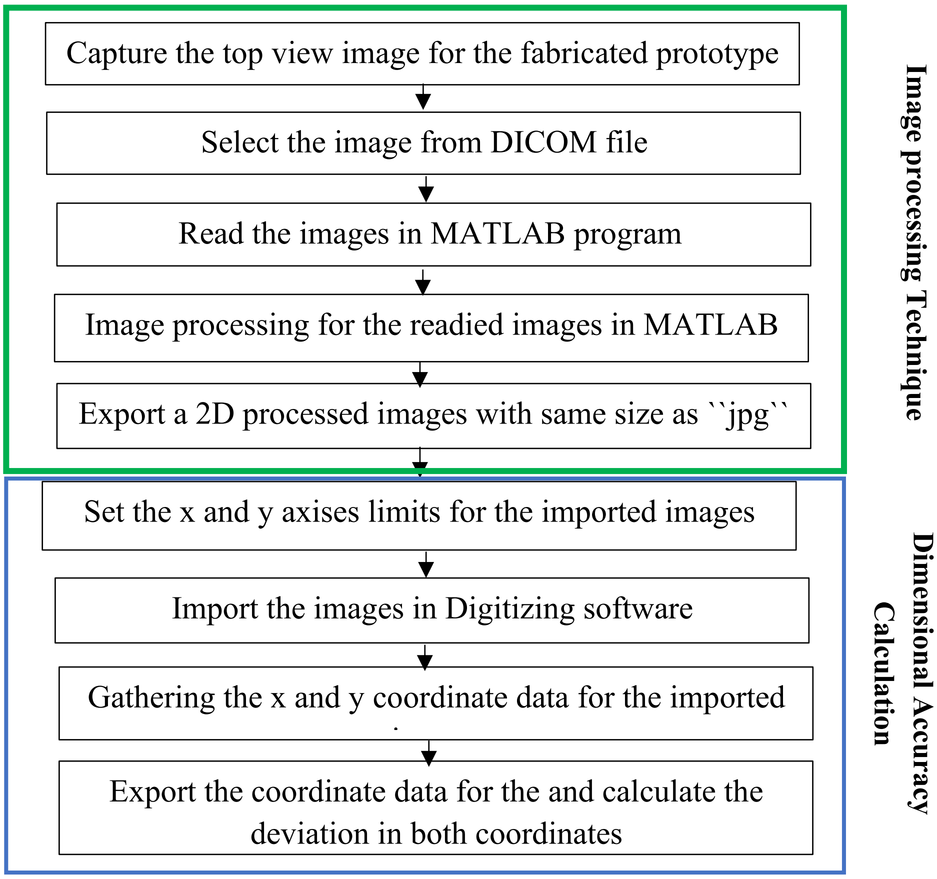


Fig. 15 The Introduced Procedure for Image Processing and Dimensional accuracy Calculation.

3.3.1. IMAGE PROCESSING TECHNIQUE

In the present work image processing using Matlab program has been achieved, starting with capture the top view for the prototype, and selecting the image from the DICOM file for the patient. After that these images have been readied in Matlab then converted from RGB image into gray scale image, also the visualization enhancement has been done. Figs. 16 and 17 present the procedure for the image processing of the prototypes image and the DICOM image respectively.

