How 3D Printing Software Enhances and Rewards Student Learning of Brain Anatomy

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EDITOR NOTE

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ABSTRACT

Dear Editor,

I am a medical imaging student at Curtin University who is exploring the use of three-dimensional (3D) printed models of human anatomy as an educational tool for health professionals, students, and patients. Volumetric medical imaging datasets, typically Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) images can be post-processed and segmented to produce 3D virtual anatomical models which may then be 3D printed. The resulting physical anatomical models support kinaesthetic learning by providing a tangible and spatial representation of complex anatomy. Access to 3D printing as an educational tool is currently limited by the high cost of commercial software, hardware and 3D printing facilities, and a lack of defined protocols and techniques to achieve accurate and time-efficient segmentation.

Image segmentation involves using manual, semi-automatic, and fully automatic processes to mark/select the voxels within a volumetric dataset which correspond to the anatomical structure chosen to be reconstructed as a 3D virtual model. Learning how to segment volumetric imaging data has significantly improved my knowledge and

understanding of anatomy. It has increased my understanding of medical imaging informatics, particularly the relationship between original DICOM (Digital Imaging and Communications in Medicine) and alternative image formats, and has built my appreciation of how CT and MRI protocols impact image reconstruction. The learning process has been highly engaging and genuinely enjoyable. This letter aims to share my experience and demonstrate how creating segmentations with 3D imaging software can enhance student learning of brain anatomy.

I used open-source software tools 3D Slicer (Brigham and Women's Hospital, Boston, Mass) and volBrain (Valencia Polytechnic University, Valencia, Spain and University of Bordeaux, Bordeaux, France) to produce segmentations suitable for 3D printing of cranial structures, including the frontal, temporal, parietal, occipital, insular and limbic lobes; four main cerebral ventricles; brain stem; and cerebellum. The literature supports the use of 3D Slicer and volBrain to calculate cranial volumes and produce 3D visualisations for research, and for clinical applications where regulations allow[1]. 3D-Slicer is increasingly used in image post-processing and segmentation and has been shown to achieve the same goal as commercial software tools for 3D printing purposes.

3D Slicer is a free, open-source software designed to process, visualise, and analyse 3D MI data. Extensions are available which massively increase the capabilities of the software beyond basic segmentation and there is a large online community for support[2,3]. VolBrain is a free, online platform which uses T1-weighted MRI data to produce detailed segmentations of the brain which measure total brain volume and intercranial volume. The process is fully automated and only requires the user to perform a file conversion from DICOM to NIFTI (Neuroimaging Informatics Technology Initiative) format[4].

I learned to operate 3D Slicer via online tutorials provided on their website and several invaluable face-to-face tutorials with more experienced users at Curtin University. I

first imported an MRI T1 MP-RAGE (magnetization-prepared rapid gradient-echo) dataset in DICOM format into 3D Slicer and saved it as an NRRD Volume file. I then segmented the cerebral ventricles from the MRI slices using mainly manual processes. I was constantly analysing the individual slices in the axial, coronal, and sagittal planes while referring to anatomy literature to ensure that my segmentation was accurate. For example, while marking the boarders of the lateral ventricles, I had to ensure that I had not ventured into the lateral sulcus or engulfed the caudate nucleus.

I then used semi-automatic and automatic segmentation methods via extensions in 3D Slicer to produce a model of the entire brain. These methods reduced the time required for segmentation significantly, however some manual editing was still necessary to remove or reconstruct anatomy that the software had not accurately defined. This corresponds to the experience of published researchers but does not exclude the potential utility of automated processes which are constantly under development[5,6].

Finally, I used volBrain to produce a fully segmented brain in NIFTI format in approximately 12 minutes. I was able to view and edit volBrain's segmentations and compared them to my original segmentations by importing them to 3D Slicer. VolBrain's segmentations required minimal further processing to be suitable for 3D printing. I found it necessary, however, to supplement volBrain's segmentation of the cerebral ventricles by combining it with my original segmentation (Figure 1).

Upon completion, I had achieved a much greater comprehension of the ventricular anatomy and its relationship with the surrounding subcortical grey matter as well as the greater intracranial anatomy. Previously, rote learning has allowed me to recognise these anatomical structures for an exam, whereas the process of segmentation required me to truly engage in a comprehensive learning process, and ultimately establish a clear understanding of the definition, location, and visuospatial relationship of the intracranial structures.

