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Construction of a 3-D anatomical model for teaching temporal lobectomy

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ABSTRACT

Although we live and work in 3 dimensional space, most of the anatomical teaching during medical school is done on 2-D (books, TV and computer screens, etc). 3-D spatial abilities are essential for a surgeon but teaching spatial skills in a non-threatening and safe educational environment is a much more difficult pedagogical task. Currently, initial anatomical knowledge formation or specific surgical anatomy techniques, are taught either in the OR itself, or in cadaveric labs; which means that the trainee has only limited exposure.

3-D computer models incorporated into virtual learning environments may provide an intermediate and key step in a blended learning approach for spatially challenging anatomical knowledge formation. Specific anatomical structures and their spatial orientation can be further clinically contextualized through demonstrations of surgical procedures in the 3-D digital environments. Recordings of digital models enable learner reviews, taking as much time as they want, stopping the demonstration, and/or exploring the model to understand the anatomical relation of each structure.

We present here how a temporal lobectomy virtual model has been developed to aid residents and fellows conceptualization of the anatomical relationships between different cerebral structures during that procedure. We suggest in comparison to cadaveric dissection, such virtual models represent a cost effective pedagogical methodology providing excellent support for anatomical learning and surgical technique training.

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1. Introduction

Training residents to become good surgeons involves more than the old adage of, “see one, do one, teach one,” as it may not be adequate for modern medical practice. While excellent understanding of patient anatomy is essential, it is also crucial for the trainee to obtain an outstanding ability to navigate within the 3-D space defined by the particular approach and underlying neuro-anatomical structures. Although anatomical understanding can be achieved using books, surgery requires integration of all levels of knowledge: spatial awareness, motor skills, and technique mastery to reach a pre-defined outcome as it is applied to a particular anatomical region. The spatial relationships of brain anatomy are one of the most challenging aspects to teach. This may stem from educational methods. With the emergence of new media and advanced visualization techniques, different institutions, and surgical departments, are starting to create and utilize 3-D virtual environments to assist in the education of the residents and

fellows. Some institutions are using 3-D models (plastic or other materials) to enable resident practice [1], however the practice requires new prototype every time and is not cost-effective [2,3]. Others have started to use computer assessments to teach and test the students in neuroanatomy [4–6] and assessed positively the effect of 3-D visualization on anatomy and embryology learning [4,7,8].

To our knowledge, the paucity of 3-D modeling for the purpose of neurosurgery education represents a gap in current training regimes and affords an opportunity for rich research. Such digital models have been used in cardiac surgery training [9], general surgery with inguinal hernia repairs [10] and plastic surgery (cleft lip) repairs [11]. Some teams are working on larger virtual reality projects, with models in which the surgeon can actually use his/her hands and have an active feedback (haptic); however, those types of training programs require extremely expensive material, and are very specific to a small community.

While temporal lobectomy is one of the common procedures performed for epilepsy, gaining adequate competency for the relationships of the underlying discrete anatomy is difficult to understand for a resident, and also difficult to teach. While observing cases in the operating room accompanied by cadaveric

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dissection aid student understanding, it usually takes multiple surgeries where the resident is engaged to truly understand the relationship of those structures.

Thus, the aim of the current digital creation is to develop an interactive 3-D model of the brain in which the different steps of lobectomies are demonstrated and the spatial relationships of underlying discrete anatomy would be revealed to the trainee. Our model was built more to provide users an appreciation of the relative position of each underlying structure, and not their exact micro-anatomy. The reiterative potential of digital models would be useful in teaching residents as models can be manipulated, enabling exploration in all directions. It would allow trainees to understand the anatomy better, before undertaking dissections or surgeries. It can be reviewed endlessly giving individuals control of pace.