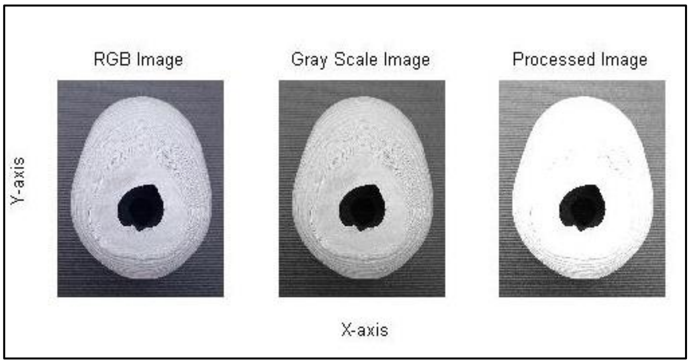


Fig. 16. The image processing of the prototypes image

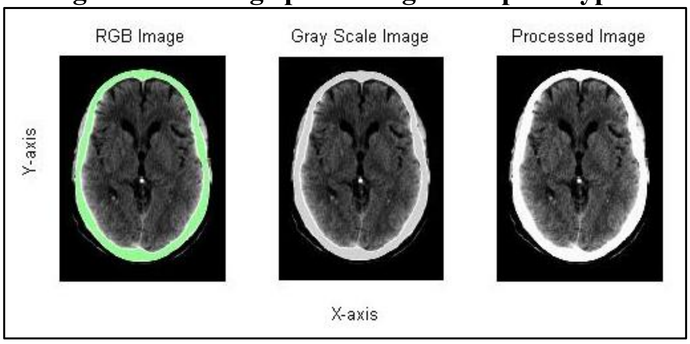


Fig.17. The image processing of the prototypes image

3.3.2. DIMENSIONAL ACCURACY COMPARISON

The enhancing procedure that adopted in the present wort have been don to get a precisions boundary for the images as a requirement for convert this boundary into x and y coordinate data for these images. Gate data digitizer software use to digitize the dominate images, which are illustrate in Fig.18.

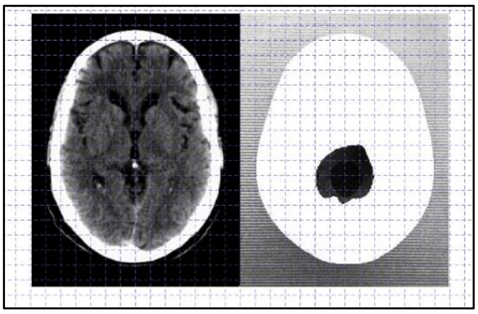


Fig. 18 The digitizing process for image.

Table 2 demonstrates the digitizing data and difference values in dimension between the 2D image for the prototype and the images from DICOM file in both x and y axes.

Table 2 The digitizing data and the difference value for prototype and DICOM image

Point no.	Prototype image		DICOM image		The difference value	
	x	y	x	y	x(prototype)-x DICOM	y(prototype)-y DICOM
1	150	3.75	150	3.75	0	0
2	197.95	13.5	198.75	13.75	-0.8	-0.25
3	238.25	39.75	237.5	40	0.75	-0.25
4	269.55	74.75	268.75	75	0.8	-0.25
5	286.75	112.75	286.25	112.5	0.5	0.25
6	291.5	162.5	291.25	162.5	0.25	0
7	288.25	212.75	287.5	212.5	0.75	0.25
8	273.2	275	273.75	275	-0.55	0
9	258.55	325	258.75	325	-0.2	0
10	223.45	367.25	223.75	367.5	-0.3	-0.25
11	182.5	386.75	182.5	387.5	0	-0.75
12	150	391.75	150	392.5	0	-0.75
13	98.75	380.55	98.75	381.25	0	-0.7
14	55.75	351.25	55	350.75	0.75	0.5
15	35.25	312.75	35	312.25	0.25	0.5
16	22.75	274	22.5	273.75	0.25	0.25
17	10.55	225	11.25	225	-0.7	0
18	5.45	175.75	5	175	0.45	0.75
19	9.55	125	10	125	-0.45	0
20	31.55	74.5	31.25	75	0.3	-0.5
21	64	37.25	63.75	37.5	0.25	-0.25
22	100.5	12.25	100	12.5	0.5	-0.25

The deviation fluctuation for the digitized points has been illustrated in Figs. 19 and 20 for x and y axis respectively.

