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3D Printed Larynx Used to Improve Student Learning

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Abstract

Students enrolled in anatomy and physiology courses typically rely on two dimensional images and fixed preserved tissues to understand anatomical structures and functions. The current project aimed to expand the tactile and kinesthetic experience in the classroom by utilizing current advances in 3D modeling and 3D printing. The initial prototype of a human larynx was selected and designed for a course that focused on anatomy and physiology for human communication. The prototype was designed with two innovative concepts. First, the model was composed of both rigid and flexible materials. Second, the model was assembled to allow movement of structures and demonstration of physiology through laryngeal muscle manipulation. Fourteen students participated in a study session to evaluate whether the model improved student learning compared to existing study materials. Students were randomly assigned to two laryngeal anatomy and physiology study sessions. One group used an existing web resource while the other group used the 3D printed model. Both groups took a 12 question pre-test before their assigned activity. After 20 minutes of the assigned activity students took a 12 question post-test. Each test included 3 closed-set questions and 3 open-set questions for both anatomy and physiology of the larynx. Overall the model and web based materials appeared to complement each other and support student learning. The majority of students who used the model reported improved comprehension of concepts.

Keywords: 3D modeling and printing, learning, larynx

1. Introduction

In fields of study relating to human anatomy, hands on learning mainly includes specimen observation, manipulation, or dissection. Unfortunately, preserved human specimens are difficult to attain specifically for programs not affiliated with a medical school, hospital, or donor program. Preserved animal specimens are a common alternative, but due to anatomical differences, do not have a direct translation to human structure and function. Often the animal specimens require an annual purchase because they are not re-usable after a dissection. Most manufactured replicas are expensive depending on the quality and size of the model and have limited physiological function. 3D printing is a possible method to make replicas of human anatomy accessible, inexpensive, reusable, and realistic. The benefits of using 3D printing in the classroom recently emerged in academic discourse. 3D printing "provides teachers with 3 dimensional visual aids that they can use in their classroom, particularly in illustrating a hard to grasp concept[1]." The goal of the current cross disciplinary project was to combine the technological advances in computer modeling and 3D printing to create a multi-material functional laryngeal model that could then be used by students and professors as a more accessible method of studying human anatomy and physiology. The novel 3D modeling and printing method combined printing filaments with different physical properties rather than the standard single plastic material. The flexible material afforded greater range of motion and manipulation. It was expected that the multi-material 3D printed model would improve student anatomy and physiology learning outcomes when compared to 3D digital models available online.

2. Methods

2.1 Development of the model

The 3D digital model was constructed using Autodesk 3Ds Max software [2]. The study team consulted anatomy and physiology resources to make the model look realistic while maximizing functionality and printability [3,4,5]. The more rigid structures of the larynx (cartilage and bone) were modeled first, followed by the flexible structures (muscle, membrane, and ligaments). A rough, hard surface model was created initially and was then subdivided using smoothing modifiers to give it a more natural look and feel (see Figure 1). The modeling process required numerous test prints to ensure that the model could be easily assembled and disassembled while still maintaining a sturdy structure.

