SAS Journal of Medicine
Abbreviated Key Title: SAS J Med
ISSN 2454-5112
Journal homepage: https://saspublishers.com

OPEN ACCESS

Anatomy

3D Printing Model of Limbic System: A Novel Mode of Visualising Neuroanatomy for Undergraduate Medical Students

Gangireddy Jyothsna[1], Anil Kumar Reddy Y[2*], Prudhvinath Reddy[3], Ashish Thulkar[4], Jasvindar Singh[5]

[1]3rd MBBS Student, All India Institute of Medical Sciences, Mangalagiri, Andhra Pradesh, India
[2]All India Institute of Medical Sciences, Mangalagiri, Guntur District, Andhra Pradesh, India
[3]Department of Radiodiagnosis, All India Institute of Medical Sciences, Mangalagiri, Andhra Pradesh, India
[4]Sr. Technical Instructor, National Institute of Design, Andhra Pradesh, India
[5]Asst. Professor, Mechanical Engineering, SRM University, Andhra Pradesh, India

DOI: https://doi.org/10.36347/sasjm.2024.v10i12.017 | **Received:** 18.11.2024 | **Accepted:** 24.12.2024 | **Published:** 30.12.2024

***Corresponding author:** Anil Kumar Reddy Y
All India Institute of Medical Sciences, Mangalagiri, Guntur District, Andhra Pradesh, India, Email: dranilreddywhy@rediffmail.com

Abstract **Original Research Article**

***Introduction*:** Three-dimensional (3D) printing of anatomical structures at rapid rate using Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT) data is widely utilized in modern era. Due to accurate restoration of complicated anatomical systems, 3D printing is increasingly being used in medicine, from fundamental anatomy through surgical practice and sophisticated research applications. No precise 3D printed limbic system models that focus on Neuroanatomy education are available. The present study was undertaken to generate scientifically accurate 3D model of the limbic system of the human brain from MRI scan data and 3D printing of the same for medical education / applications. ***Methods*:** MRI scanned data of the brain of unknown adult patient was obtained from the department of radiodiagnosis with approval of Medical Record Department. The general process involved to create the physical model of limbic system from original imaging data can be divided into four steps. i) Image data acquisition, ii) Image processing, iii) 3D printing and iv) Post-processing. ***Results*:** A three-dimensional printed model of the limbic system that depicts various components of the system was successfully created. All the structures shown in the 3D digital model were accurately generated in physical model. A single limbic system model print takes 5-6 hours using specific settings on the given printer (Ultimaker S5). The weights of the 3D printed limbic system model, including supports prior to removal, are roughly 190-220g at the specified settings ***Conclusion*:** This 3D model would be helpful for spatial visualization of the various structures comprising the limbic system.
Keywords: Limbic System, MRI Scanned data, 3D Printing, 3D Model, FDM.

INTRODUCTION

Anatomy is the foundation of clinical examination, surgery, and radiology, thus medical and healthcare students must have a solid grasp of the major concepts, structures, and their interrelationships during undergraduate education [1]. In our opinion, understanding 3D ideas is one of the most difficult aspects for a medical student. The capacity to discern 3D anatomical characteristics in 2D cross-sectional clinical imaging can be difficult, and the dynamic nature of embryological development adds an additional level of complexity [2].

Charles W. Hull initially described three-dimensional (3D) printing in 1986, and it has been widely employed throughout the last 30 years. Hull's "stereolithography" technology creates solid objects from digital data. Hull co-founded 3D system, which commercialized the first stereolithographic apparatus (SLA), or 3D printer, in 1987. The goal of incorporating technology-enhanced-learning (TEL) techniques into our practices is to improve undergraduate medical student learning of clinically relevant anatomy. In this chapter, we will look at the significance of visualization and visual learning in anatomy as a scholarly foundation for TEL integration [4].

Three-dimensional (3D) printing of anatomical structures at rapid rate using Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT) data is widely utilized in modern era [5]. The limbic system is a complex set of collection of structures from the telencephalon, diecephalon and mesencephalon. It includes the olfactory bulbs, hippocampus, amygdala, anterior thalamic nuclei, fornix, mammillary body, septum pellucidum, habenular commissure, cingulate gyrus, parahippocampal gyrus, limbic cortex, and limbic midbrain areas [6]. The limbic system performs variety of functions including emotion, olfaction, behavior, adrenaline flow, motivation and long-term memory.

In anatomy education, high-quality 3D printed replicas of cadaveric material using 3D scanner, CT and MRI data were produced for teaching purposes [5-7]. 3D printed models of human parts are a useful aid to enhance patient understanding of their disease and surgical plan which will increase the patient's confidence in the treatment process and also improve the doctor-patient relationship [4-7]. Availability of the 3D image data helps to make multiple copies of any organ or dissected specimen, at any size scale and is suitable for teaching under any circumstances. 3D print technology constructs complex functional 3D structures layer by layer from various materials, uses the data from computer-aided-design (CAD) model or scan and converts into a 3D physical model [8].

