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Evaluation of a Three-Dimensional Educational Computer Model of the Larynx: Voicing a New Direction

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ABSTRACT (Email Abstract) OBJECTIVE:

To evaluate a novel method of teaching laryngeal anatomy.

DESIGN:

Prospective, randomized, controlled trial.

SETTING:

University educational program.

METHODS:

Computer model development: A three-dimensional (3D) educational computer model of the larynx was created from high-resolution computed tomography and magnetic resonance images of cadaveric necks using segmentation software (*Amira*) (Visage Imaging, Inc., Carlsbad, CA). E-learning authoring software (*Articulate*, Articulate Global, Inc, New York, NY) then was used to make the model interactive and multimedia. The model was launched on a Web-based platform. Model evaluation: One hundred students (age 23.8 ± 2.2 years; 55% male) were randomized to either the 3D computer model group (3D group) (n = 50) or the standard written instruction group (SWI group) (n = 50).

MAIN OUTCOME MEASURES:

The primary outcome measure was the score on a 20-question laryngeal anatomy test; the secondary outcome measure was a student opinion questionnaire.

RESULTS:

The mean score on the laryngeal anatomy test was 14.2 ± 2.8 (72.0 ± 15.1%). The mean score for the 3D group was 13.6 ± 3.0 (67.0 ± 16.1%) versus 14.8 ± 2.5 (76.0 ± 12.7%) for the SWI group (t = 2.194, df = 98, p < .031). A majority of students felt that the 3D model was effective, clear, user-friendly, and a preferred supplement to traditional methods of instruction. The 3D group rated the computer model more enjoyable than the SWI group.

CONCLUSIONS:

A 3D educational computer model of the larynx was not shown to be superior to written lecture notes in its efficacy in teaching anatomy; however, it was judged to be a preferred and valuable supplement to traditional teaching methods.

Translated Abstract Sommaire OBJECTIF:

L'étude avait pour objectif d'évaluer une nouvelle méthode d'enseignement de l'anatomie du larynx.

TYPE D'éTUDE:

Il s'agit d'une étude prospective, comparative, è répartition aléatoire.

CADRE:

L'étude a été réalisée dans le cadre d'un programme universitaire d'éducation.

MéTHODE:

Conception du modàle informatique – Un modàle informatique, éducatif, en trois dimensions (3D) du larynx a été créé è partir d'images du cou de cadavres, obtenues par résonance magnétique et par tomodensitométrie è haute résolution è l'aide d'un logiciel de segmentation (*Amira*, Visage Imaging, Inc.; Carlsbad [CA]). Un logiciel auteur d'apprentissage en ligne (*Articulate*, Articulate Global, Inc.; New York [NY]) a ensuite été utilisé pour rendre le modàle interactif et multimédia, apràs quoi celui-ci a été lancé sur une plateforme Web. Évaluation du modàle – Cent étudiants (âge: 23.8 ± 2.2 ans; hommes: 55%) ont été dirigés au hasard vers le groupe d'évaluation du modàle informatique 3D (groupe 3D) (n = 50) ou vers le groupe d'enseignement écrit ordinaire (groupe EEO) (n = 50).

PRINCIPAUX CRITàRES D'éVALUATION:

Le principal critàre d'évaluation consistait en les résultats è un examen comptant 20 questions sur l'anatomie du larynx, et le critàre secondaire d'évaluation, en un questionnaire sur l'opinion des étudiants.

RéSULTATS:

Le résultat moyen è l'examen sur l'anatomie du larynx était de 14.2 ± 2.8 (72.0 ± 15.1%). Le résultat moyen dans le groupe 3D s'est établi è 13.6 ± 3.0 (67.0 ± 16.1%) contre 14.8 ± 2.5 (76.0 ± 12.7%) dans le groupe EEO (t = 2.194, df = 98, p < .031). La plupart des étudiants trouvaient le modàle 3D efficace, clair et convivial, et qu'il constituait un supplément de prédilection aux méthodes traditionnelles d'enseignement. Le groupe 3D aimait mieux le modàle informatique que le groupe EEO.

CONCLUSIONS:

Le modàle informatique, éducatif, en trois dimensions du larynx ne s'est pas montré plus efficace que les notes de cours écrites dans l'enseignement de l'anatomie; par contre, il était considéré comme un supplément précieux et de prédilection aux méthodes traditionnelles d'enseignement.

Keywords
computer modeling, larynx, medical education, three-dimensional imaging.