2. Methods

2.1. Development of digital model

High-resolution digital photographs of cross-sections from the Visible Human Project Female (VPH) [12] were chosen for the reconstruction and the details of similar approaches have been described previously [13,14]. Briefly, 629 slices of interest were converted into gray scale (Adobe Photoshop CS3, San Jose, CA), then imported into Amira 5.0 (Mercury Computer System, Chemsford, MA) for 3-D segmentation and mesh surface rendering. Segmentation of some anatomical regions of interest (aROI) were initially based on image intensity thresholding then corrected manually if required, on each slice for principal structures. Each aROI was identified, labeled, and coded with a different color. Most segmentation was done in the axial plane, however, when there was a doubt, or when two different structures seemed to blend in the image, coronal sections were used.

After segmentation, a post-processing phase was achieved using Amira in order to reconstruct a 3-D images from all the 2-D slices and the inherent structures identified therein. The data was reconstructed into a 3-D polygons mesh representing each material. The polygon number represents mesh surface topography and is directly proportionally to image precision. In order smooth the digital surface, reducing polygon counts acts to filter the visual data and enable better computation efficiency. Care is taken not to reduce polygon numbers such that anatomical distortion occurs. Because of the primary interest for the current study is the temporal lobe and deep nuclei, we first segmented these structures, while we kept a vaguer image for the internal capsule, the brainstem and the cerebellum.

Using the demonstration module in Amira with the segmented and reconstructed data, various visualizations were developed to complement the 3-D temporal lobectomy prototype simulation potential. These visualizations consisted of the brain rotating in Z axis coupled with anatomical structure transparency in order to visualize more internal structures while maintaining spatial relationships with the cortex (Fig. 1a). Furthermore, each segmented structure can be digitally added or removed in either deep or superficial sequence in order to aid user comprehension of spatial relationship of discrete structure using the process of syncretion [15].

The next step was to virtually reproduce the main anatomical steps taken during a temporal lobectomy. While in the operating room, a surgeon would use bipolar forceps, suction, and scalpel to perform a neocortical resection followed by an amygdalohippocampectomy; digital simulation steps were undertaken to illustrate the process. In order to mimic resection on the virtual brain, we created virtual cuts in the model. These virtual cuts were performed in the same order as would normally occur in the operating room. By creating a virtual cut, underlying structures were exposed clearly through the dissection. The neocortical resection was then completed as an en-bloc resection. Visualization of the temporal horn of the ventricle was apparent once the cortex was removed (Fig. 1b). Similar steps were taken for the amygdalohippocampectomy. Bone and skin were added to the initial brain model to increase the reality effect of surgery.

2.2. Pilot testing of digital model

The model was presented to 8 subjects, novices (5), residents (2) and one fellow in Neurosurgery as a small informal pilot study. For the residents and fellow, the model was presented just before a case in the operating room; while for the novices, it was presented in a laboratory environment. It was presented in the form of a 3 min video, which could be stopped or rewound by the subject as needed, or with the subject sitting freely interacting with the model in Amira, enabling him/her to add and subtract different structures, rotating and zooming the model. The novices were also presented with a short powerpoint slides showing drawings and 2D pictures of the relevant anatomy. The presentation was followed by a subjective questionnaire in which we asked whether some structures were better visualized and learned using the classical view with 2-D images, the 3-D model seen as a movie, or the 3-D interactive version of the model. The main structures of interest were the ventricles, the hippocampus and their relationship to the temporal lobe, as well as the deep brain nuclei.