3D digital models of brain available in Anatomage table or visible human body lack the physical touch of the organ, student satisfaction, and limited to understanding the theoretical teaching only. Whereas, 3D printed physical anatomical models are valuable supplements to traditional teaching tools and promising in improving anatomy education as well as enhancing students learning satisfaction and experience [9]. Although the theoretical teaching of the limbic system is extremely important, practical studies are essential to consolidate the theoretical aspects. A colorful 3D model of organs provides better hands-on experience and physical feeling along with better understanding of the complex structures of anatomy [9, 10].

Due to accurate restoration of complicated anatomical systems, 3D printing is increasingly being used in medicine, from fundamental anatomy through surgical practice and sophisticated research applications. Educational models including bone, skull, lateral ventricles, kidney, liver, duodenum, heart, and cerebral aneurysm, have been constructed using 3D printing technology [5-11]. However, no precise 3D printed limbic system models that focus on Neuroanatomy education are available. This study aimed to create a scientifically accurate 3D model of the human brain's limbic system from MRI scan data and 3D printing of the same for medical education / applications.

MATERIAL AND METHODS

Type of Study: Prospective study in Health education.

Duration of Study: 3 Months

Ethical Clearance: The study of was approved by the Institutional Ethical Committee vide reference no. AIIMS/MG/IEC/2022-23/178 dated 29.07.2022

Sample Collection:

MRI scanned data of the brain of unknown adult patient was obtained from the department of radiodiagnosis with approval of Medical Record Department. It was ensured that MRI image data is free of any anomalies like tumors, clots and internal injuries.

The general process involved to create the physical model of limbic system from original imaging data can be divided into four steps (Fig.1). i) Image data acquisition, ii) Image processing, iii) 3D printing and iv) Post-processing.

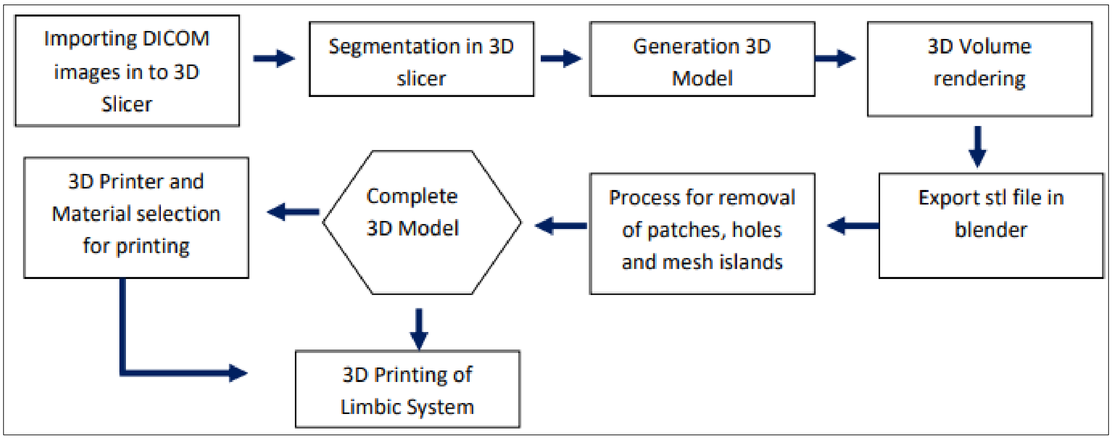

Figure 1: Framework for obtaining 3D models from medical images

i. Image Data Acquisition:

An unknown adult patient's MRI scan of the head was acquired from the Radiodiagnosis department. The brain MR imaging data in DICOM (Digital Imaging and Communications in Medicine) format was used to generate a 3D model file that can be printed. The MRI scan provides the most precise 2D pictures of the brain and surrounding organs, tissues, glands, and so on (Fig. 2).

ii. Image Processing:

3D printers do not directly receive MR image data collected in DICOM files. Individual items (or components) defined by surfaces that encompass a region of space are understood by these printers. Standard Tessellation Language (STL) is a file format used to specify these surfaces. Surfaces were defined in the STL format as a collection of triangles (called facets) that fit together like a jigsaw puzzle. CAD models are generated utilising MR imaging data through unique segmentation, processing, and conversion to get the essential data for 3D printing of limbic system models.

Segmentation:

The MR imaging data saved in DICOM, segmented using 3D Slicer software (Free open source) [20]. Segmentation was done to obtain only the 3D model of the limbic system excluding everything else. Thus, various structures of limbic system must be isolated from the other components in the DICOM data. Which is known as segmentation. Each tissue in the medical imaging has a distinct spectrum of pixel intensities. Segmentation methods take advantage of this characteristic to digitally isolate the necessary tissue for executing specific operations on it. The segmented image data was enhanced for important features by manipulation using 3D slicer. The threshold tool is used to segment the desired organ or tissue from medical pictures by identifying the organ or tissue's pixel range. By defining the pixel range of distinct limbic system components, we may conduct thresholding and segment them from the rest of the tissues and skull in the image. The smoothing process is used to enhance the smoothness of the 3D object's surface. A smooth object has a continuous surface, and its surface polygons link to adjacent polygons seamlessly. A sequence of local operations are performed on a mesh to gradually reduce the number of triangles and vertices until the required reduction is reached and further reductions are not possible owing to topological or other restrictions. To choose the needed limbic system structures, a threshold range of 189 to 434 (editable intensity range) was chosen, and then targeted structures were painted in each sequential image (Fig. 2 and Fig. 3).

