

Three-dimensional Educational Computer Model of the Larynx

Voicing a New Direction

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Objectives: To create a 3-dimensional (3D) educational computer model of the larynx, to assess the feasibility of this learning module on a Web-based platform, and to obtain student feedback on the module.

Design: Male and female adult cadaveric necks were scanned with microcomputed tomographic and magnetic resonance imaging scanners. Key structures were identified on each slice of the computed tomogram and/or magnetic resonance image and analyzed with a segmentation software package. Then, the images were exported into Microsoft Powerpoint. Visual text and audio commentary were added. Real cases of a child's larynx, an adult with a tracheostomy, and a patient with laryngeal carcinoma were included. The computer module was launched on a password-protected, Web-based platform.

Participants: Fifty-eight first-year medical students (38% male; mean [SD] age, 23 [1.8] years) were invited to evaluate the module and to complete a survey.

Results: Most students thought that the 3D computer module was effective (60%), clear (66%), and user friendly (72%); most students (81%) thought that it was easier to understand laryngeal anatomy when they could visualize it in 3D; and most students (83%) said that they would like lectures better if they were supplemented with 3D computer modules.

Conclusion: A 3D educational computer model of the larynx has been successfully created and warmly received by medical students.

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COMPUTER TECHNOLOGY has flourished over the past few decades and has revolutionized modern medical education. An emerging application of computer technology is the use of 3-dimensional (3D) educational computer tools in teaching human anatomy. These programs help to convey the 3D aspects of human anatomy that have been traditionally taught by human cadaver dissection laboratories and 2D anatomy atlases. The need for these tools in teaching human anatomy is growing for several reasons. First, the traditional teaching method of cadaver dissection may be less effective for some organs, such as the larynx. Some laryngeal structures are too small (eg, the arytenoid cartilages), and some are too delicate (eg, the recurrent laryngeal nerve). Dissecting these structures requires advanced dissection skills, practice, and time, which most medical students lack.¹ Second, there has been a decrease in the use of cadavers in anatomy medical school curricula.² One study from Australia has shown that 8 of the 11 Australian medical schools do not

use cadaver dissections to teach anatomy.² This trend may be attributable to the increasing cost and decreasing availability of cadaveric materials and time.³ Third, there has been a trend toward distance education and satellite campuses. Building and maintaining a second cadaver laboratory in a satellite campus would be associated with considerable practical and economic challenges.

Three-dimensional educational computer models address many of the disadvantages of cadaver dissections. A computer can magnify small, delicate structures; computer models are not affected by the shortage of human cadavers; computer models can be launched over the internet, making them ideal for distance education; and, finally, after development, the maintenance costs of such models are relatively inert. Although this computer technology exists, it has not been routinely incorporated into medical curricula. The larynx inherently has complex 3D anatomy and is therefore particularly amenable to this novel teaching methodology. To our knowledge, there has never been a 3D, interactive, Web-based computer learning mod-

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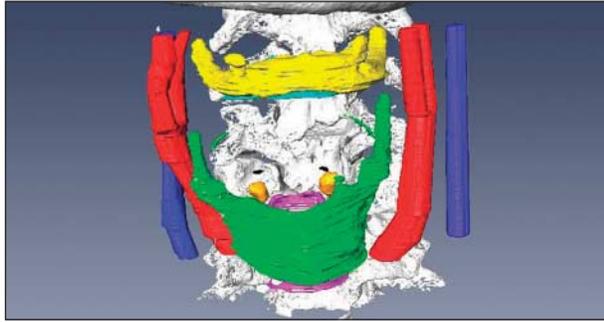


Figure 1. An example of the 3-dimensional educational teaching model.

ule of the larynx created by imaging human cadavers. Our objectives were (1) to create a 3D educational computer model of the larynx; (2) to assess the feasibility of this learning module on a Web-based platform; and (3) to obtain student feedback of the module.

METHODS

PHASE 1: CREATION OF THE 3D LEARNING MODULE

Adult male and female cadaveric necks were removed at autopsy and preserved in formaldehyde. The specimens were scanned using a flat-panel, conebeam laboratory microcomputed tomographic (CT) scanner (eXplore Ultra; GE Healthcare, London, Ontario, Canada).⁴ The scanner was operated at an x-ray tube voltage of 120 kV and a current of 20 mA, with 0.15 mm of added copper filtration. The transaxial and axial fields of view were approximately 14 cm and 10.2 cm, respectively. The scan protocol used 680 rows of 1024 pixels in the flat-panel detector. Each scan was acquired over an acquisition interval of 16 seconds, during which 1000 projection views were acquired in 1 gantry rotation. The 3D images were reconstructed with an isotropic voxel spacing of 153 μ m.