Teaching human anatomy has been the foundation of health sciences curricula for many decades. A survey of American postgraduate residency directors showed that they rank anatomy as the most important basic science.[1] Consequently, the majority of residency programs report that anatomy is either extremely important or very important to the mastery of their discipline., [1]

Despite the importance of human anatomy to the education of many health professionals, the number of hours dedicated to gross anatomy in medical school curricula has decreased over the years. A survey of North American medical schools revealed that in 1902, an average of 549 hours were dedicated to gross anatomy. This average dropped to 330 hours by 1955 and to 190 hours in 1991, with further reductions to 165 hours reported in 1997.[1,2] The reasons for this trend are multifactorial. In recent years, there has been a shortage of qualified instructors to teach human anatomy, as well as increased student enrolment in medical schools., [3] There also was a rapid expansion of medical knowledge in the twentieth century; however, the total time for medical school education has not changed., [2] As a result, curricula hours have been redistributed to accommodate more material and teach more efficiently.

The time-honoured method of teaching human anatomy through cadaver dissection is well acknowledged. It is a widely held belief that cadaver dissection provides students with an important three-dimensional (3D) view of human anatomy[4] and an appreciation of inherent anatomic variability. Cadaver dissection, however, has decreased in medical school curricula in the United States,, [5] the United Kingdom,, [4] Australia,, [6] and Holland., [7] There are several reasons suggested for this trend. First, it is expensive to maintain a cadaver dissection laboratory., [2] Second, there is decreasing availability of cadaveric materials., [2] Third, cadaver dissections are time consuming, [2] and may not be the most efficient way to teach human anatomy., [8] Fourth, cadaver dissections are not good for demonstrating surface anatomy, nervous system anatomy, skeletal anatomy, or the anatomy of delicate organs,, [2] such as that of the larynx. Some anatomic structures are too small to see or isolate, such as the vocalis muscle or the recurrent laryngeal nerve. Moreover, most students lack the advanced dissection skills and the practice time required to dissect these structures., [9] Finally, in recent years, there has been a trend toward distributed medical education. A second cadaver laboratory in a satellite campus could be associated with significant practical and economic challenges., [10] This combination of factors has led to the development of 3D computer models to teach human anatomy.

Computer models address many of the disadvantages associated with traditional cadaver dissection. The maintenance costs of computer models are fairly low and stable. Computer models are not affected by the increasing costs or decreasing availability of human cadavers, nor are ethical considerations raised. Computer models can be used by students outside of formal lecture time so that they do not consume valuable classroom hours. Small, delicate anatomic structures can be magnified by computer to enhance the student's understanding. Surface anatomy, nervous system anatomy, and skeletal anatomy can be displayed quite well via computerized renditions. As technology continues to expand, the Internet provides a globally accessible platform for launching these computer models, making them ideal for distributed medical education. Furthermore, computer models can convey the 3D aspects of human anatomy that traditionally have been taught by cadaver dissections.

In a previous article, we described the creation of an interactive, Web-based, 3D computer learning model of the larynx constructed using images of human cadavers.[10] The purpose of the present study was (1) to evaluate the efficacy of this model in teaching laryngeal anatomy and (2) to assess students' impressions of this novel educational approach.

Methods Computer Model Development

A 3D educational computer model of the larynx was created from high-resolution computed tomography (CT) and magnetic resonance images of two cadaveric necks (one male and one female) using commercially available segmentation algorithms in the *Amira* 4.1 software package (Visage Imaging, Inc., Carlsbad, CA). An example of the adult female laryngeal model is depicted in **fig1**. *Articulate* (Articulate Global, Inc, New York, NY), an e-learning authoring software tool, then was used to make the model interactive and multimedia. The model was launched on a Web-based platform through a password-protected online website, WebCT Vista (Blackboard Inc, Lynnfield, MA). More details on the computer model development can be found in our previous publication.[10]

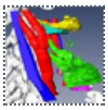

Figure 1
An example diagram of our three-dimensional educational computer model.

Study Design

We conducted a prospective, randomized controlled trial.

Population Under Study

The study included anatomy students in the schools of Medicine, Dentistry, and Physical Therapy.

Outcome Measures

The primary outcome measure was each participant's score on a 20-item Web-based test that assessed the student's level of knowledge of laryngeal anatomy. The secondary outcome measure was each participant's responses to a student opinion questionnaire that addressed various aspects of the 3D-based method of instruction.