3D Model Generation:

The limbic system model segmented data was saved as a STL file (Stereolithography). We load the STL files into Blender v2.73a (http://www.blender.org/, free and opensource) [21], a 3D modelling and rendering application, for hole filling, patching, mesh refining, and export for 3D printing. The 3D model is developed by stacking the chosen areas in each successive image slice. Smoothing and decimation processes give the model some real-world geometry. The 3D data is saved as a triangular mesh.

Mesh refining enables for image correction as well as size, colour, and texture adjustment for better 3D printing models. The limbic system 3D model created for segmentation is unsuitable for usage. It contains various faults, discontinuities, and is not watertight, therefore mesh refinement is required. Staircasing defects caused by the resolution of the medical picture, as well as discontinuities created during the segmentation process are erased. Unwanted segments are deleted during the segmentation process, while other relevant structures are joined to make it useable.

The STL file format's binary representation is a straightforward, freely defined method for expressing an object's surface as a triangular mesh. STL have notionally become mainstream technology for quick prototyping and 3D printing.

iii. 3D Printing:

3D printing of limbic system model requires computer-aided Design (CAD) data which is required for 3D printing and a file format acceptable to the 3D printer. The 3D printer accessible to the department is Ultimaker S5 which uses ultimaker cura software to create highly accurate 3D models of objects with various textures, size and geometries which makes it suitable for printing selected specimens.

3D Printing Setup:

Ultimaker S5 has dual-extraction print head with an auto-nozzle lifting system and swappable print cores use Fused Filament Fabrication (FFF) technology. High quality PLA filament (1.75mm diameter: Melting Point: 210^{o} C) compatible with wide range of 3D printers selected for printing of limbic system model. Ultimaker 3D printer is capable of printing 0.25 mm to 0.8mm layer resolution, optimized for Polylactic acid (PLA). The digital data in STL file format for 3D printing of limbic system was imported to the ultimaker cura software (Fig. 4).

Table 1: Format for 3D Printing model (3DP)

Printer	Printing process	Acronym	Material	Layer height (mm)	Organ printed	Support structure removal
Ultimaker S5	Fused Filament Fabrication (FFF)	FFF	Tough PLA	0.1	Limbic system model	Support material was removed manually after printing

The limbic system 3D model STL file format was loaded into the ultimaker cura programme, and the following parameters were applied for the model's final printing (Fig. 4):

Scaling – X 82.06 mm, Y 51.84 mm, Z 63.6mm.
Material - Polylactic acid (PLA)
Printing Temperature – 210.0
Build plate Temperature – 60^0 c
Layer height – 0.1mm
Wall thickness – 0.8mm
Top/Bottom thickness – 1.2mm
Print speed – 45mm/S
Infill density – 20%
Infill Pattern - Traingles
General support – Yes
Support Extruder – Extruder 2
Support Overhang Angle – 45^0
Support Horizontal expansion – 1mm

iv. Post Processing:

The presence of all structures produced in the digital model was confirmed by carefully inspecting the 3D printed object (Fig. 7). Overhanging models are difficult to produce with 3D printers; they require support structures or the usage of support material. As a foundation support for printing the model, support material was generated in Ultimaker Cura programme. Following the printing, the support material was carefully removed manually, and brushing was used to clean and remove dust particles.