Magnetic resonance images (MRIs) were also acquired using a 3-T high-definition MRI scanner (Signa; GE Healthcare, Waukesha, Wisconsin) using a quadrature birdcage radio-frequency coil (diameter, 18 cm; length, 20 cm). Volumetric coverage of the human neck specimen was achieved using thin-slice 2D MRI, with a slice thickness of 1 mm and superior-inferior coverage of 100 mm (100 contiguous slices). The in-plane resolution was 0.25 mm. The MRI pulse sequence was a 2D, fast, spin-echo sequence, with proton density-weighted contrast achieved using a long repetition time (4000 milliseconds) and a short echo time (8.2 milliseconds). Fat suppression was applied to achieve better contrast with soft-tissue structures within the specimen.

The CT and MRI scans were exported in a standard Digital Imaging and Communications in Medicine (DICOM) format and analyzed with an Amira 4.1 segmentation software package⁵ (Visage Imaging, Carlsbad, California). Key structures were outlined on each slice of the CT and the MRI, thus giving the area of each structure. The areas on each slice were added together to render the 3D volume and shape of each structure. Each structure was assigned a unique label and color coded for identification. Each label could be individually toggled on to visualize the structure or toggled off to make the structure invisible. Structures could be manipulated and zoomed in and out within Amira 4.1. An example of the adult female laryngeal model is shown in **Figure 1**.

The 3D laryngeal model was exported as joint photographic experts group (jpg) files from Amira 4.1 into Micro-

- 1) Have you ever taken anatomy before?
 - a) Yes
 - b) No
- 2) What is your gender?
 - a) Male
 - b) Female
- 3) What is your age? _____
- 4) Before medical school, what is your highest level of education?
 - a) Bachelor of Sciences (3 years)
 - b) Honours Bachelor of Sciences (4 years)
 - c) Bachelor of Arts (3 years)
 - d) Honours Bachelor of Arts (4 years)
 - e) Masters of Sciences
 - f) Masters in a subject other than sciences
 - g) PhD of Sciences
 - h) PhD in a subject other than sciences
- 5) The optimal time to spend on this 3D computer model of the larynx is:
 - a) 15 min
 - b) 30 min
 - c) 45 min
 - d) 1 hour
 - e) other please specify: _____
- 6) Do you regularly engage in any of the following activities: painting, sculpture, carpentry, or 3D graphic design? (yes or no)
- 7) How much experience do you have playing 3D video games?
 - a) Never (I have never played 3D video games)
 - b) Some (I play, or have played in the past, not more than once a month)
 - c) Moderate (I play, or have played in the past, more than once a month but less than 5 times per month)
 - d) Lots (I play, or have played in the past, 5 times per month or more often)

Please answer the following questions by assigning a rating based on the following scale:

- a) Strongly agree
- b) Moderately agree
- c) Somewhat agree
- d) Neutral
- e) Somewhat disagree
- f) Moderately disagree
- g) Strongly disagree

- 8) The 3D computer module was effective in helping me understand laryngeal anatomy.
- 9) The 3D computer module was clear.
- 10) The 3D computer module was user friendly.
- 11) The 3D computer module was too long and too detailed.
- 12) I enjoyed learning laryngeal anatomy with the 3D computer module.
- 13) I would prefer lectures if they were supplemented with 3D computer modules.
- 14) I would prefer if lectures were replaced by 3D computer modules.
- 15) I prefer to learn on my own by studying from notes and textbooks.
- 16) It is easier for me to understand laryngeal anatomy when I can visualize them in 3D with the computer module.
- 17) I prefer learning on the computer than on hard copy.
- 18) I prefer learning at my own pace than at a pace determined by a lecturer/teacher.
- 19) I prefer being taught by a computer than by a human being.
- 20) I feel comfortable using a computer.

Please share any comments you may have:

Figure 2. Survey for users of the 3-dimensional (3D) educational computer model of the larynx.

soft Powerpoint (Microsoft, Seattle, Washington). Three special cases were included: a child's larynx, an adult with laryngeal cancer, and an adult with a tracheostomy. These 3 models were created from real patients with clinical CT scans performed at the London Health Sciences Centre, London, Ontario, Canada.

