Do Three-dimensional Visualization and Three-dimensional Printing Improve Hepatic Segment Anatomy Teaching? A Randomized Controlled Study

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INTRODUCTION: Hepatic segment anatomy is difficult for medical students to learn. Three-dimensional visualization (3DV) is a useful tool in anatomy teaching, but current models do not capture haptic qualities. However, three-dimensional printing (3DP) can produce highly accurate complex physical models. Therefore, in this study we aimed to develop a novel 3DP hepatic segment model and compare the teaching effectiveness of a 3DV model, a 3DP model, and a traditional anatomical atlas.

MATERIALS AND METHODS: A healthy candidate (female, 50-years old) was recruited and scanned with computed tomography. After three-dimensional (3D) reconstruction, the computed 3D images of the hepatic structures were obtained. The parenchyma model was divided into 8 hepatic segments to produce the 3DV hepatic segment model. The computed 3DP model was designed by removing the surrounding parenchyma and leaving the segmental partitions. Then, 6 experts evaluated the 3DV and 3DP models using a 5-point Likert scale. A randomized controlled trial was conducted to evaluate the educational effectiveness of these models compared with that of the traditional anatomical atlas.

RESULTS: The 3DP model successfully displayed the hepatic segment structures with partitions. All experts agreed or strongly agreed that the 3D models provided good realism for anatomical instruction, with no significant differences between the 3DV and 3DP models in each index ($p > 0.05$). Additionally, the teaching effects show that the 3DV and 3DP models were significantly better than traditional anatomical atlas in the first and second examinations ($p < 0.05$). Between the first and second examinations, only the traditional method group had significant declines ($p < 0.05$).

CONCLUSION: A novel 3DP hepatic segment model was successfully developed. Both the 3DV and 3DP models could improve anatomy teaching significantly. (J Surg Ed 73:264-269. © 2015 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: hepatic segments, 3D visualization, 3D printing, anatomical education, Likert scale

COMPETENCIES: Medical Knowledge, Professionalism, Systems-Based Practice

INTRODUCTION

Hepatic segmental anatomy, first proposed by Claude Couinaud in 1956, is the basis of modern functional and surgical liver anatomy.[1-3] Therefore, good understanding of anatomical structures of hepatic segment is of great importance for medical students. However, the complexity of the hepatic ducts' distribution makes this subject difficult to master.[4]

Many tools, such as anatomical atlases and corrosion casts, have been used to teach this anatomy. Among these, three-dimensional visualization (3DV) of computer hepatic segment models is a valuable aide because it vividly details

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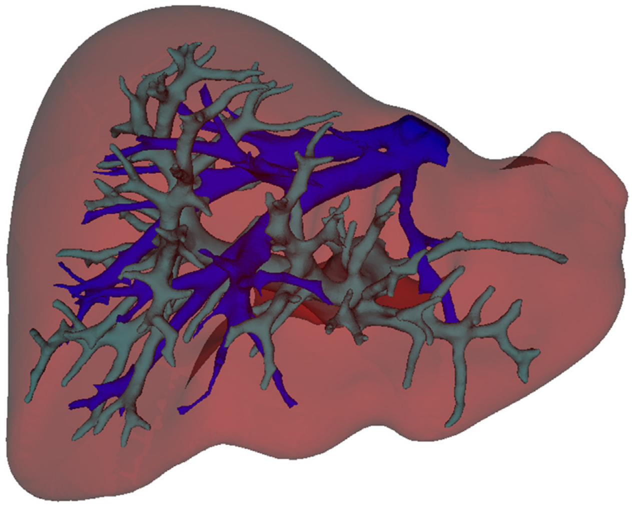

FIGURE 1. 3D computer models of the hepatic vessels and parenchyma. The cyan structure is the portal vein, the blue structure the hepatic vein, and the brown structure the hepatic parenchyma.

the internal hepatic segments and their structures.[5,6] Crossingham et al.[7] used interactive three-dimensional (3D) liver models to help teach trainees the liver's complex spatial anatomy. Jurgaitis et al.[8] further confirmed that computer-generated 3DVs of the liver images could teach clinical hepatic anatomy to medical students more effectively than two-dimensional atlases. However, 3DVs lack many of the haptic qualities of a physical specimen; therefore, they cannot completely replace physical teaching aids.