Laryngeal Anatomy Test

Because a detailed review of the literature did not reveal any standardized tool for the evaluation of knowledge on laryngeal anatomy, a test was developed specifically for the purposes of this project. Our laryngeal anatomy test was written by two anatomy professors (T.W., P.H.), after which all questions were evaluated by an experienced and board-certified otolaryngologist (K.F.), an otolaryngology resident (A.H.), and a second-year medical student. This test then was assessed in a pilot study involving 23 medical students.[10] The first 13 questions were factual questions, whereas the last 7 questions were questions that evaluated each participant's understanding of 3D spatial relationships or their ability to identify a structure from a diagram that required mental rotation (see the **Appendix** for examples of [I] a factual question and [II] a 3D question). Each student's final score was the number of questions answered correctly.

Student Opinion Questionnaire

The survey was assessed on a trial basis by 58 medical students in a pilot study.[10] This survey collected demographic information and student opinions using a 5-point Likert scale indicating each respondent's degree of agreement with statements that addressed various aspects of the teaching material. Available responses were 5 = strongly agree; 4 = agree; 3 = neutral; 2 = disagree; and 1 = strongly disagree.

Model Evaluation

Participants were recruited by e-mail and through class announcements and randomized into two groups by means of a random number generator. The first group was identified as the 3D computer model group (3D group). The second group was identified as the standard written instruction group (SWI group). Those in the SWI group used the same text as those in the 3D group, with the exception that all of the 3D images were replaced with static two-dimensional (2D) images of the same structures. The text was displayed on a computer screen so that the medium was consistent between groups. All participants were given 45 minutes to study laryngeal anatomy within their respective group. Afterward, they were given 15 minutes to complete the 20-question test on laryngeal anatomy and then complete the student opinion questionnaire.

Statistical Analysis

Following acquisition of all participant data, statistical analysis was performed using a commercially available software package (*SPSS* version 16, SPSS Inc., Chicago, IL, 2007). Primary analyses included the generation of measures of central tendency (means, standard deviations) for demographic variables and total scores obtained on the anatomy test in each experimental group (3D group vs SWI group). Overall scores between the groups were compared using a one-way analysis of variance with an a priori probability level set at .05. To determine if differences existed between the study groups, we also conducted Student *t*-tests for nonpaired samples. Again, for these *t*-tests, the probability level was set at .05.

The student opinion survey was first analyzed with frequency charts. To determine differences in responses between the 3D and SWI groups, we calculated a mean response by quantifying the scaled response. As noted, a higher mean represented a more favourable response to the statement. Means were compared with the Student *t*-tests for nonpaired samples with an a priori probability level set a .05. A Bonferroni correction factor was also calculated for these comparisons.

All aspects of this study were approved by the Research Ethics Board at the University of Western Ontario (REB #13062E and #13454E).

Results

One hundred students (age 23.8 ± 2.2 years; 55% male) volunteered as participants for the study. Fifty students were randomized to each group (3D group vs SWI group). The mean age among those in the SWI group was 24.4 ± 2.47 years versus 23.1 ± 1.56 years in the 3D group (t = .312, df = 98, p < .02). Other than age, there were no statistically significant differences between the two groups, as shown in **Table 1**. On initial inspection, the SWI group had a larger number of medical students than the 3D group; however, no significant differences in test scores were identified based on educational level or class.

Table 2 shows the mean raw scores for the 20-question test on laryngeal anatomy. The mean total score for the 3D group was 13.6 ± 3.0 (67.0 ± 16.1%) versus 14.8 ± 2.5 (76.0 ± 12.7%) for the SWI group, a difference that was significantly different (t = 2.194, df = 98, p < .031). The 3D score is the sum of the scores of the seven 3D questions. The mean 3D score for the 3D group was 3.5 ± 1.4 (50.0 ± 20.0%) versus 3.9 ± 1.4 (65.0 ± 20.0%) for those in the SWI group, and this difference was not found to be significant.

Table 1
Demographic Characteristics of the Two Groups

Table 2
Scores on the 20-Question Test on Laryngeal Anatomy

Regarding the student opinion survey, most students (61%) indicated that the 3D computer model was effective at helping them learn and understand laryngeal anatomy. A small majority of students felt that the 3D model was clear (53%) and user-friendly (54%). Most students would prefer lectures if they were supplemented with 3D computer models (73%) but not replaced by them (72%). The majority of students (83%) felt that it was easier for them to understand laryngeal anatomy when they were provided with the opportunity to visualize laryngeal structures in 3D using the computer model. Collectively, those who were exposed to the 3D method of anatomy instruction indicated a strong preference for it.

fig2 presents differences in responses to the student opinion survey between the 3D and SWI groups. Two differences were noted. The 3D group rated the computer model more enjoyable than the SWI group (p = .02). The 3D group felt more strongly that lectures should not be replaced by computer models than the SWI group (p = .01). The rest of the responses were similar between the two groups.