PHASE 2: LAUNCHING THE MODULE ON A WEB-BASED PLATFORM FOR MEDICAL STUDENTS

The 3D computer module of the larynx was launched in January 2008 and presented to first-year medical students at the University of Western Ontario, London. The module was distributed through a password-protected online Web site that is maintained by the Department of Information Technology at the university. Volunteers were invited by e-mail and class announcements to go through the module and then to complete a survey on their opinions of the module (**Figure 2**). No remuneration was offered and participation was voluntary. All

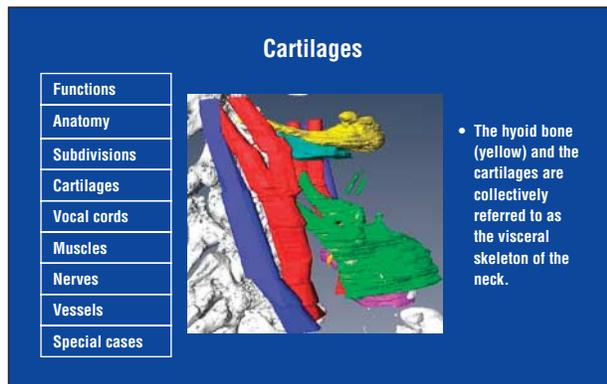


Figure 3. This slide from the computer module shows the imported 3-dimensional model and the sidebar for navigation on the left. Visual text was added on the right for visual learners, and audio commentary was added for auditory learners.

aspects of this study were approved by the research ethics board at the University of Western Ontario.

RESULTS

PHASE 1: CREATION OF THE 3D LEARNING MODULE

Five 3D models were created: an adult male, an adult female, a child's larynx, a patient with a tracheostomy, and a patient with laryngeal carcinoma. Visual text was added for visual learners and audio commentary was added for auditory learners to explain the anatomy of the images. A sidebar was added so that the students could navigate through the computer module. Hyperlinking was also available within the text so that students could choose to learn more about a topic. Topic selections included functions, anatomy, subdivisions, cartilages, vocal cords, muscles, nerves, and vessels (**Figure 3**). Clinical vignette icons were added to link anatomy with clinical scenarios. For example, the epiglottis slide was linked to the clinical vignette of epiglottitis (**Figure 4**). Another clinical scenario involved a patient with laryngeal carcinoma (**Figure 5**). Endoscopic photographs were also included so that the students could correlate textbook anatomy to clinical anatomy. A sample video of the adult larynx is available at <http://www.archoto.com>.

PHASE 2: LAUNCHING THE MODULE ON A WEB-BASED PLATFORM FOR MEDICAL STUDENTS

This module has been launched successfully on a password-protected online Web site. One hundred forty-seven first-year medical students were invited to participate in our study. Fifty-eight students (39%) evaluated the computer module and completed the survey. Twenty-two of the students (38%) were male, and the mean (SD) age was 23 (1.8) years. Thirty-four students (59%) had previously taken anatomy, and 52 students (90%) had science degrees. The survey results are summarized in the **Table**. Most students (60%) thought that the 3D computer module was effective in helping them understand

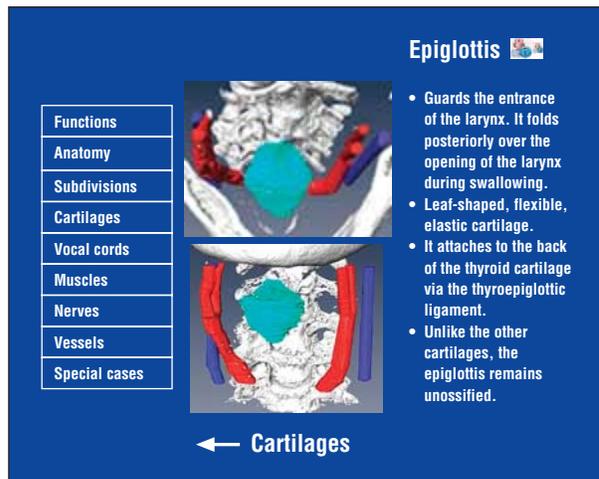


Figure 4. This slide from the computer module shows the epiglottis from different viewpoints in the center. On the left, there is a sidebar for navigation. On the right, there is text to explain the diagrams. The clinical vignette icon, shown in the top right corner, links the epiglottis slide to the case of epiglottitis. The "Cartilages" link on the bottom brings the user back to the main chapter on cartilages.