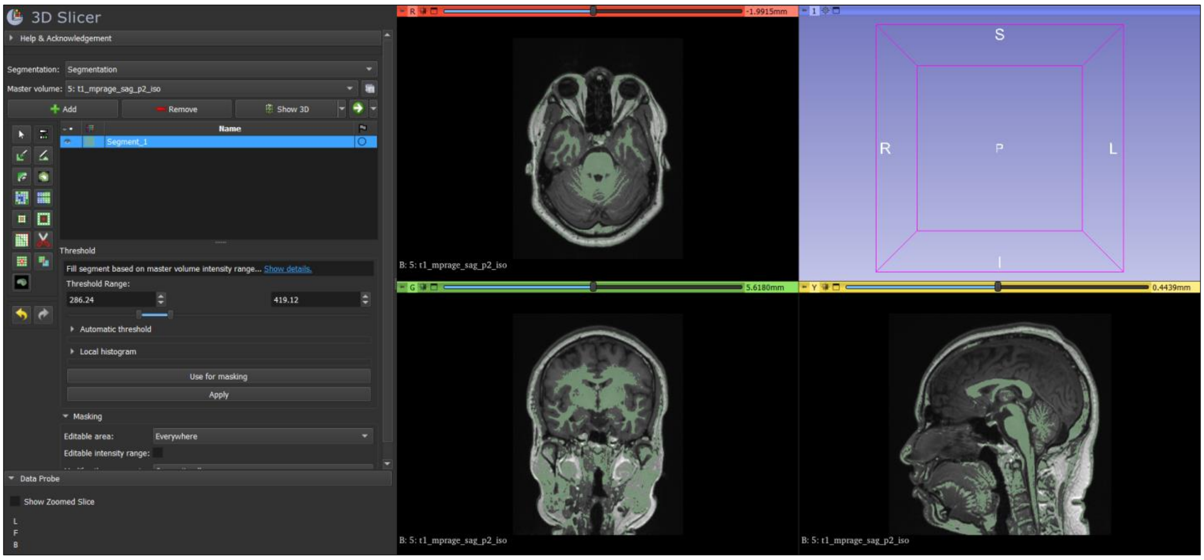

Figure 2: 3D slicer user interface after loading the DICOM data

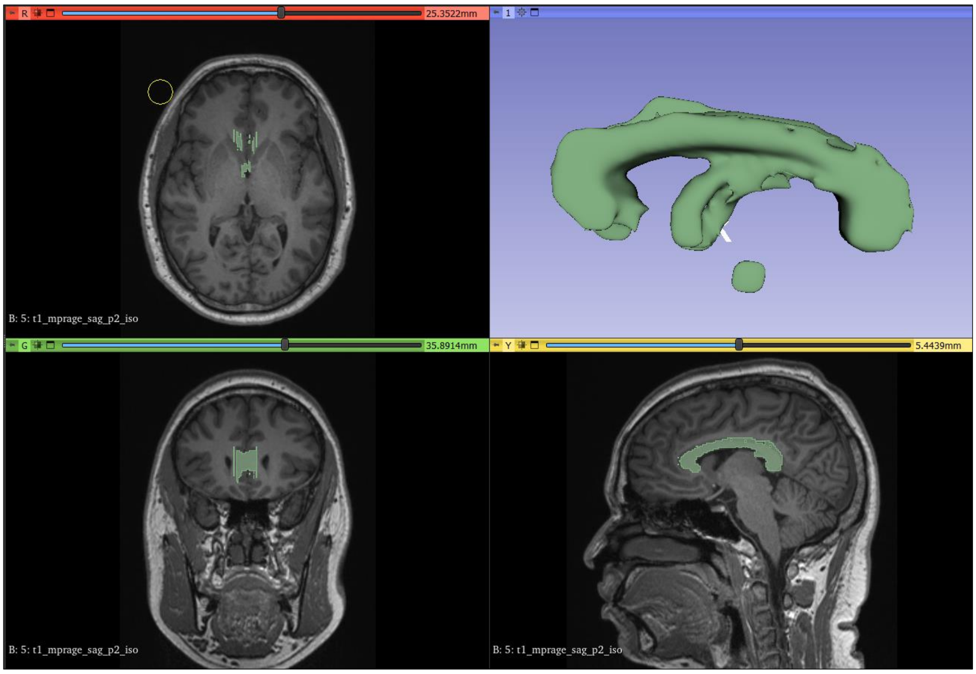

Figure 3: Process of generating 3D model of limbic system combining the colored layers in each image

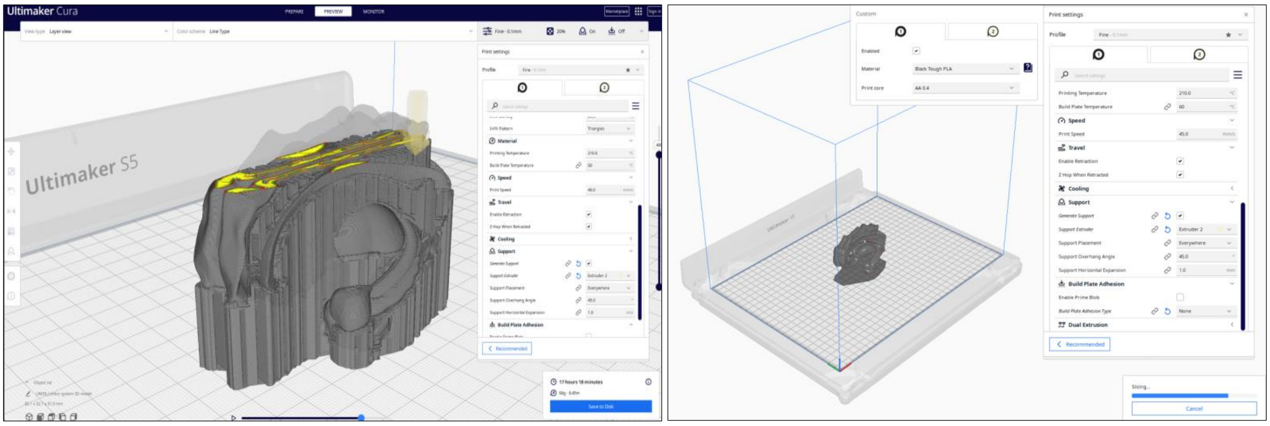

Figure 4: STL file of limbic system with print settings in Ultimaker cura software.