A feasible way to produce physical hepatic segment models is three-dimensional printing (3DP), or rapid prototyping production, because it can transfer the complex computer models to physical ones through additive production. This technology has been developed over decades and used in the medical field for years.[9-12] For example, physical models of the lung with arteries, veins, and tracheal bronchus, and pulmonary segments have been printed.[13] More recently, physical liver models with complex networks of vascular and biliary structures have been printed for preoperative planning in donor liver transplantation.[14] But so far, no hepatic segment models have been printed for anatomy teaching, nor have the effects of using such models for education been evaluated.

Therefore, in this study, we aimed to develop a novel 3DP hepatic segment model and evaluate the teaching effectiveness of 3DV and 3DP models compared with that of traditional instruction with anatomical atlases.

MATERIALS AND METHODS

3D Reconstructions of Hepatic Structures

A healthy candidate (female, 50-years old) was recruited. After a vascular contrast agent was injected, enhanced computed tomography (CT) scanning was performed with a Brilliance CT 64-channel scanner (Philips, Eindhoven, Netherlands) and compiled into sectional images. Then, 2 experienced radiologists examined the liver dataset to exclude liver disease. The upper abdomen data included 397 sectional images in 0.5-mm intervals with a pixel size of 0.684 mm.

The CT dataset was processed and edited using a medical image 3DV system originally developed by our university.[15-17] Interactive image processing functions, such as "Threshold," "Region growth," and "Edit," were used to segment the contours of the hepatic vessels and parenchyma. After 3D calculation, the 3D models of the hepatic parenchyma, portal vein, and hepatic vein were reconstructed (Fig. 1).

3DV Hepatic Segment Model

The computer models of the liver were then processed with the medical image 3DV system. After dividing the computer model of the parenchyma into 8 hepatic segments according to *Gray Anatomy*[18] and adding computer models of the portal and hepatic veins, the 3DV hepatic segment model was obtained. Each structure of the 3DV model was then exported as a .stl file (Fig. 2).

3DP Hepatic Segment Model

The .stl files of the parenchyma segments were processed in the software Geomagic 12 (3D Systems, Morrisville, NC). The parenchyma's upper surfaces were removed, with only the parenchyma's bottom surface and segmental partitions remaining. The 3D models of the portal and hepatic veins were added, and the 3D computer models of the hepatic segments were designed.

The 3D hepatic segment models were processed by the software ZEdit 3.21 (3D Systems, Rock Hill, SC) and assigned unique colors according to the 3DV model. After being virtually cut into thin layers of 0.0875-mm intervals in ZEdit 3.21, the data were transferred into a

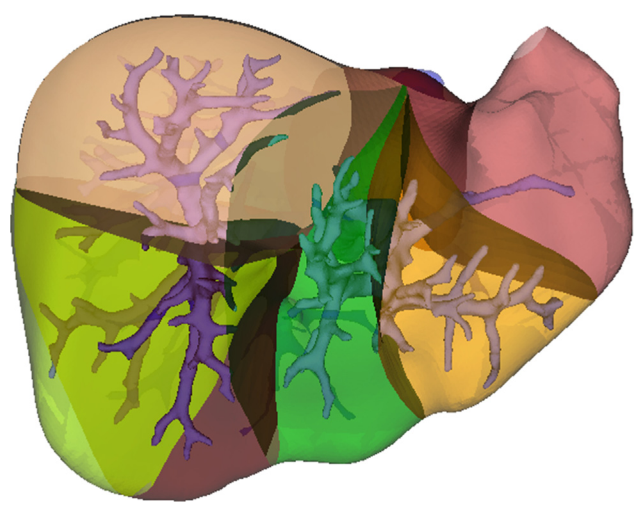

FIGURE 2. A 3DV model of the hepatic segments.