Figure 2
Results of the student opinion survey. To determine differences in responses between the three-dimensional (3D) and standard written instruction (SWI) groups, we calculated a mean response by quantifying the response on the 5-point Likert scale: 5 = strongly agree; 4 = agree; 3 = neutral; 2 = disagree; 1 = strongly disagree. Thus, a higher mean represented a more favourable response to the statement. Only two differences in responses were noted. The 3D group rated the computer model more enjoyable than the SWI group (p = .02). The 3D group felt more strongly than the SWI group that lectures should not be replaced by computer models (p = .01).

Discussion

An emerging application of computer technology is the use of 3D educational computer models to teach complex human anatomy. These models should have an intuitively distinct educational advantage over traditional lectures, textbooks, and cadaver dissections. These advantages, however, have not always been demonstrated by previous research. Interestingly, our study demonstrated that a 3D computer model of the larynx does not confer educational advantage to health science students but that students tend to like this approach.

Our findings are consistent with the equivocal results derived from previous studies. Garg and colleagues conducted three studies with a 3D computer model of wrist carpal bones and failed to identify any educational advantage of the model.**11–13** They concluded that multiple orientations had a small benefit for learners with good spatial ability but substantially increased the educational load for learners with poor spatial ability. Some authors suggested that humans synthesize spatial information presented in oblique orientations by first rotating it back to the standard view and then learning the visual information., **14** A student with poor spatial ability may be overwhelmed by multiple oblique views and have difficulty mentally rotating the image back to standard views and, therefore, be disadvantaged by multiple views., **15** In our study, we attempted to gauge spatial ability in our survey in the same way as Nicholson and colleagues by asking students if they engage in any other activities that require spatial ability, such as painting, sculpting, carpentry, or 3D design., **9** None of these variables appeared to significantly impact their scores on their laryngeal anatomy test.

A randomized controlled study testing the effectiveness of a 3D model of the middle and inner ear by Nicholson and colleagues did demonstrate some educational advantage to medical students.**9** Their study, however, was different from the present study in several ways. First, the middle and inner ear are anatomically small relative to the larynx and wrist carpal bones. As such, the model was able to fully capitalize on the computer's ability to magnify microscopic structures. Second, it may be easier to illustrate the larynx or carpal bones in two dimensions than the structures of the middle and inner ear. Third, participants in the study by Nicholson and colleagues were provided with a fully interactive model in which users could rotate 360° in three dimensions in real time. In our study and the Garg and colleagues studies,, **11–13** the models offered limited interactivity. Lastly, the sample size in the Nicholson and colleagues study was small, generating data on only 57 subjects., **9** Our study had a sample size of 100.

Another factor to consider is learning style as it may play a substantial role in the acquisition of complex anatomic knowledge. New material may be learned more effectively if it is presented in a format that is conducive to the learner's strengths.**16** In the present study, the majority of students had science backgrounds and may be more accustomed to rote memory of facts as a learning style and not visuospatial learning. Kolb suggested that specific learning “modes” drive the effectiveness of learning and that concrete experience and active experimentation are primary., **17,18** Simply put, perhaps the optimal method of teaching complex visuospatial anatomic relationships to novice learners in the health sciences is not using a 3D model but, rather, using concrete statements, simple 2D diagrams, and didactic teaching. Our observation that performance was better in the SWI group may reflect not only learning style but the expected and common approach to education in the sciences.

Our 3D computer model can be considered a high-fidelity model and the standard written method of instruction a low-fidelity model. Previous research into surgical education for junior students has shown that well-designed low-fidelity models confer the same benefit as training on high-fidelity counterparts. For example, Grober and colleagues compared a high-fidelity live rat vas deferens model versus a low-fidelity silicone tubing model while teaching junior surgical residents how to perform microvascular anastomoses of the vas deferens.**19** While instructing medical students in how to remove midureteral stones, Matsumoto and colleagues compared a high-fidelity commercial machine with a low-fidelity model consisting of a plastic cup, Penrose drains, and straws., **20** Anastakis and colleagues compared a high-fidelity human cadaver model versus a low-fidelity bench model to train junior surgical residents in basic surgical procedures such as chest tube insertion., **21** Friedman and colleagues similarly compared a high-fidelity full-scale simulator with a low-fidelity corrugated tubing model while teaching junior anesthesiology residents how to perform a cricothyrotomy., **22** Finally, for the instruction of respiratory therapists regarding fibre-optic oral intubations, Chandra and colleagues compared a high-fidelity computerized virtual reality bronchoscopy simulator with a low-fidelity nonanatomic model., **23** All five studies concluded that providing technical skills training to novice students using a low-fidelity model is just as effective as such training with a high-fidelity model. Our study is consistent with these previous studies. Our low-fidelity model of standard written instructions was at least as effective as our high-fidelity 3D computer model at teaching laryngeal anatomy to junior students.

