

SEGMENTATION AND CREATION OF BRAIN TUMOR MODEL BASED ON ADVANCED TECHNIQUE

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Abstract

Background: 3D printing technology has many advantages in biomedical applications and, recently, in neurosurgery. Its benefits reflect patients and surgeons because it gives a complete, clear, and accurate model of the brain with tumors before the operation. Students can also benefit from these models to study and know the realistic three-dimensional shape of the brain.

Aim: This study aims to 1. construct a 3D brain tumor model using 3D slicer software and 3D printing technology, 2. Compare the model created by the software and the constructed model to ensure the accuracy of the printing process, and 3. Use these models for training before the operative and for educational purposes.

Materials and methods: MRI, 3D slicer, de Vinci 1.0 A 3D printer, PLA filament, and digital caliper were used in this study. Five subjects with different pathologies and ages participated in this study to construct their brain tumor model.

Result: The results of the present study showed successive 3D constructed models for those five subjects. In addition, it showed no large differences in dimensions between the computerized and made 3D model; this indicates that the 3D printer produces an accurate model with dimensions the same as the model created by MRI images of the patient.

Conclusion: This study concluded that 3D printing technology offers a useful technique for making affordable brain tumor models for surgical preparation and operator training. The number of errors is decreased since smaller models produce more accurate results than larger ones.

Keywords: MRI, 3D Slicer, 3D Printer, Neurosurgery, Brain Tumours, Brain Segmentation.

Introduction

The brain is the most complex organ with several functional units [1, 2]. A brain tumor is the progress of abnormal cells in the brain or in the spinal cord that can cause problems with brain function. Tumours are classified according to their origins and whether they are benign or cancerous (malignant) [3]

There are two main types of primary central nervous system tumors in adults: glioma and meningioma [4].

Glioma tumors arise from glial cells that support neurons in the central nervous system (CNS), such as oligodendrocytes and astrocytes [5]. It is the most common central nervous system

tumor and accounts for 40–50% of all brain tumors [6]. Gliomas can develop spontaneously (primary glioma) or progress from a low grade to a high grade (glioblastoma). The most common type of central nervous system tumor is a malignant glioma, and glioblastoma is its most malignant type [7, 8, 9]. Rapid, extremely invasive growth, widespread neovascularization, and high mortality are the characteristics of glioblastoma [10].

Meningiomas are the most commonly diagnosed brain tumor from meningotheial cells [11]. Most meningiomas are benign, slow-growing tumors that develop from the brain's outer coverings beneath the skull. About one-third of adult brain tumors are this type of tumor. They are frequently seen in the cerebral hemispheres underneath the skull [12].

after taking a medical history and doing a neurological examination, the most crucial diagnostic test is an MRI of the brain with a contrast-enhancing agent [13, 14]. Magnetic resonance imaging (MRI) is the preferred imaging technique for soft tissue malignancies due to its unmatched soft tissue contrast and 3d imaging capability [15]. Conventional MRI can show how a brain tumor looks anatomically, but it is cannot offer vital physiologic and functional information for tumor grading, prognosis, and treatment response [16].

There are a lot of definitions and terminologies used to describe 3D printing such as additive manufacturing, and rapid prototyping [14]. 3D printing: is a process by which 3D solid objects of any shape or geometry can be created from a digital file. The creation is achieved by laying down successive layers of a specific material until the entire object is created. Each of these layers represents a thinly sliced horizontal cross-section (similar to an ordinary printer's output, which is why it is called printing) of the eventual object [17].

There are literature reviews related to this study some of these reviews are:

In (2015), Naftulin et al. [ref], described the process for producing life-sized 3D brain model prints using MRI and 3D skull prints using CT. For 3D printing of the brain and skull, the authors have incorporated a standardized, primarily accessible technique. The author explained how to convert medical neuroimaging DICOM images to STL files, a standard 3D model file format that can be sent to 3D printing services. This research also showed how to convert STL files to gcode files for printing on Pc. On two different accessible desktop 3D printers, researchers successfully produced 19 patient hemispheres of the brain from seven patients. The costs of each brain hemisphere are \$3–4 in consumable plastic filaments, and the entire process takes about 14–17 hours [18].