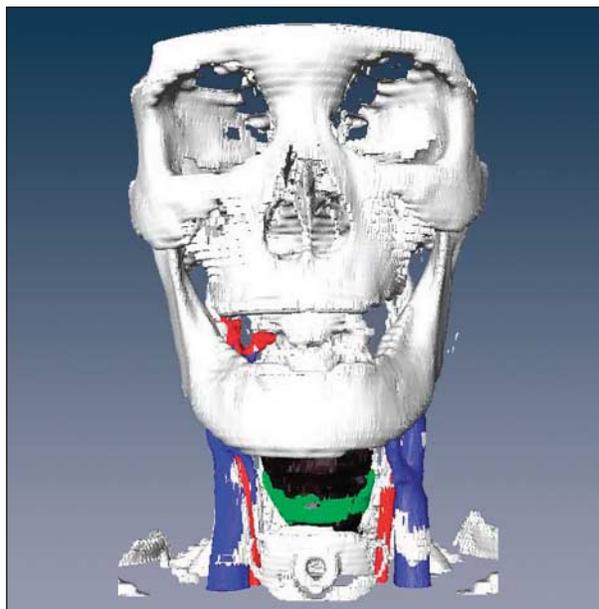


Figure 5. Three models were built based on actual cases: a child's larynx, an adult with a tracheostomy, and an adult with laryngeal carcinoma. This model was based on a clinical computed tomographic scan of a patient with laryngeal carcinoma. The tumor is shown in black.

laryngeal anatomy; most thought that the 3D computer module was clear (66%) and user friendly (72%); most (48%) enjoyed learning laryngeal anatomy with the 3D computer module; most (81%) thought that it was easier to understand laryngeal anatomy when they could visualize it in 3D with the computer module; and most (83%) said that they would prefer lectures if they were supplemented with 3D computer modules.

Some positive comments from the students were as follows:

- "I like the perspectives offered by a 3D model that are not clear even in good textbooks."
- "I really like the 3D aspect because all our dia-

Table. Survey Results From First-Year Medical Students Who Evaluated the Computer Module

Survey Results	No. (%)		
	Agree	Neutral	Disagree
The 3D computer module was effective in helping me understand laryngeal anatomy	35 (60)	12 (21)	11 (19)
The 3D computer module was clear	38 (66)	6 (10)	14 (24)
The 3D computer module was user friendly	42 (72)	6 (10)	10 (17)
I enjoyed learning laryngeal anatomy with the 3D computer module	28 (48)	16 (28)	14 (24)
I would prefer lectures if they were supplemented with 3D computer modules	48 (83)	6 (10)	4 (7)
It is easier for me to understand laryngeal anatomy when I can visualize it in 3D with the computer module	47 (81)	4 (7)	7 (12)

Abbreviation: 3D, 3-dimensional.

grams and notes are in 2D, and it's so hard to place everything together and it's VERY hard to be oriented."

- "Great model. Helped me understand a complex, small, detailed structure. The movies are cool."

Negative comments fell into the following 3 categories:

- Technical problems
"I had problems accessing the videos, which made me less willing to complete the module."
- Pace of the videos
"I felt that the pace of the videos (speaking and images) were actually way too fast."
- Volume of information
"Way too much information and too difficult to understand if this was the first thing you learned about this topic."

COMMENT

LITERATURE REVIEW

Three-dimensional imaging educational tools have been used in some areas of head and neck anatomy. Nicholson et al¹ built a 3D computer model of the ear. They chose the ear because the middle and inner ear structures are too small, delicate, and complex to dissect in a cadaver. They also believed that the ability to manipulate the 3D structures of the ear in space were critical in learning the 3D anatomical relationships in the ear. They built their model from high-resolution MRIs. They conducted a randomized controlled trial on medical students and proved the efficacy of their model in teaching ear anatomy.

Rubin et al⁶ built a 3D laryngeal model from MRIs and CTs of a cadaver larynx. Their 3D structure was made up of multiple units, with each unit being an individual muscle, cartilage, or ligament. The advantages of their model were that (1) structures could be viewed in any

plane and from any direction; and (2) the larynx could be rotated along any axis. The disadvantages of their model were that (1) it was very labor intensive to build; (2) it was based on only 1 cadaver larynx and any abnormalities of that 1 larynx would therefore be illustrated in the model; (3) although different views of the larynx could be seen, the model could not be manipulated in real time; and (4) although the goal of was medical education, its efficacy was never tested on students. Their model also was not launched on a Web-based platform.

