Original Investigation

Using 3D Modeling Techniques to Enhance Teaching of Difficult Anatomical Concepts

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Abbreviations and Acronyms

3D
three-dimensional

VHP
Visible Human Project

CT
computed tomography

Rationale and Objectives: Anatomy is an essential component of medical education as it is critical for the accurate diagnosis in organs and human systems. The mental representation of the shape and organization of different anatomical structures is a crucial step in the learning process. The purpose of this pilot study is to demonstrate the feasibility and benefits of developing innovative teaching modules for anatomy education of first-year medical students based on three-dimensional (3D) reconstructions from actual patient data.

Materials and Methods: A total of 196 models of anatomical structures from 16 anonymized computed tomography datasets were generated using the 3D Slicer open-source software platform. The models focused on three anatomical areas: the mediastinum, the upper abdomen, and the pelvis. Online optional quizzes were offered to first-year medical students to assess their comprehension in the areas of interest. Specific tasks were designed for students to complete using the 3D models.

Results: Scores of the quizzes confirmed a lack of understanding of 3D spatial relationships of anatomical structures despite standard instruction including dissection. Written task material and qualitative review by students suggested that interaction with 3D models led to a better understanding of the shape and spatial relationships among structures, and helped illustrate anatomical variations from one body to another.

Conclusions: The study demonstrates the feasibility of one possible approach to the generation of 3D models of the anatomy from actual patient data. The educational materials developed have the potential to supplement the teaching of complex anatomical regions and help demonstrate the anatomical variation among patients.

Key Words: 3D visualization; open-source software; anatomy.

INTRODUCTION

The teaching of anatomy is in crisis, as the discipline is disappearing from many academic institutions, being subsumed by disciplines such as cell biology (1). However, anatomy remains a vital element of any medical educational curriculum. Accurate diagnosis of alterations in organs or human systems requires a deep knowledge of anatomy. Radiology can play a critical role in helping medical students to recognize gross anatomical structures and their relationships to one another. The rapid development and application of imaging in medicine over the past 20 years has led to a better assessment and understanding of organ function in health and disease. In parallel, the emergence of increasingly sophisticated mathematical models, image processing, and visualization tools in the field of biomedical imaging research has enabled sophisticated three-dimensional (3D) representation of anatomical structures (2). The Visible Human Project (VHP) of the National Library of Medicine pioneered the development of digital image libraries of volumetric data to serve as a common reference point for the study of human anatomy. The VHP was initiated to attempt to provide rich datasets from computed tomography (CT), magnetic resonance imaging (MRI), and cryosection of representative male and female cadavers at an average of 1-mm intervals (3). Detailed animations and interactive 3D models of the human body, such as the Visible Human 3D Anatomical Structure Viewer, have been developed using the VHP data to facilitate learning of anatomy, radiological, and surgical procedures (4–7). By offering the possibility to add or remove

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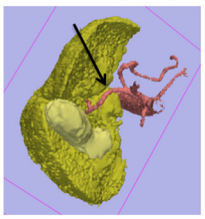
Abdomen Quiz Q3. Where is the left renal vein relative to the superior mesenteric artery?

- ❑ The vein passes posterior to the artery, anterior to the aorta
- ❑ The vein passes anterior to the artery and aorta
- ❑ The vein crosses the aorta superior to the origin of the artery
- ❑ The vein does not cross the aorta or the artery
- ❑ None of the above

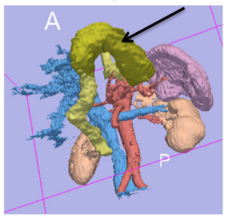
Abdomen Quiz Q4. Where are the adrenal glands relative to the spine?

- ❑ Near the front of the vertebral body
- ❑ Near the most posterior portion of the rib
- ❑ Near the transverse processes
- ❑ Near the junction of rib and vertebral body
- ❑ Not near the spine

Abdomen Quiz Q5 and 6. Identify the structure pointed at by the black arrow.



- ❑ Portal Vein
- ❑ Common Hepatic Artery
- ❑ Proper Hepatic Artery
- ❑ Common Bile Duct
- ❑ Cystic Duct



- ❑ Pancreas
- ❑ Stomach
- ❑ Duodenum
- ❑ Spleen
- ❑ Portal Vein

Figure 1. Abdomen quiz. The figure shows examples of questions from the online abdomen quiz that was offered to first-year medical students to assess their comprehension in the areas of interest. The associated screenshots show three-dimensional (3D) models of the abdominal structures of two different cases: Q5, abdominal aorta and its branches (*red*), liver (*dark yellow*), and gall bladder (*light yellow*); Q6, stomach (*dark yellow*), duodenum (*light yellow*), abdominal aorta and its branches (*red*), inferior vena cava (*blue*), hepatic vein (*blue*), kidney (*light pink*), and spleen (*light purple*). (Color version of figure is available online.)

anatomical structures and to observe an organ from different angles, 3D computer-aided visualization can enhance teaching of complex anatomical areas. A wealth of innovative anatomy education resources have been developed including tools such as Anatomy.tv (8) and the Visible Body (9), as well as digital atlases generated from cadaver and clinical imaging data such as the Visible Ear (10), the Digital Anatomist Project (11), and RadStax (12). Although these resources provide a very rich set of tools for radiological anatomy education, one of the most essential aspects of anatomy education is for students to realize the often dramatic degree of variation from one body to another. With the advent and wide availability of multi-detector CT scanners, it is now a routine to obtain data in living patients that can be reconstructed at 1 mm or smaller increments. We propose to use this volume of data to demonstrate the degree of anatomical variation between patients for medical education purpose. This paper presents the results of our pilot study to assess the feasibility of the development of teaching modules for anatomy education of first-year medical students based on 3D reconstructions from actual patient data. We chose three of the most complicated regions of the body for this project, and recruited fourth-year medical students to participate in building models. In this way, we used senior students in a manner analogous to a traditional approach, where senior students could serve as preceptors for junior students, sometimes preparing prosections for anatomical study. Our students prepared "digital prosections", learning the anatomy of these regions themselves in the process. Our goal was to determine the feasibility of this method of teaching, and to elicit feedback from first-year anatomy students on whether they felt that the use of 3D models helped them gain a deeper understanding of the shape and spatial organization of anatomical structures, as well as an appreciation of anatomical variation among patients that is so important in actual clinical practice.

Needs Assessment

Medical school institutional review board approval was obtained for use of anonymous student feedback and anonymous optional test results. Two anonymous optional online quizzes consisting of 13 questions each were offered to students in a first-year medical anatomy course. Students were informed that quiz results would have no affect on their course grade and that quiz material would not be used in the final exam for the course. The first quiz covered structures in the upper abdomen and the second quiz covered structures in the pelvis. A quiz for mediastinal structures was also developed but was not administered because of technical difficulties. Questions in the quizzes were designed to assess both student ability to recognize structures in 3D representations in various orientations and demonstrate their understanding of spatial relationships between structures. Figure 1 shows a set of representative quiz questions for the upper abdomen.

3D Modeling of Anatomy

Anonymized CT datasets from 16 patients were collected, including imaging of the mediastinum (five datasets), the abdomen (six datasets), and the pelvis (three female datasets and two male datasets). Institutional review board exemption for the use of anonymized clinical images for teaching purpose was obtained from the hospital of origin of the cases. Cases were selected for their optimal demonstration of normal anatomy as well as for variation in anatomy. Some cases included minor abnormalities or anomalies in comparison to normal