In (2018), Kumar et al. [ref], used two-dimensional MRI scans to plan and conduct the procedure. It is difficult to execute a safe operation if the size and specific position of the tumor is unknown, and this can occasionally result in lasting harm to normal tissues. Such issues might be mitigated by having firsthand knowledge of the tumor, which is why the current study attempts to generate 3D printed models of brain tumors using medical image processing software dependent on MRI datasets. 3D slicer software would incorporate MRI data recorded as Digital Imaging and Communications in Medicine (DICOM). Using an STL file created by a 3D slicer, a 3D printer creates a physical 3D model. As a result, the brain tumour 3D printed model might be used as a tool for preoperative operation planning [19].

Materials and Method

The materials and methods of the present research are involved three stages: the first stage includes brain tumor segmentation using 3D slicer software, the second stage comprises printing the computerized model using a de Vinci printer, and the third stage involves measurements of the dimensions of the computerized and printed model to make a comparison between them using a digital caliper. This study was performed in Dr. Saad Al-Wetry Teaching Hospital for Neuroscience in Baghdad/Iraq.

1. Using a development platform, unique solutions for research and industrial products may be easily built and deployed. The **3D slicer** (version 4.11.2) is a desktop app for clinical and biological applications with an emphasis on advanced image computing challenges. It was used for tumor and brain segmentation. The steps of brain tumor segmentation can be summarized in three tables (Table 1, Table 2, and Table 3) and shown in Figure.1.

Table 1 Image Acquisition Steps.

Image acquisition	
Step 1	Obtain standard MRI preoperative images with 1 mm thickness
Step 2	Examine DICOM data for quality and sequence.
Step 3	Import DICOM into the 3D Slicer.

Table 2 Steps for Tumor Segmentation.

Tumour Segmentation	
Step 1	Locate the tumor in all planes (axial, sagittal, coronal).
Step 2	Select Segment Editor.
Step 3	Use “Paint Tool” to highlight the tumor.
Step 4	Select Segment Editor.
Step 5	The image was viewed and saved as an STL file.
Step 6	Export the STL file to the desktop.

Table 3 Brain Segmentation for STL File Creation.

Brain Segmentation, Figure.1	
Step 1	Select the Thresholding tool to highlight the region around the tumor.
Step 3	Select Erase tool to eliminate any undesired structures from the final model
Step 4	Select Segment Editor.
Step 5	saved as an STL file.
Step 6	Exported STL file to the desktop.

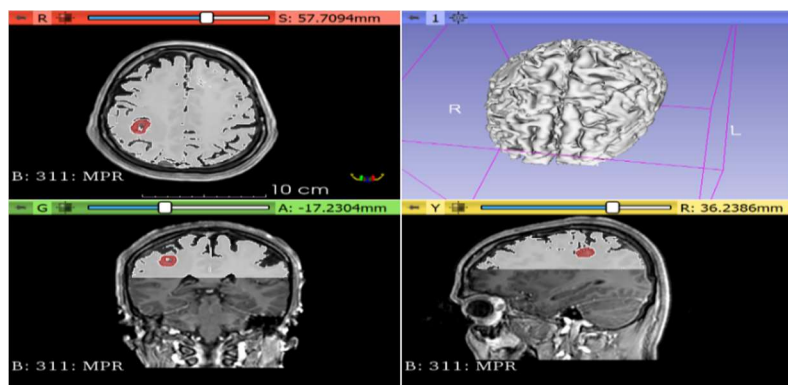


Figure.1 3D model of the brain.

2. A da Vinci 1.0 A 3D Printer with PLA filament was used in this research and the printer has the following features:

Brand	XYZ
Technology	FFF (Fused Filament Fabrication)
Build Volume	7.9" x 7.9" x 7.9" (200 x 200 x 200 mm)
Position Accuracy	X/Y 12.5-micron Z: 0.0004 mm
Layer Resolution	100 - 400 microns
Print Speed	Max. 120 mm/s
Number of Heads	1
Nozzle Diameter	0.4 mm
Nozzle Temperature	Max. 235 °C / 455 °F
Print Bed Temperature	40 ~ 90 °C / 104 ~ 194 °
Supported Materials	Polylactic Acid (PLA)/ABS
Slicer Software	XYZware
Software Input Formats	stl
Software Output Format	G-Code
Connectivity	USB 2.0 Cable
Input Rating	100V/240V AC, 50/60Hz
Working Voltage	12V DC
Dimension	18.4" x 22" x 20" (468 x 558 x 510 mm)