Rolland et al⁷ built an endotracheal intubation training tool for medical students, residents, physician assistants, nurse-anesthetists, prehospital care personnel, and other allied health professionals. Their tool uses an "augmented reality visualization" system with a head-mounted projective device and a mannequin-based simulator. When an attempt is made to intubate the mannequin, the head device allows visualization of the internal airway anatomy to determine if the intubation is successful.

Fried et al⁸ built a virtual laryngoscopy model that showed 3D views from inside the larynx. They used CTs and MRIs from 3 patients: 1 with a normal larynx, 1 with squamous cell carcinoma, and 1 with posterior laryngeal glottic stenosis. Their goal was not to use their tool for medical education but to clinically apply their tool to preoperative planning, staging, and intraprocedural guidance for biopsies.

Three-dimensional imaging educational tools have been used to teach anatomy in other areas of the body. Garg et al⁹⁻¹¹ conducted 3 randomized controlled trials on the efficacy of an interactive 3D educational computer model of the carpal bones. The intervention group used a 3D model that showed multiple views of the carpal bones. The control group was limited to certain "key" views of the carpal bones, such as dorsal and palmar views, which are typically shown in anatomy atlases. From these 3 studies, the authors concluded that the "dynamic display of multiple orientations provided by computer-based anatomy software may offer minimal advantage to some [ie, spatial] learners."¹¹

Hariri et al¹² conducted a randomized controlled trial on the use of a shoulder arthroscopy simulator to teach shoulder anatomy. The control group was shown 2D views. Unfortunately, both groups scored poorly on the anatomy tests, and no statistical significance was found between the groups. The study, however, may have been limited by a small sample size and may have lacked statistical power.

ADVANTAGES OF OUR MODEL

In our study, we created a 3D educational computer model of the larynx. Our module has several advantages. Because it is 3D, it shows structures from different viewpoints. It has high fidelity based on current technology. It is interactive and self-paced by the student instead of being paced by a lecturer. It is based on more than 1 cadaver/patient so that it illustrates the variability in human anatomy. This is 1 key advantage of our model over the model of Rubin et al.⁶ Furthermore, our model also includes special cases and clinical vignettes customized

to the clinical scenarios that may be experienced by students in practice. It is also Web based and accessible by any student on the World Wide Web.

DISADVANTAGES OF OUR MODEL

There are some disadvantages to our model. It cannot be manipulated on a standard computer. The segmentation tool that was used to create the model is not readily accessible to students and therefore requires a somewhat specialized platform for viewing and manipulation. The model can only be manipulated on computers with the software installed. Building the model is time and labor intensive.

STUDENT FEEDBACK

Our computer module was warmly received by the medical students. Most students thought that the key aspect of the module was the 3D representation of the larynx. Most students also thought that computer modules could supplement, but not replace, traditional lectures. Our goal was to create a supplement to the traditional curriculum, so we believe that our model was initially successful.

We also believe that we can address the negative comments raised by the students. Because our computer module was launched within the password-protected Web site that is maintained by the university, the Department of Information Technology took responsibility for any technical problems. Technical assistance was available to students via e-mail. We have also slowed the pace of the videos to prevent overwhelming the students. In the future, we may be able to allow better student interaction and pacing of the particular models. Also, for our pilot study, we created an artificial environment in which the students had not yet received their formal ear, nose, and throat lectures. Therefore, the students may have found the volume of information in the computer module overwhelming. We envision that future medical students would receive their ear, nose, and throat lectures first and then use the module as an adjunct; thus, with some background in laryngeal anatomy, the students will be able to manage the volume of information in our module.

In conclusion, we have successfully created a 3D educational Web-based computer module of the larynx that has been warmly received by first-year medical students. For future directions, we plan to conduct a randomized, controlled trial to assess the efficacy of this computer module for teaching laryngeal anatomy to medical students.

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Author Contributions: Dr Hu had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Hu, Wilson, Ladak, Haase, and Fung. *Acquisition of data:* Hu and Ladak. *Analysis and interpretation of data:* Hu and Fung. *Drafting of the manuscript:* Hu and Fung. *Critical revision of the manuscript for important intellectual content:* Wilson, Ladak, Haase, and Fung. *Obtained funding:* Hu, Ladak, and Fung. *Administrative, technical, and material support:* Hu, Wilson, Ladak, Haase, and Fung. *Study supervision:* Wilson, Ladak, and Fung.

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