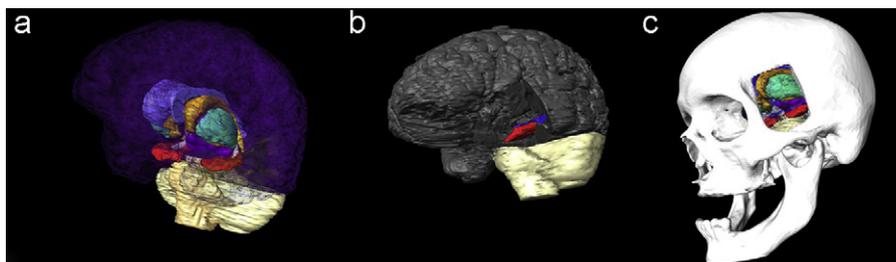


Fig. 1. (a) Lateral view of the entire brain with the cortex and white matter made transparent to visualize the corpus callosum (light blue), the caudate (amber), the putamen (green), the hippocampus (red) and the fornix (white). Lobectomy (neocortex removed) with visualization of the ventricle (blue) and the hippocampus (red). (b) Lateral view of the entire brain, this time with an opaque cortex and the neocortex from the anterior temporal lobectomy removed. The ventricle (blue) and hippocampus (red) are seen as a result of the removal of the temporal neocortex. (c) The skull with a craniotomy window as would be done for a temporal lobectomy have been added to the model in order to give to the trainee and idea of what would be within the field in the operating room. The cortex has been made transparent to allow them to see the other structures in relation to the craniotomy site.

3. Results

3.1. Model development

The brain was segmented into 19 reconstructed structures (Table 1). The fidelity of the detail was kept moderate in order to provide a model that would be digitally nimble while users interact with it, rotating or magnifying it using a normal desktop computer. Bright colors were chosen for each structure in order to delineate them easily from each other (Fig. 2a) and to provide users an appreciation of the relative position, and not their exact

micro-anatomy. High contrast colors also enabled a color coding system to recognize each structure, instead of using labels that would have obstructed the view. The level of transparency of all the structures can be varied, and therefore the internal structures can be visualized.

Once the model was constructed, we chose to display it using three different techniques. First, a classical “canonical view” approach was developed using different snapshots of the model with varying transparency of overlaying structures in a text book-like fashion. Although these are static images, they provide a good way to introduce the model to the students. It can be shown during a lecture for example, to familiarize students with the model and its color coding. In addition, to the 3-D anatomy, some of the original VHP cross-sections were introduced in the 3 different orthogonal cuts (axial, coronal and sagittal). This helped students understand what structures looks like in a cadaveric state (Fig. 2b).

The second approach was to display the model as digital video in order for the student increase their spatial appreciation of the different structures. The video of the model rotating can be used on any computer. Here, the user can stop, start or rewind the model visualization in order to review important steps in the surgery. The video of the procedure was developed such that the resident user could see the brain from the same aspect as they would in the OR. Here however, the use of transparency of the skin/bone and cortex creates better spatial understanding adjacent structures. We therefore started with a quick skin incision, and bone flap, then

Table 1
Segmented brain structures.

Left and right cerebral hemisphere	Gray matter
	White matter – internal capsule
Ventricles	Lateral, third and fourth
Corpus callosum	
Hippocampus	
Fornix + mamillary bodies	
Thalamus	
Putamen	
Globus pallidus	
Caudate nucleus	
Cerebellum	
Brainstem	