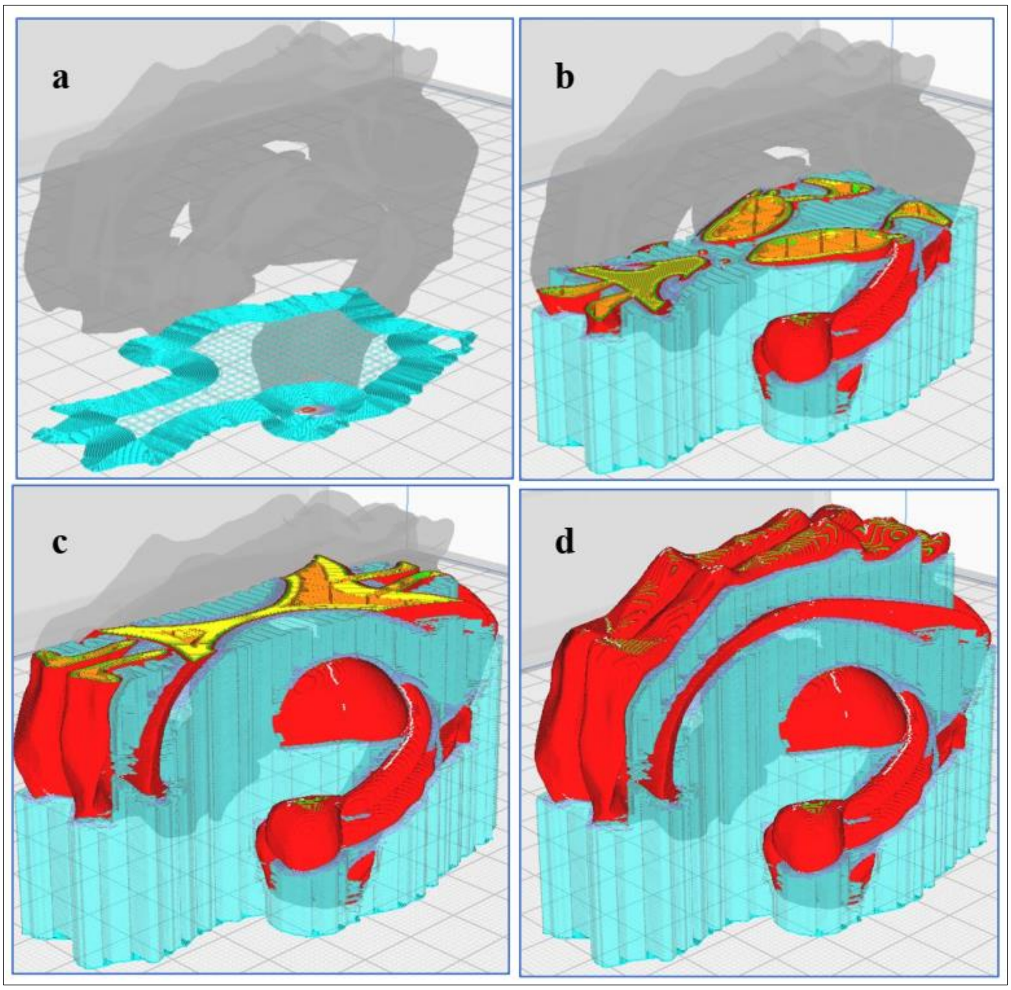

Figure 5: Layer by layer print model of limbic system in Ultimaker cura software (a,b,c & d)

OBSERVATIONS AND RESULTS

A three-dimensional printed model of the limbic system that depicts various components of the system was successfully created. It is a life-size model comprising various structures that can be conveniently exhibited. The fornix, thalamus, cingulate gyrus, corpus callous, hippocampus, amygdala, mamillary bodies, parahippocampal gyri, pineal body and hypothalamus comprised the limbic system model so developed and printed. All the structures shown in the 3D digital model (Fig. 3) were accurately generated in physical model. The tiniest structures, such as thin sections of the brain, were most likely to be damaged by inadequate resolution. 3D model print duration and weight are determined by the overall object size being established by any appropriate cropping.

Adult MR imaging data from the radiodiagnosis department was used to create the 3D model of the limbic system. It was difficult to segment limbic system components using threshold range since surrounding tissue had the same threshold range. The various limbic system structures should be painted very carefully using the paint tool in 3D slicer, otherwise the model would show several undesired items as well as faults and patchy holes, which reduces overall quality of the 3D model (Fig. 3). Print accuracy and model resolution are determined by the digital 3D model and the print settings configured for the 3D printer. The print settings specified in the approach produced a flawless 3D model of the limbic system, with distinct demarcations between the corpus callosum, fornix, thalamus, and parahippocampal gyri (Fig.5 and Fig. 7).

The overall process of completion of 3D printing of limbic system takes an average of 28 hours, which includes the preprocessing for 3D model generation, 3D printing and post print cleaning. The time and amount of PLA needed for printing are mostly determined by the volume of the object, layer thickness, number of shells, and amount of infill. A single limbic system model print takes 5-6 hours using the above-mentioned settings on the given printer (Ultimaker S5). The weights of the 3D printed limbic system model, including supports prior to removal, are roughly 190-220 g at the specified settings. The image post processing analysis required 1.3 hours. The total amount of the material used for the model was approximately 250g, which cost around 1000 INR. The final printed model after removing the support material weighs 120g. Reprinting the limbic system model with a different orientation or portion requires significantly less preprocessing time because the original STL generated from the DICOM can be reused. Once the model is printed, a visual comparison between the digital and physical model of the limbic system shows a good orientation match in order to understand the complexity of the limbic system and its functional use (Fig. 7).