Net Weight	24 kg
Operating Systems	Windows 7 / 8 / 8.1 / 10 (64 bits) macOS 10.10 / 10.11 / 10.12 / 10.13 / 10.14
Minimum Hardware Requirements	For PC: CPU 4th Generation Intel® Core™ i5 Processor or more / RAM: 8GB/ Hard disk space: 20GB or more For MAC: RAM: 8GB / Hard disk space: 20GB or more
Operating Temperature	15 ~ 32 °C / 59 ~ 89.6 °F
Operation Humidity	30 ~ 60 % RH (no condensation)

3. After segmentation and saving the file as a Standard Triangle Language (STL), the file is then sent to **Ultimaker Cura** software (cura 4.12.1) to produce a physical 3D model, as shown in Figure.5.

Ultimaker Cura is a 3D printer software tool that assists users in preparing printing projects and incorporates CAD software to streamline processes.

Ultimaker Cura enables seamless integration of 3D printers, software, and material, resulting in consistently excellent prints.

Every model created for printing must be translated into instructions that 3D printers can read by Ultimaker Cura. This is accomplished by slicing the model into thin layers and saving the file as a copy file.

There are three steps for printing a 3d model:

Step 1: Design

A 3D model is the first thing required. STL file formats are supported by Ultimaker Cura.

Step 2: Prepare

Ultimaker Cura divides the model into slices ready for printing in seconds. Users can preview it, resize it, and change the settings as needed.

Step 3: Print

Send files directly to the 3D printer Using a USB stick or save files to an SD card.

4. The **Digital Caliper** is a precise tool for measuring internal and exterior distances with exceptional precision. The distances/measurements are read from an LCD. The main features of the digital caliper are the following:

Attribute	Value
Measuring Range	0-150 mm (6 inches)
Certification	CE

Accuracy	0.1 mm
Material	Plastic

Digital calipers are simple to use since the measurements are presented, and the distance may be read in metric or imperial units by moving the inch/mm button. The on/off button is used to turn on the display. After that, bring the exterior jaws together until they contact, then push the zero button. The distances may then be measured using the digital caliper.

For Anatomical accuracy measurements, the dimension of the brain tumor was measured using an electronic caliper with an accuracy of 0.1 mm from anterior to posterior (AP), and from left, to right (LR) as shown in Figure.2 to confirm the precision of the 3d printed brain model.



Figure.2 The distance measured from anterior to posterior (AP) using a digital caliper.

These results were compared to those obtained from a computerized model, which has been measured with 3D Slicer's measuring tool (Figure.3). Because the brain shape is irregular, the anatomic positions for measurements were determined using surface landmarks. Sharp points on the brain surface were selected, and the distance between them was measured. To make the caliper more efficient, the most prominent point from each surface was chosen as the surface marker for measuring. The measurements were taken three times for each anatomical region, and the mean value was derived.

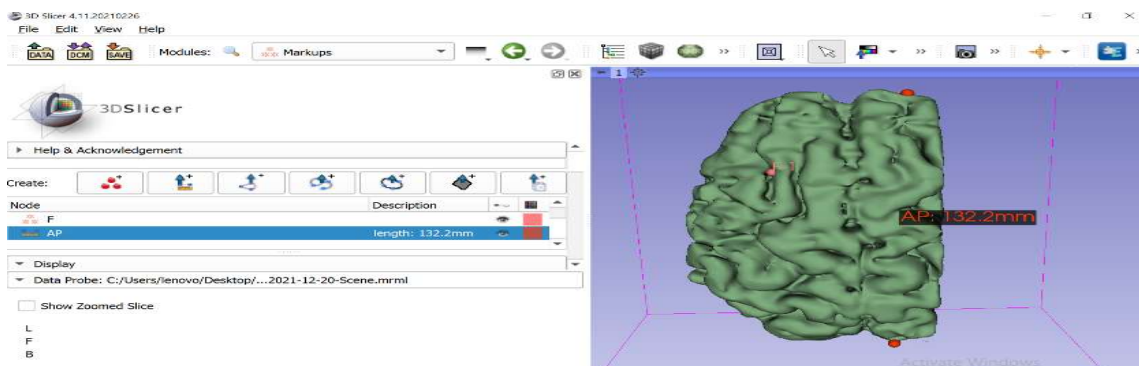


Figure.3 The distance measured from anterior to posterior (AP) using a 3D slicer measuring tool.