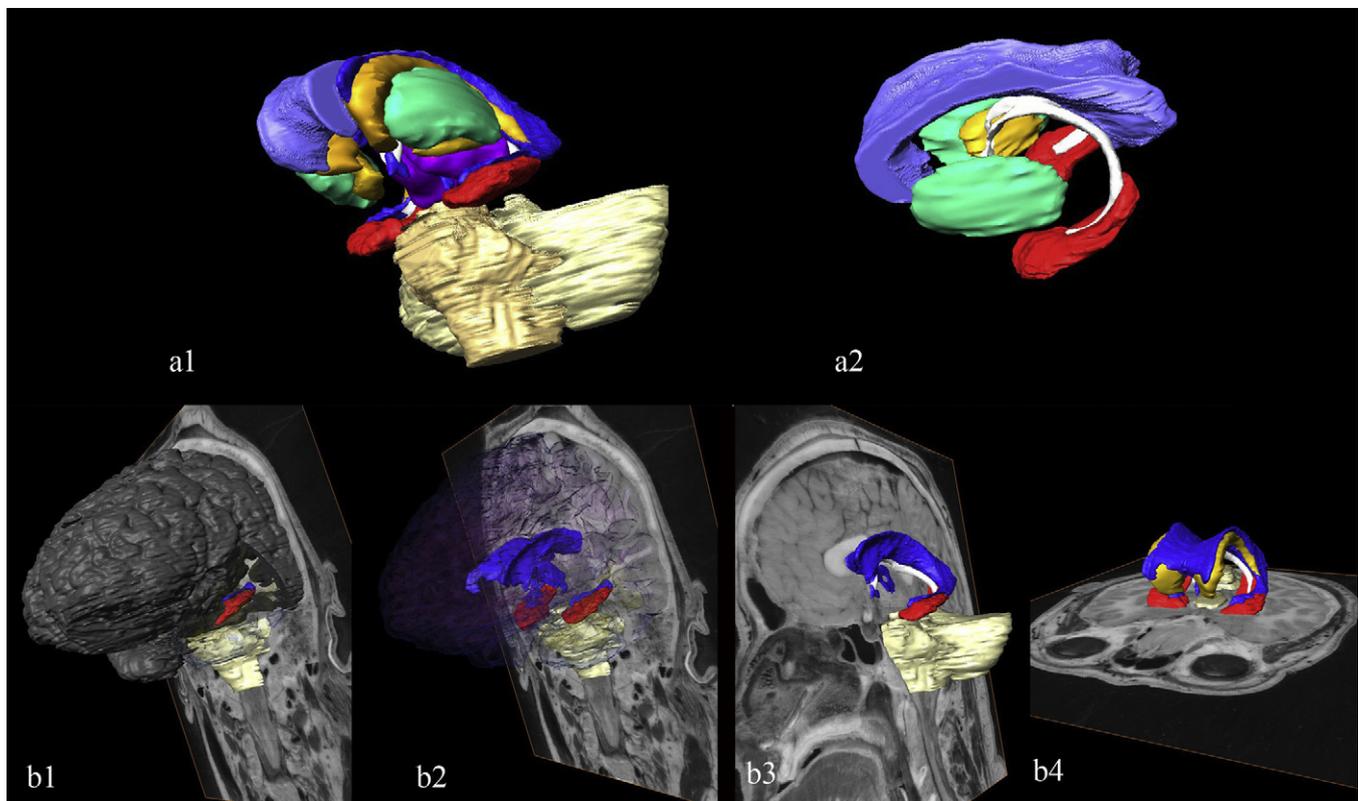


Fig. 2. (a1) Antero-posterior view with a tilt of the basal nuclei with the cortex and white matter removed. The brainstem and cerebellum have been left in order to see their spatial relationship with the basal nuclei. We visualized the corpus callosum (light blue), the ventricle (dark blue), the thalamus (purple), the putamen (green), the globus pallidus (yellow), the hippocampus (red) and the fornix (white). (a2) Lateral view of the internal structures with the cortex, white matter, the ventricles and some basal nuclei removed in order to see the fornix and hippocampus better. (b1) Antero-lateral view of the brain, associated with a coronal section, enabling the visualization of the 3-D model as well as the visual human data and therefore seen better some small structures, but keeping the spatial relationship between objects. The temporal neocortex has been removed as seen after a temporal lobectomy. The ventricle is seen in blue and the hippocampus in red. (b2) Antero-lateral view the cortex and white matter made transparent associated with a coronal section. All the internal structures except the ventricle (blue) and hippocampus (red) have been removed. (b3) Antero-lateral view of the brain associated with a sagittal section of the visible human slice. The ventricle (blue), hippocampus (red), fornix (white), cerebellum and brainstem (cream) are visualized in relation to the slice. (b4) Antero-posterior view of the ventricular system (blue) with the caudate nucleus (yellow), the hippocampus (red) and fornix (white) in relation with an axial slice of the visible human body.

the temporal lobectomy approach commenced with successive cuts in the cortex of the temporal lobe, as would be achieved by suctioning the gray and white matter in the OR.