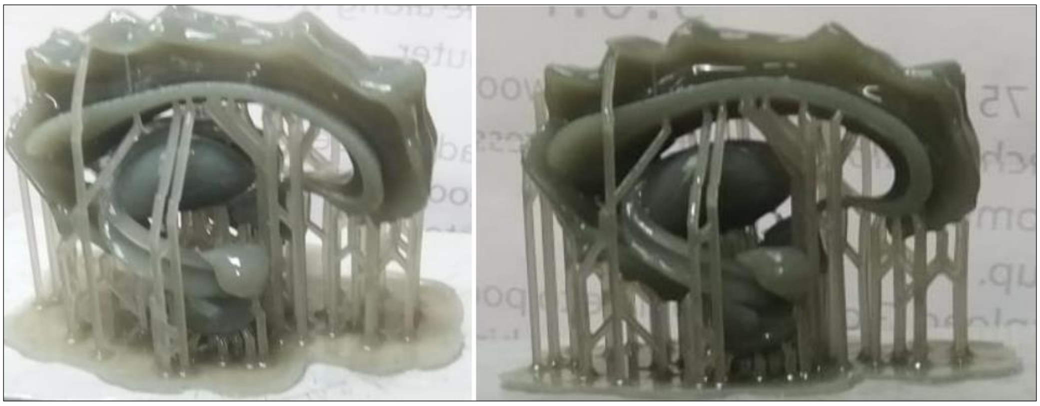

Figure 6: 3D printed model of limbic system with support material.

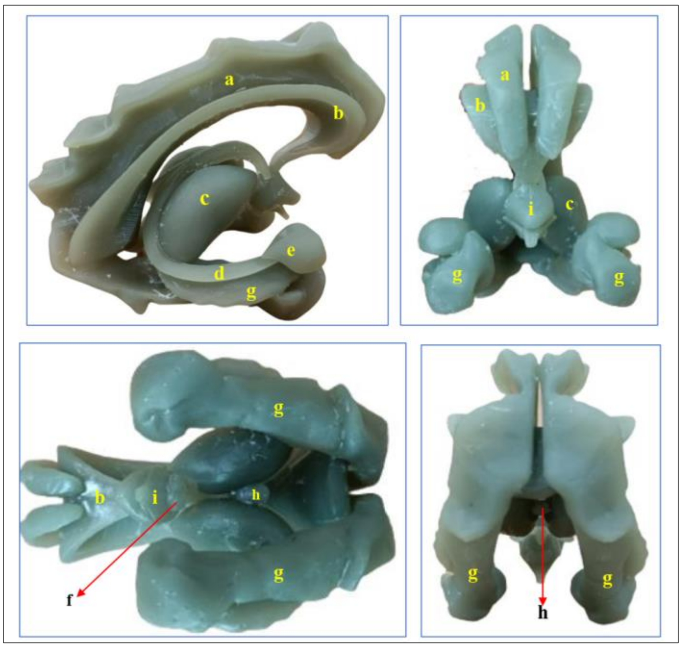

Figure 7: Postprocessed 3D printed model of limbic system. a. Cingulate gyrus, b. Corpus callosum, c. Thalamus, d. Fornix, e. Amygdala, f. Mamillary bodies, g. Parahippocampal gyri, h. Pineal body, i. Hypothalamus

Discussion

This study outlined the process of creating 3D digital model of limbic system from MR imaging data and successfully printed the limbic system model. 3D printed model of limbic system is effective in visualization of its complexity in teaching human neuroanatomy to first year medical students. Yammine K [10], and Maureen E. Estevez [12], focused on 3D tools for teaching human neuroanatomy. Both studies back up the physical model, and the formation of accessible internal representations of three-dimensional space may be aided by the right design of instructional interventions that act as an effective tool for bridging 2D learning and 3D comprehension of brain anatomy.

In the present study, 3D model was printed with the use of Fused Filament Fabrication (FFF) technique. Stereolithography, selective laser sintering (SLS), and fused deposition modelling (FDM) are three additive manufacturing processes often utilized to create anatomical models [14-16]. FDM method is the least expensive technique accessible and works by extruding and solidifying materials, most often plastics [16]. A computer-controlled extrusion nozzle deposits heated polymer in layers. This technology has a fine enough spatial resolution (about 0.007 mm) for most clinical purposes, and these printers may be employed in mimicking anatomical structures. However, the manufacturing time is longer and the surface quality is less polished than with the other approaches [17-19]. Stereolithography and SLS are often more expensive than FDM [19].

The model produced in this study were made using poly(L-lactide) (PLA) adopting FFF because of their high quality, cheap overall cost of the printers, and lower material prices. Several scholars have shown that "hands-on" physical intervention can be beneficial in increasing the learning of complicated three-dimensional connections, and that the experience is seen as "useful" and somewhat pleasurable by the learner.