Table 2 and Figs.19, 20 present the deviation value between the printed prototype and the DICOM file, these value between (0-0.8)mm, this deviation could be observed duo to many reasons such as, the difficulties to detect the boundary of the images during image processing technique, the solidification troubles such as shrinkage or expanding during the 3D printing process, and illumination problems during capturing images.

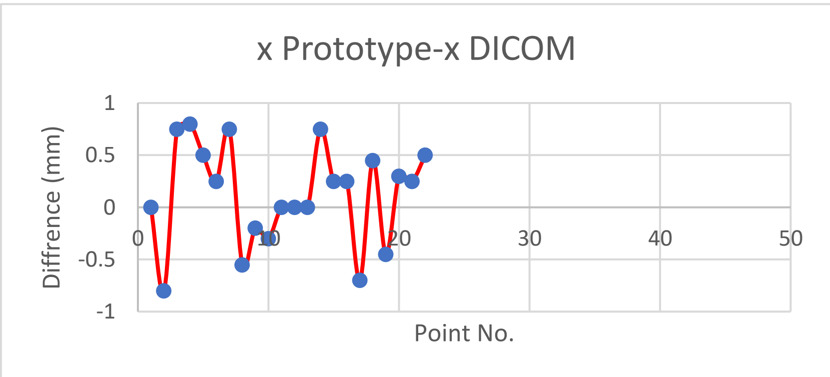


Fig.19: Deviation fluctuation in x-axis between prototype and DICOM image.

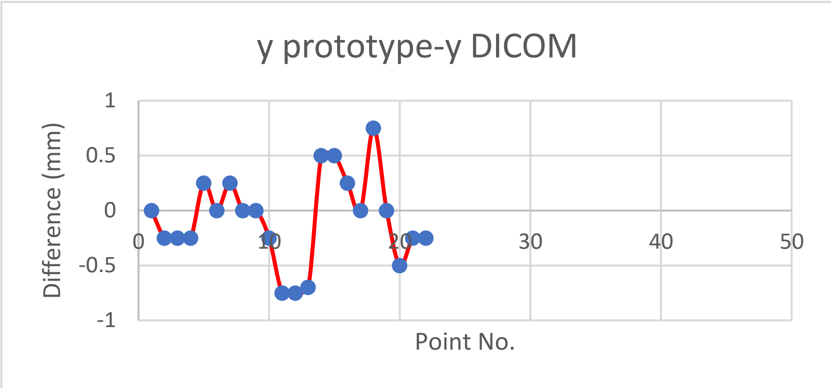


Fig.20: Deviation fluctuation in y-axis between prototype and DICOM image.

4. CONCLUSION

The present work introduces a framework to understanding and applications of additive manufacturing process for medical domains, CT/MRI scans data for the patients were gathered directly form the scans device with DICOM formats, then converted into 3D model with STL file format using InVesalius 3.1 software. A CAD model pre-processed to enhancement the quality of mesh model and reconstructing the patches of model, rather than solve the imperfections in model using Meshmixer software.

CURA software used to generating the path of fabrication with G-cods format for a 3D processed model, The adopted case studies were fabricated as 3D physical models using 3D printing technique with PLA material. The printing parameters were selected with regarding to complexity state of models to obtaining high level of surface quality and precise anatomic features. Surface roughness for the created models have been measured, which ranged (0.65-1.846) $\mathscr{M}$m for the printed modes, also an image processing technique have been adopted to compare the dimensional accuracy between the prototypes and the DICOM image, where the maximum deviation value was (0.8mm). According to the obtained results for 3D printing process, surface roughness, and dimensional accuracy, it can be concluded that, the adopted strategies were simplified to use by any interested in biomedical domain, and proved a good effectualness to create any suggested human body parts.

ACKNOWLEDGEMENTS

This work is supported by Production Engineering and Metallurgy Dept. University of Technology Al Senaah street Baghdad-Iraq, Neurosurgery Teaching Hospital Bur Said (Port Said) Street Baghdad-Iraq.

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