Once arriving at the ventricle, the neocortex was removed. The cortex was also made transparent, and rotated through different angles, and then a slow rotation in the anterior–posterior axis, followed by a rotation in the inferior–superior axis was done to give a complete view of all important structures in relation to the temporal lobe and ventricular system. The hippocampus was then removed. At that point, snapshots of the different structures of the 3-D model, as well as a cross section of the initial Visible Human slice are shown, so the resident still has an idea of how the structure would look like on a cadaver. A bone window was re-added at the end of the procedure, once again to give to the resident an idea of the point of view he/she would have in the OR (Fig. 1c).

Finally, the third display constitutes an interactive version of the model. Here, complete interaction and viewer control is possible and all components of the model can be visualized on a laptop or computer screen. Further, the model is viewable in stereoscopy 3-D using dual polarized projectors (InFocus IN36, Wilsonville, OR). This system, by producing 2 different images displayed for each eye will create a stereoscopic effect (the image is displayed on a screen and the user is wearing linearly polarized lenses with the disparity between the two images seen producing the stereoscopic effect).

3.2. Pilot testing

In general, the participants indicated that the relationship of each structure was better understood using both the 3-D model and the 3-D interactive version than the 2-D images. It was also felt that the interactive 3-D version was harder to use at first but had a better potential to learn at once one pace, and therefore more useful to study each of the structures and their location in space. The questionnaire also highlighted the fact that for younger residents, the viewing of the model before a case was helping in the understanding of the procedure.

4. Discussion

While our model is still at its origin, these initial steps aim to improve upon current resident educational techniques. This type of computer model, unlike surgical simulators, allows the trainee to learn different steps of a procedure, as if he/she were observing in an operative room. We anticipate the model provides good general understanding of normal anatomical spatial relationships in the region of the operation, which are essential for a surgeon.

Different teams have published data on 3-D virtual anatomy models and the benefit of such learning tools are emerging [16]. 3-D interactive models have also moved to the general public knowledge with different websites developing 3-D virtual human, such as the visible body for iPad [<http://itunes.apple.com/us/app/visible-body-3-D-human-anatomy/id446207961?mt=8&ls=1>], different neuro-anatomy models [17,18], or the Google body [<http://bodybrowser.googlelabs.com/>]. However, to date, there is a paucity of virtual anatomy models built to teach a specific neurosurgical procedure. Henn et al. [18,19] developed one based on cadaveric dissection and although it displays different points of views, interactivity and spatial perception may be lacking. Most 3-D models for surgical training are still physical models [1,2], or the procedure is demonstrated on a cadaver forcing each observer to decipher their personal perspective of the specimen to that of the view of the surgeon.

The more step-wise progression from digital model, to cadaver, to observation in the surgical suite, may illustrate the pedagogic potential of 3-D models in surgical training. While there are more costly and realistic simulators created, a relatively simple digital model that captures the essence of the procedure, yet is portable and could be used in a classroom setting or on an individual computer shows great promise.

A larger study using this model is underway to investigate the educational value of this prototype not only to understand a procedure but also to have a better understanding of the underlying neuroanatomy.

5. Conclusion

In comparison to single use cadaveric dissections, virtual models like the one portrayed here could represent an effective methodology providing support for anatomical learning, introduction, and training of surgical techniques. Digital models provide not only a simplified method for illustrating structures and procedures, they can be used repeatedly by the learner in a self-paced environment not offered in cadaveric dissection. Further, independent learning can occur with such learning models without requiring the presence of an expert as feedback is provided by the digital model. The dynamic nature of digital models provides a unique method to visualize structures from different angles without having to remove other structures.

Finally, for residents who might not have access to cadaveric labs prior to the OR, such a model could help them revise the surgical steps of a procedure before assisting in the OR the next day. Therefore, the incorporation of digital models at multiple stages of student, resident, and fellowship will inevitably aid understanding of the surgery better and learn faster. The effects of digital learning on surgical conduct and patient morbidity and mortality remain to be addressed.

Conflict of interest statement

None declared.

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