The development of multi-material 3D printers has facilitated the creation of more realistic neurosurgical models that resemble real tissues. As technology progresses, such models may be able to enhance neurosurgeons' training in a virtual operating theatre environment, thereby increasing the training experience. The most advanced generation of 3D printers (da Vinci 1.0 A) was used to make the model.

The surgeon could better describe the patient's disease, location, intended surgical strategy, and operating risks using a 3D printed model. As a result, improved communication and understanding of the condition may make it easier to obtain informed consent.

Figure. 4 represents the computerized and constructed brain tumor model, one of these five cases. This case includes patients with large-size cavernoma located in the brain's parietal lobe. In this case, the part of the brain was printed before the surgery for training.

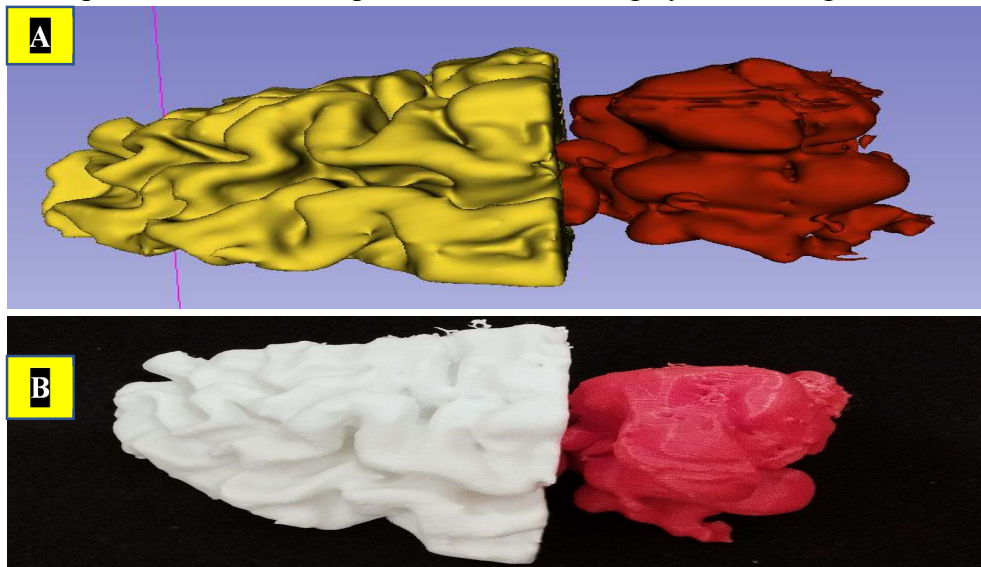


Figure.4 patient with Cavernoma A) 3D computerized model B) 3D printed model.

The mean absolute difference at two anatomical landmarks (the diameter from the left to right and from the anterior to posterior) was measured to ensure the printer's accuracy and the resulting printed models. These measurements were done using a digital clipper tool (as described previously) for the created 3D models and a ruler tool for the software model.

The measurements were taken for each model to compare the results of the 3D slicer software and the 3D printed model. Table.4 shows the 3D model accuracy measurements.

The root mean square error was calculated from Table.4 at two main landmarks of the obtained models for measuring if there are large differences between the computerized model and the constructed model or if they are within the acceptable range.

At LR, the root mean square of brain diameter measurements between the computerized model and 3D printed model was 0.16354; this indicates there are no large differences between them, as shown in Figure.5, which is within an acceptable level.

At AP measurements, however, the resulting root mean square was 0.00797724; this also means that there are no large differences between them, as shown in Figure.6, which was also

within an acceptable level.