Although each phase is critical, the segmentation processing that defines the tissue pixel range and mesh refinement for hole filling, patching, and deleting undesired parts are the most significant processes in generating an accurate 3D model. Segmentation was done using 3D slicer version 5.0.3, which is a free open-source software. 3D slicer software designed for research supports for multi-modality imaging including MRI, CT and microscopy. It is useful for data sets segmentation, surfaces, quantifications, annotations and transformations in 2D, 3D and 4D [20].

The STL file generated in 3D slicer by segmentation was imported to blender for cropping in a 3D modelling program. Blender is a free and open-source 3D modelling and rendering program. A Boolean add-on(https://github.com/vitorbalbio/code/tree/master/BoolTool) simplifies the keystrokes involved in object editing [21]. At this point, if we wish to crop an object, for example to highlight certain regions and/or ensure the print fits on ultimaker 3D printer.

The department has access to an Ultimaker S5 3D printer, which uses Ultimaker Cura software to generate very accurate 3D models of items with varying textures, sizes, and geometries, making it perfect for printing chosen specimens [8-15].

Ultimaker S5 comes equipped with following technological refinements:

- Enhanced adaptive bed leveling
- Interactive LED touch screen with print previews
- Filament flow sensor that auto-pauses print jobs
- Front glass doors for an enclosed build chamber
- Temperature stability within the build chamber.
- Hardened components suitable for more abrasive materials

Ultimaker 3D printer is capable of printing 0.25 mm to 0.8mm layer resolution, optimized for Polylactic acid (PLA), Tough PLA, ABS, CPE, PVA. PLA was chosen to print the limbic system model. PLA consistently warps less than ABS and produces fewer cleave layers at higher printing speeds [7]. In post print cleaning, the 3D model printed in acrylonitrile butadiene styrene (ABS) material is a little easier to clean. However, we printed the model in PLA due to its advantages in the FDM process. We performed a systematic exploration of all parameters available in ultimaker 3D printer. With the most dependable setting being repeated at least thrice, we printed a prototype using several settings. Given that various printers and surroundings may call for modest alterations to these parameters, especially depending on the intended use of the print. However, the majority of failures will be visible within the first few layers, allowing for early empiric parameter change even when printing quickly. In general, slower prints are more likely to be successful.

The ability to create physical objects that can be handled in the hands offers several advantages over traditional 2D representations of image data and even 3D computer-based virtual models. In addition to being more durable and non-toxic than fixed tissue, 3D models can be effective teaching tools [22, 22]. Using these models, one may put implanted devices on a joint replacement, examine the skull to evaluate the precise final spatial fits, and prepare for surgical techniques like any bone windows. Other imaging modalities, such ultrasound, can be employed in addition to CT and MRI to produce patient-specific 3D models [23].

We have used printed model of limbic system in neuroanatomy teaching to the 1st MBBS students, to help illustrate arrangement of various structures of limbic system and have received positive feedback and appreciation from the students. Given the focused nature of many complex structures outlined in the model, streamlined and inexpensive 3D printing allow us to hold the objects of our attention in hand and mind's eye simultaneously. While 3DP is useful whenever there is enough time to develop models, it is most useful when the model is very complicated or uncommon [24, 25].

The significance of the printed 3D limbic system model was reviewed with pioneer anatomists of the department. All of them applauded the investigators efforts in creating a model using MR imaging, as it was the department's first 3D model. They opined that the model could be printed together with one half of the cerebral hemisphere. If possible, individual components of the model should be printed using different colored materials, with each component removable.

Conclusion

The study illustrates how to create an exact and appropriate 3D model of the limbic system. This 3D model would be helpful for spatial visualization of the various structures comprising the limbic system. Given that there were no commercially available models of the limbic system, a 3D printed model might be an option for teaching neuroanatomy to undergraduate medical students. These 3D generated physical models are valuable supplements in preoperative planning, patient understanding of their disease and also improve the doctor-patient relationship.

The current model may be expanded to include more structures for thorough neuroanatomy instruction. The 3D limbic system model STL file will be useful for creating more copies as needed.