My final 3D virtual model looked fantastic, and I felt a true sense of accomplishment (Figure 2). The process of segmentation successfully 'gamified' my anatomical learning to the point where I am excited to continue the process of segmentation to create 3D models of other body systems. Through 3D modelling there is an opportunity to create a rewarding and tangible product presented as a 3D print (Figure 3 A,B &C) or interactive virtual reality model, which to reach, students must deeply engage in learning sectional anatomy. The preliminary experience has laid good foundation for me to conduct further research, mainly focusing on creation of more 3D printed models including diseased cases for medical education and clinical training purpose. I look forward to further enhancing my experience in image processing skills and my knowledge in 3D printing technology.

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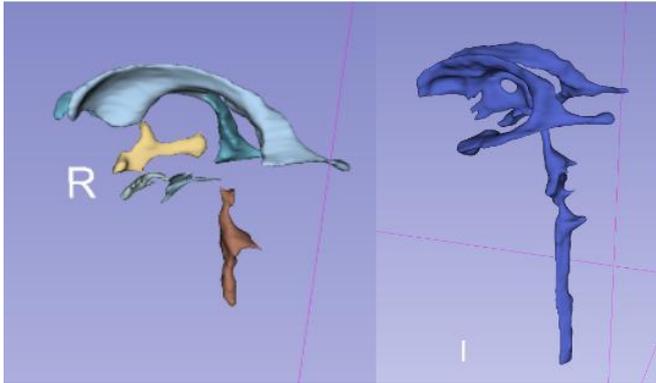
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Figures

Figure 1: Comparison of fully automatic segmentation of cortical ventricles by volBrain (left) and manual segmentation using 3D Slicer (right).
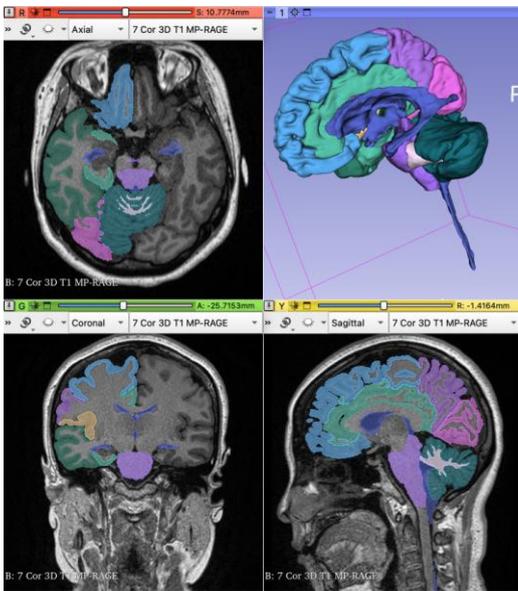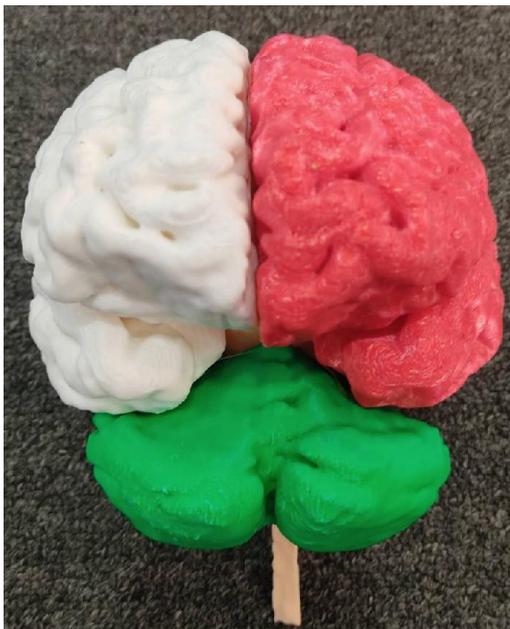

Figure 2: Completed segmentation of brain anatomy in 3D Slicer with the left lobe removed to reveal the cortical ventricles and brainstem on the virtual 3D model.

A

B

C

Figure 3: 3D printed brain models. A: 3D printed model showing bilateral cerebral lobes. B and C: Frontal and posterior views of 3D printed cerebral lobes (white and red colours), cerebellum (green colour) and brain stem and spinal cord (cream colour). The models were printed using polylactic acid on a Raise3D N2 Plus fused deposition modelling 3D printer.