Development of a 3D Printed Neuroanatomy Teaching Model, University of Ottawa

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ABSTRACT

Gross anatomy is seen as one of the basic bodies of medical knowledge. Likewise, neuroanatomy is foundational to clinical neurosciences. However, neuroanatomy is different from gross anatomy due to the complexity of the central nervous system, and the fact that some of its structures cannot be dissected or demonstrated in anatomy cadaveric lab. The use of anatomical models in medical curricula has been reported as an effective tool in anatomy learning. They have been used to replace cadaveric material when the latter is difficult to acquire, or when the anatomical structures cannot be dissected (for instance the brain ventricles). Moreover, anatomic models allow leaners to visualize the structures in a 3-dimensional modality. The goal of this study was to create a 3D printed neuroanatomy model in order to complement the University of Ottawa anatomy models' library, and help medical students visualize the pathway of different nervous tracts on a 3D simulation model. To assist with this, 2D images of slices of the cerebrum, brainstem, and spinal cord sections were downloaded online to be imported to Adobe Photoshop CC 2015. The images were manually converted to black and white, and separated into different layers to export each component separately into Tinker CAD (online software). The different components were then assembled on Tinker CAD to create 3D printer compatible files. The files were printed using white ABS on a Replicator 2X MakerBot printer. Two survey questions (Likert style) were sent to students via Google docs to evaluate their satisfaction with the model.

RÉSUMÉ

L'anatomie macroscopique est connue comme une base de la connaissance médicale. De même, la neuroanatomie est la fondation aux neurosciences cliniques. Pourtant, la neuroanatomie est différente de l'anatomie macroscopique due à la complexité du système nerveux central, et le fait que quelques structures ne puissent pas être disséquées ou démontrées dans un laboratoire d'anatomie. L'usage de modèles anatomiques dans les programmes médicaux a été rapporté comme un outil efficace pour l'apprentissage de l'anatomie. Ils ont été utilisés pour remplacer le matériel cadavérique qu'on ne peut pas facilement acquérir, ou si la structure anatomique ne peut pas se faire disséquer (par exemple, les ventricules du cerveau). De plus, les modèles anatomiques permettent aux apprenants à visualiser les structures dans une modalité tridimensionnelle. Le but de cette étude comprenait de créer un modèle de la neuroanatomie imprimé en 3D, pour ajouter à la bibliothèque de modèles anatomiques de l'Université d'Ottawa, et assister aux étudiants de médecine à visualiser les différentes voies nerveuses dans un modèle de simulation 3D. Pour assister à cette tâche, des sections de lames 2D du télencéphale, du tronc cérébral, et de la moelle épinière ont été téléchargées en ligne pour être importés dans Adobe Photoshop CC 2015. Les images ont été converties à noir et blanc, et séparées dans des différentes couches pour exporter chaque composant séparément dans Tinker CAD (logiciel en ligne). Les différents composants ont ensuite été assemblés dans Tinker CAD pour créer des fichiers compatibles avec l'imprimant 3D. Les fichiers ont été imprimés en utilisant un ABS blanc dans l'imprimant Replicator 2X MakerBot. Deux questions de sondages (en style Likert) ont été envoyées aux étudiants par Google docs pour évaluer leur satisfaction avec le modèle.

Unlike many components of the contemporary medical school curriculum, the study of anatomy has a history that extends back through the centuries to Aristotle and Galen. In medicine, gross anatomy has been seen as foundational, one of the basic bodies of knowledge that must be mastered as part of medical training in order to apply the diagnostic and treatment skills required for clinical competence (1). "Likewise, neuroanatomy has been seen as foundational to clinical neurosciences, and it is included in every North American medical curriculum," according to Mauteen & D'Eon (2). "Neuroanatomy is the cornerstone upon which is built an understanding of the nervous system and its disorders," according to Crossman (3).