Competing of Interest: The project report was approved by ICMR-STS Program

References

1. Sugand, K., Abrahams, P., & Khurana, A. (2010). The anatomy of anatomy: a review for its modernization. *Anatomical sciences education*, *3*(2), 83-93.
2. Rengier, F., Mehndiratta, A., Von Tengg-Kobligk, H., Zechmann, C. M., Unterhinninghofen, R., Kauczor, H. U., & Giesel, F. L. (2010). 3D printing based on imaging data: review of medical applications. *International journal of computer assisted radiology and surgery*, *5*, 335-341.
3. Hull, C. W. (1986). inventor; UVP, Inc., assignee. *Apparatus for production of three-dimensional objects by stereolithography*. United States patent US 4,575,330.
4. Bücking, T. M., Hill, E. R., Robertson, J. L., Maneas, E., Plumb, A. A., & Nikitichev, D. I. (2017). From medical imaging data to 3D printed anatomical models. *PloS one*, *12*(5), e0178540.
5. Pandzic, A., Hodzic, D., Hajro, I., & Tasic, P. (2020, January). Strength Properties of PLA Material Obtained by Different Models of FDM 3D Printer. In *Proceedings of the 31st DAAAM International Symposium on Intelligent Manufacturing and Automation, Mostar, ISSN* (pp. 1726-9679).
6. Standring, S. (Ed.). (2021). *Gray's Anatomy E-Book: Gray's Anatomy E-Book*. Elsevier Health Sciences.
7. Naftulin, J. S., Kimchi, E. Y., & Cash, S. S. (2015). Streamlined, inexpensive 3D printing of the brain and skull. *PloS one*, *10*(8), e0136198.
8. Ye, Z., Dun, A., Jiang, H., Nie, C., Zhao, S., Wang, T., & Zhai, J. (2020). The role of 3D printed models in the teaching of human anatomy: a systematic review and meta-analysis. *BMC medical education*, *20*, 1-9.
9. Kulkarni, N., Patil, S., Kashyap, A., & Manohar, S. (2021). Generation of a 3D printed brain model from MRI scan data to assist in Brain Surgery using open source tools. *Asian Journal For Convergence In Technology (AJCT) ISSN-2350-1146*, *7*(1), 75-80.
10. Yammine, K., & Violato, C. (2015). A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. *Anatomical sciences education*, *8*(6), 525-538.
11. Jin, Z., Li, Y., Yu, K., Liu, L., Fu, J., Yao, X., ... & He, Y. (2021). 3D printing of physical organ models: recent developments and challenges. *Advanced Science*, *8*(17), 2101394.
12. Estevez, M. E., Lindgren, K. A., & Bergethon, P. R. (2010). A novel three-dimensional tool for teaching human neuroanatomy. *Anatomical sciences education*, *3*(6), 309-317.
13. Blender. (2018). Blender. https://www.blender.org/. Accessed 3 Oct 2018.
14. Gargiulo, P., Árnadóttir, Í., Gíslason, M., Edmunds, K., & Ólafsson, I. (2017). New Directions in 3D Medical Modeling: 3D-Printing Anatomy and Functions in Neurosurgical Planning. *Journal of healthcare engineering*, *2017*(1), 1439643.
15. Błaszczyk, M., Jabbar, R., Szmyd, B., & Radek, M. (2021). 3D printing of rapid, low-cost and patient-specific models of brain vasculature for use in preoperative planning in clipping of intracranial aneurysms. *Journal of Clinical Medicine*, *10*(6), 1201.
16. Fedorov, A., Beichel, R., Kalpathy-Cramer, J., Finet, J., Fillion-Robin, J. C., Pujol, S., ... & Kikinis, R. (2012). 3D Slicer as an image computing platform for the Quantitative Imaging Network. *Magnetic resonance imaging*, *30*(9), 1323-1341.
17. McMenamin, P. G., Quayle, M. R., McHenry, C. R., & Adams, J. W. (2014). The production of anatomical teaching resources using three-dimensional (3D) printing technology. *Anatomical sciences education*, *7*(6), 479-486.
18. Tack, P., Victor, J., Gemmel, P., & Annemans, L. (2016). 3D-printing techniques in a medical setting:

a systematic literature review. *Biomedical engineering online*, *15*, 1-21.

19. Tetsworth, K., Block, S., & Glatt, V. (2017). Putting 3D modelling and 3D printing into practice: virtual surgery and preoperative planning to reconstruct complex post-traumatic skeletal deformities and defects. *Sicot-j*, *3*.
20. Šljivic, M., Pavlovic, A., Kraišnik, M., & Ilić, J. (2019, October). Comparing the accuracy of 3D slicer software in printed enduse parts. In *IOP conference series: materials science and engineering* (Vol. 659, No. 1, p. 012082). IOP Publishing.
21. Xu, W. H., Liu, J., Li, M. L., Sun, Z. Y., Chen, J., & Wu, J. H. (2014). 3D printing of intracranial artery stenosis based on the source images of magnetic resonance angiograph. *Annals of translational medicine*, *2*(8).
22. Adams, J. W., Paxton, L., Dawes, K., Burlak, K., Quayle, M., & McMenamin, P. G. (2015). 3D printed reproductions of orbital dissections: a novel mode of visualising anatomy for trainees in ophthalmology or optometry. *British Journal of Ophthalmology*, *99*(9), 1162-1167.
23. Samuel, B. P., Pinto, C., Pietila, T., & Vettukattil, J. J. (2015). Ultrasound-derived three-dimensional printing in congenital heart disease. *Journal of digital imaging*, *28*, 459-461.
24. Negi, S., Dhiman, S., & Sharma, R. K. (2014). Basics and applications of rapid prototyping medical models. *Rapid Prototyping Journal*, *20*(3), 256-267.
25. Strkalj, G., & Dayal, M. R. (2014). Working together, sharing resources: An interuniversity collaboration to advance anatomy education. *Anatomical Sciences Education*, 501-502.