The effect of both bench model fidelity and level of training was investigated by Sidhu and colleagues.**24** Their study compared a high-fidelity human cadaver model with a low-fidelity plastic model for teaching junior and senior surgical residents to perform vascular anastomoses. They found that the senior surgical residents performed better with the high-fidelity model. In comparison with previous studies, these surgical residents were not novices, and all had previous experience with vascular anastomoses. The investigators concluded that novice students need to learn the basic motor tasks and are overwhelmed by the extra information provided by a high-fidelity model. In contrast, more senior students appear to benefit from the extra information that a high-fidelity model provides. Our study population consisted of novice students, which could explain why our low-fidelity model generally was as effective as our high-fidelity one.

Overall, students reported positive impressions of the 3D computer model, and this result also is consistent with past studies.**10,19,25,26** Clausner and Wilson created a 3D stereoscopic model of the wrist., **25** Although the 3D model conferred no educational advantage, their survey indicated a preference to learn using this modality in the future. Corton and colleagues compared an interactive, computer-based learning module with a conventional, paper-based format to teach pelvic anatomy to obstetrics residents., **26** Although improvement in anatomy knowledge was not significantly different, students perceived computer-assisted learning as better for learning anatomic information. A similar finding was reported by Grober and colleagues; an overwhelming majority of participants (90%) preferred working with a high-fidelity model and rated it significantly better in terms of overall educational value., **19** The importance of student preference should not be overlooked. It is important to engage students and maintain their interest and enthusiasm for learning., **19**

Our study has several strengths. First, we recruited a relatively large sample of 100 students, whereas other similar published studies in medical education typically have used smaller samples of 22,**22** 23,, **21** 27,, **24** 28,, **23** 40,, **20** 50,, **19** and 57., **9** Second, we sought to tightly control potential confounding variables, including (1) time, (2) content, and (3) medium. All other unknown variables were controlled for by randomization. Essentially, the only variable we tested was the influence of 3D versus 2D images. Third, we specifically created and designed our own educational models of the larynx for this study instead of using a commerically available model.

Our study also has limitations. First, we included medical, dental, and physical therapy students, creating what might be criticized to be an overly heterogeneous population. However, our data across the different fields of study show that the students were similar in age, gender, and educational background. Furthermore, on randomizing students to the two arms, with the exception of age, the two groups were statistically similar. With respect to age, the statistical difference noted was driven by the random inclusion of five students who were 30 years old in the SWI group, whereas all others were ≤ 28 years. In contrast, the 3D group had only a single student who was older than 27 years. Given the relatively narrow age range of all students (20–30 years), the impact of this statistical difference was felt to be insignificant. Second, our study only tested short-term memory and not the long-term retention. Owing to logistical challenges, we were not able to repeat the testing to assess long-term retention; but this area warrants further research. Third, we did not extensively assess the validity of our primary outcome measure, the test on laryngeal anatomy. A review of the literature did not reveal any validated tool assessing laryngeal anatomy knowledge. However, we did attempt to confirm construct validity by having three experts evaluate the instrument's content. We also conducted a pilot study on the test.**10** This limitation is shared by other studies in medical education., **10,25** Future directions for research could include investigating the effects of long-term retention, spatial ability, learner experience level, and student preferences.

Conclusions

In conclusion, a 3D, interactive, Web-based, educational computer model of the larynx was created and evaluated in a prospective, randomized, controlled trial. Although its efficacy at teaching laryngeal anatomy does not appear to be superior to written lecture notes, students believe that it is effective, clear, user-friendly, and a preferred supplement to traditional teaching methods. Hence, computer models of this type may meet many of the evolving needs of medical education and have been received positively by students.

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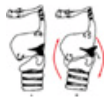
Appendix

This 20-question test on laryngeal anatomy was the primary outcome measure of the study. Question I is an example of a factual question. Question II is an example of a 3D question. Asterisks indicate the correct answer.

1. The largest cartilaginous portion of the larynx is
2.
    1. cricoid cartilage
    2. arytenoid cartilages
    3. thyroid cartilage*
    4. epiglottis
3. The muscle best suited for the movement from position A to position B, depicted in the diagram, is
4.
    1. sternothyroid
    2. thyroarytenoid
    3. interarytenoid
    4. cricothyroid*



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