Table.4 Comparison of measurements of the brain diameter between 3D slicer software and 3D printed model.

Case No.	Mean diameter on 3D slicer software model (cm)		Mean diameter on the 3D printed model (cm)		The difference in diameter in absolute value (cm)	
	LR	AP	LR	AP	LR	AP
1	11.9	15.22	11.36	15.21	0.54	0.01
2	4.79	8.8	4.79	8.8	0	0
3	8.12	13.22	8.12	13.21	0	0.01
4	5.97	7.57	5.92	7.56	0.05	0.01
5	4.91	10.8	4.9	10.78	0.01	0.02

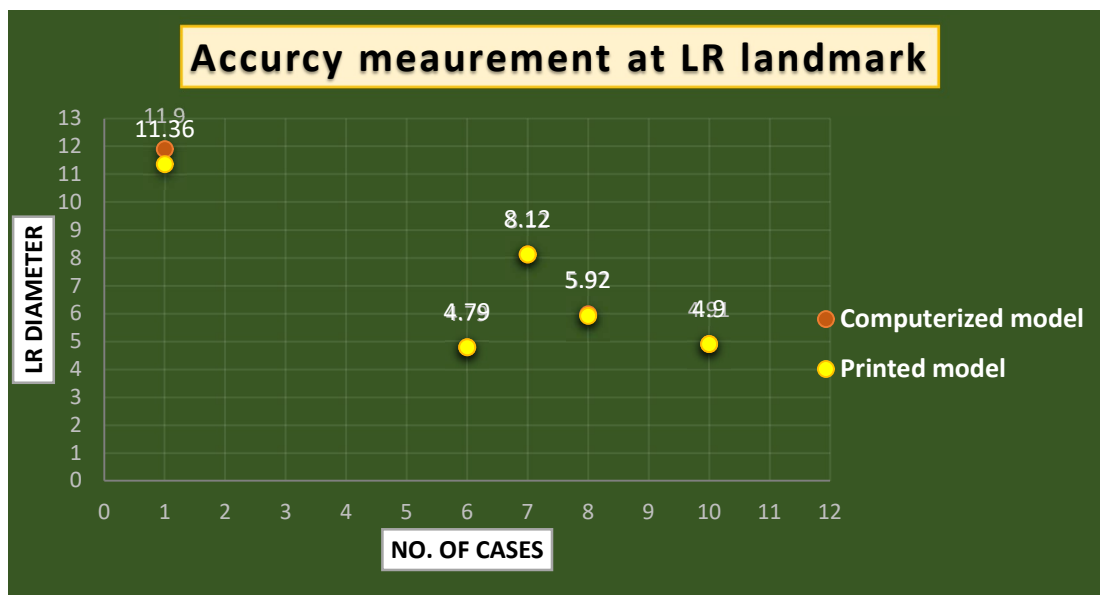


Figure.5 LR diameter of the computerized and created model.