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However, neuroanatomy is quite different from gross anatomy, and this is attributable to the complexity of the central nervous system (CNS), as well as the many structures that are difficult to dissect and demonstrate in the anatomy cadaveric lab (for example, the brain ventricles, the nervous tracts, etc.). Moreover, CNS lesions do not manifest with local signs and symptoms. Although this is also true of other organ systems, such as the cardiovascular system, the difference is the inaccessibility of the CNS to direct physical examination. For instance, a lesion in the dorsal column-media lemniscus pathway will manifest as loss of touch sensation below the level of the lesion and it will present in a different side of the body based on the location of the lesion along the tract (e.g. above or below the medulla). Therefore, for lesions of the nervous system there is the need for a certain level of mastery of neuroanatomy to associate a lesion with the exact structure in the nervous system that induced it.

Anatomical models have long been used in anatomy education to supplement or replace cadaveric material when the latter is difficult to acquire. From the 14th until 18th century in France, Germany and Italy, anatomy was studied with the help of ivory figurines made by artists. After the invention of plastic, new opportunities in the study of anatomy were developed. At the beginning of 20th century, anatomy lessons were taught using plastic models of organs (4). Gültiken stated that the subjects introduced by plastic models are easier to learn and comprehend, as formaldehyde may mask the finer details of the anatomical complex (5). Therefore, the use of three-dimensional (3D) anatomical models is ubiquitous in medical education. They allow the user to move away from the clutter, discomfort, and complexity of a cadaveric dissection and further clarify characteristics or functions of an anatomical structure that are not readily apparent in situ (6).

One of the neuroanatomy objectives at the University of Ottawa is for the students to locate the different nervous pathways and identify the outcome of a lesion in any part along the different tracts. The nervous pathways are very fine structures that cannot be dissected or demonstrated in anatomy cadaveric lab, and they are not purchasable from the market as 3D models. To address this issue and allow students to better identify the tracts, clarify the interconnectedness of the nervous system and facilitate the "locate the lesion" diagnostic approach, a 3D printed neuroanatomy model exclusive to the University of Ottawa was created to complement its anatomy library.

METHODS

2D images of slices of the cerebrum, brainstem, cervical, thoracic, and lumbar spinal cord were downloaded online and imported to Adobe Photoshop CC 2015. The images were manually converted to black and white, which were then separated into different layers and exported separately into Tinker CAD (online software). The different components were then assembled on Tinker CAD to create 3D printer compatible files (stereo lithography STL format). The files were printed using white ABS on a Replicator 2X MakerBot printer in the Faculty of Medicine' Health Sciences library at the University of Ottawa (7). The printed pieces measured 5x4x0.5 cm, 8x4x0.5 cm and 10x8x1 cm for the spinal cord, the brain stem, and the cerebrum slices, respectively. The pieces were then mounted on metal rods, and wires were passed through to demarcate the spinothalamic tract, corticospinal tract, and dorsal column-medial lemniscus pathway (**Figure 1**). The 3D model was introduced to students in neuroanatomy sessions and was kept in the lab allowing student access at any time. After approval by the Ottawa Health Research Institute-Research Ethics Board (OHRI-REB), two survey questions (Likert style) with a consent letter were sent to students via a Google

Figure 1. 3D printed neuroanatomy model showing the corticospinal, spinothalamic and dorsal column-medial lemniscus tracts

docs to evaluate their satisfaction with the model. The overall response rate to the survey was 43.8% (70 out of 160 possible students). Students responding to the survey were those who regularly attend the labs. 79% (n = 55) of the students stated that the 3D model helped them better memorize the pathway of the tracts at different levels of the CNS and 80% (n = 56) stated that it enhanced their understanding of difficult neuroanatomy concepts (**Figure 2**).