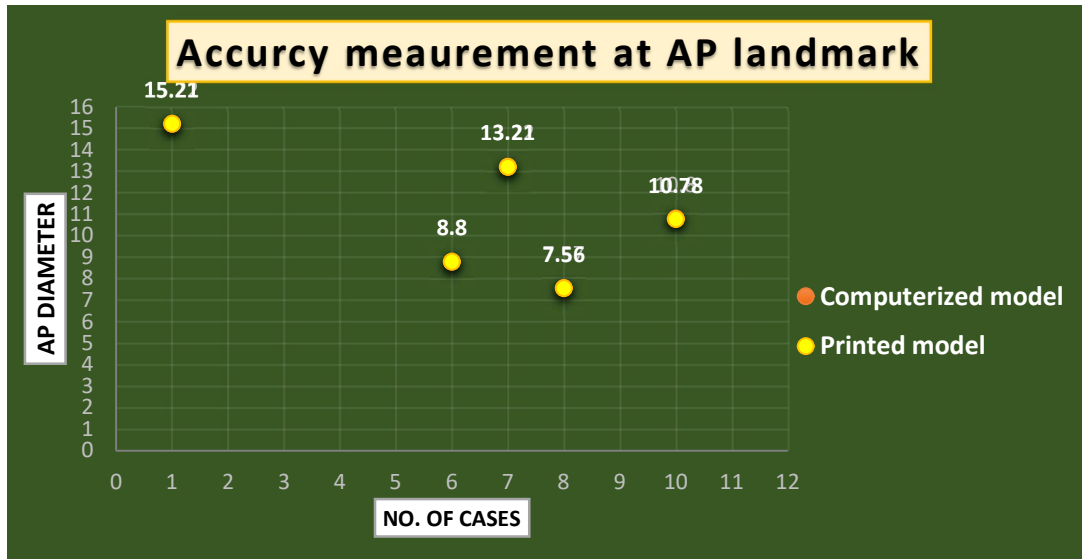


Figure.6 AP diameter of the computerized and created model.

Conclusion

After printing the model with the 3D printer and making a comparison between the software and hardware models for five subjects. The following were concluded in this research:

1. This technical study provides a practical method for creating brain tumor models surgical planning and trainer training at a reasonable cost.
2. Verify the accuracy of the printer.
3. Smaller models give more accurate results than the bigger ones, therefore, reducing the percentage errors.

References

- [1] Carter, R. et al., 2014. *The Human Brain Book: An Illustrated Guide to its structure, function, and disorders*, New York, NY: DK Publishing.
- [2] H. Auns, et al., 2010. Non- Linear Principal Component Analysis Neural Network for Blind Source. *Research Journal of Applied Sciences, Engineering and Technology*, pp.180–190.
- [3] Sheard, R., & Pelosi, E. (2022). *Understanding brain tumours: A guide for people with brain or spinal cord tumours, their families and friends*. Cancer Council of New South Wales.
- [4] Brat, D. J., & Perry, A. (2018). *Practical surgical neuropathology: A diagnostic approach*. Elsevier.
- [5] Hygino da Cruz, L. C., Vieira, I. G., & Domingues, R. C. (2011). Diffusion MR imaging: An important tool in the assessment of brain tumors. *Neuroimaging Clinics of North America*, 21(1), 27–49. <https://doi.org/10.1016/j.nic.2011.01.010>

- [6] Hayat, M. A. (2011). *Tumors of the central nervous system: Gliomas: Glioblastoma*. Springer.
- [7] Turner, S. G. (2022). *Central nervous system tumors*. IntechOpen.
- [8] Scholars Portal. (n.d.). *Primary central nervous system tumors: Pathogenesis and therapy*.
- [9] American Brain Tumor Association. (2015). *About brain tumors: A primer for patients and caregivers*.
- [10] Hayat, M. A. (2015). *Tumors of the central nervous system, volume 14: Glioma, Meningioma, neuroblastoma, and spinal tumors*. Springer Netherlands.
- [11] Norden, A. D., Reardon, D. A., & Wen, P. Y. (2011). *Primary central nervous system tumors: Pathogenesis and therapy*. Humana Press.
- [12] Forshult, S. E. (2007). *Magnetic Resonance Imaging: Mri: An overview*. Faculty of Technology and Science, Physics, Karlstad University.
- [13] Hattingen, E., & Pilatus, U. (2016). *Brain tumor imaging*. Springer.
- [14] Schepper, D. (2006). *Imaging of soft tissue tumors*. Springer.
- [15] Pillai, J. J. (2014). *Functional brain tumor imaging*. Springer.
- [16] (PDF) *3D printing - researchgate*. (n.d.). Retrieved August 9, 2022, from https://www.researchgate.net/publication/272789911_3D_printing.
- [17] Kelly, J. F. (2014). *3D printing: Build your own 3D printer and print your own 3D objects*. Que.
- [18] Naftulin, J. S., Kimchi, E. Y., & Cash, S. S. (2015). Streamlined, inexpensive 3D printing of the brain and skull. *PLoS ONE*, 10(8). <https://doi.org/10.1371/journal.pone.0136198>.
- [19] Sandeep Kumar, Y., Ramalinga Reddy, S., Naveen Kumar, Y., Saran Gopal, H. v., & Sai Charan, B. (2018). Development of 3D Printed Brain Tumour for Surgical Biopsy. *IOP Conference Series: Materials Science and Engineering*, 390(1). <https://doi.org/10.1088/1757-899X/390/1/012020>.