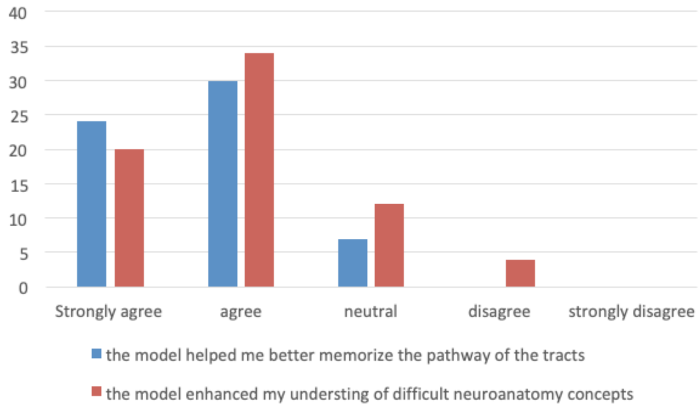

Figure 2. Students' perception of the neuroanatomy model as an educational tool (Second year medical students at the University of Ottawa, n=70).

DISCUSSION

The best model for investigating human anatomy has always been the human cadaver itself, because, in most cases, all the parts are present in the correct arrangement, the fine membranous and facial elements are intact, and the presentation of structures (soft, hard, smooth, rough, dry, moist) is accurate. It is safe to say that, from the beginning of curiosity, early man investigated wounds and organs of their dead brethren (6). However, in today's regulated and socially conscious institutions, access to a cadaver may be limited through budgetary or social issues, or, even if a cadaver is available, presentation of the desired cadaveric anatomy may be confusing, such as that of the pelvic spaces and fascia. Further, sometimes the structures cannot be demonstrated in cadaveric labs such as the nervous pathways. These issues can be addressed with fabricated anatomical models. Recent technological advances in 3D printing have resulted in increased use of this technology in the medical field (1,8). At the University of Ottawa, anatomy is taught to pre-clerkship students on a system base (musculoskeletal, vascular, respiratory, renal, gastrointestinal, endocrine, reproductive and nervous systems). The labs start with 30 minute PowerPoint presentation followed by a quiz of two multiple-choice questions. The students then spend an hour with their assigned tutors exploring the cadavers; the sessions are supplemented by the 3D plastic models. Neuroanatomy is taught to medical students in their second year of studies. It is a complex subject and it even has the reputation of the subject that students fear the most. Some of the neuroanatomical structures cannot be demonstrated in the anatomy cadaveric lab. This issue was addressed by creating a 3D printed model of the nervous pathways. A survey of two Likert style questions was then sent to students. The majority of students responding to the survey were satisfied with the model as they stated that it enhanced their learning and helped them better understand difficult neuroanatomy concepts. 3D printing is one technological advancement that may reduce the need for purchasing a large library of physical 3D anatomical models. These models provide versatility; they can be tailored to the desired learning objectives and to conform to learner characteristics. They offer a great advantage over static 2D images in terms of orientation and exploration of internal structures. Moreover, the advantage of printing the models using different colors allow better visualization of anatomical structures. The only limitation of this technique is that it can be time consuming depending on the size of the printed object.

CONCLUSION

Neuroanatomy is perceived as a complex subject and educators are encouraged to deliver it in a simplified, easy to understand fashion. The use of different instructional approaches allows students to successfully retain information. 3D printing has advanced tremendously over the past two decades, becoming fundamental in the development and construction of physical 3D anatomical models. Advantages of these models over cadaveric specimens include their application in many educational formats (lectures, online material, and print) in addition to being portable, non-perishable and cost effective. These models can be altered to enhance desired learning objectives or to conform to learner characteristics. They offer a great advantage over static 2D images in terms of orientation and exploration of internal structures. 3D printing as an educational tool is uniquely flexible in responding to the evolving environment, leading to improved student learning outcomes and more retention of information. Therefore, it is recommended to continue developing opportunities where 3D printing can supplement traditional learning approaches. One future directive would be the assessment of the use of 3D teaching tools on students' examination performance.

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