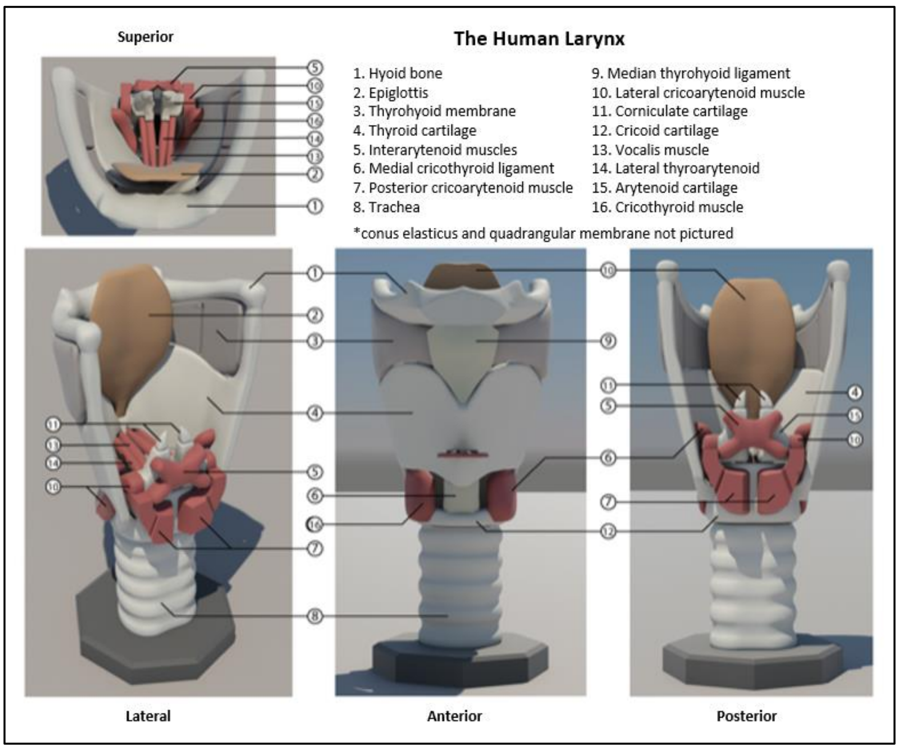

Figure 1. View of 3D digital model created in Autodesk 3Ds Max software

The 3D digital model was printed using Fused Deposition Modeling (FDM) [6]. FDM printers heat up rolls of filament and layer it, in very thin layers, on top of each other [7]. Most FDM printers have only a single extruder, meaning that only one type of filament can be used at a time. This means that each printed part can be made of only one material. To address this limitation, the 3D digital larynx model included individual pieces and the pieces were printed separately and then assembled.

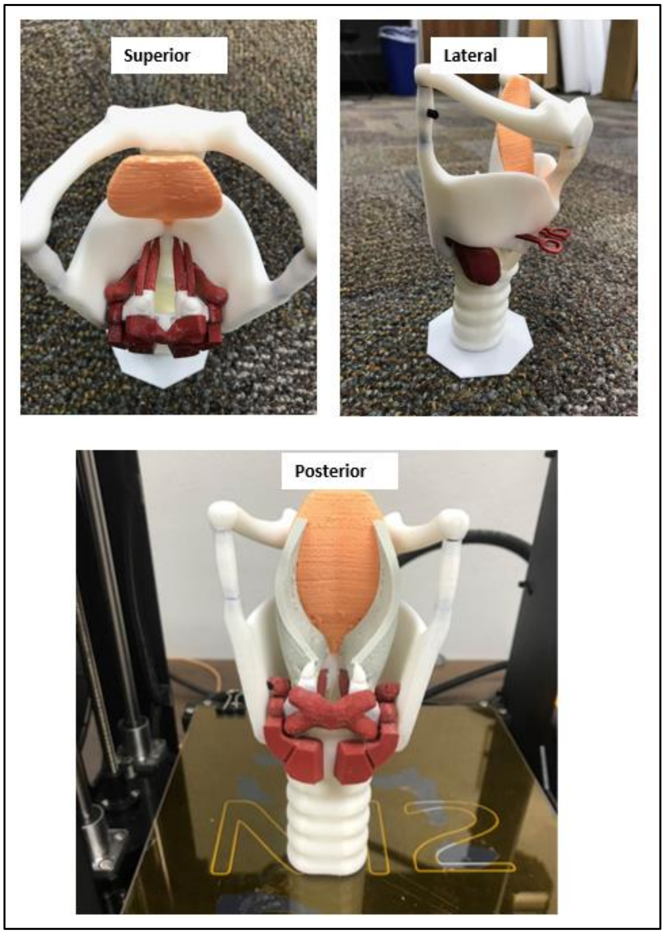

Figure 2. View of assembled 3D printed larynx. Rigid structures visible in white and flexible structures visible in red, grey, and tan.

The standard rigid PLA plastic filament was used to 3D print the cartilage and bone. Rigid structures included the trachea, thyroid, cricoid, arytenoids, corniculate cartilage, and hyoid bone. A flexible plastic, NinjaFlex [8], was used to print the muscles, ligaments, membranes, and one cartilage. Flexible structures included the interarytenoids, vocalis, posterior cricoarytenoid, lateral cricoartytenoid, cricothyroid, quadrangular membrane, conus elasticus, cricothyroid ligament, median thyrohyoid ligament. A 3.5-millimeter nozzle was used for the PLA plastic and a 5-millimeter nozzle was used for the ninjaflex plastic. Parts were assembled using a pin connection system. Assembly did not require any adhesive (see Figure 2).

2.2 Study Session to Evaluate Model

The 3D printed model was evaluated during study sessions. Study sessions consisted of a pre-test, activity, and post-test. A participant could earn up to 12 points on the pre-test and the post-test. The pre-test and post-test each included twelve questions, three anatomy closed-set, three anatomy open-set, three physiology open-set, and three physiology closed-set. The open-set questions required students to write a short answer. An example of an open-set anatomy question was, "Name the structure that rests superior to the trachea and the intrinsic laryngeal muscle that attaches to it". An example of an open-set physiology question included, "What voice quality is produced when there is an opening in the glottis due to a pathology such as nodules?" The closed-set questions included multiple-choice, matching, and true false questions. An example of a closed-set anatomy question included, "True or False: The arytenoid cartilage attaches to the cricoid cartilage." An example of a closed-set physiology question was, "True or

False: Frequency of the voice can be increased by relaxing the vocalis muscle." The pre-test and post-test did not include the same questions, but questions were similar.

Following the completion of the pre-test, students were randomly assigned to a study activity. One group used an existing web resource [5] to review laryngeal anatomy and physiology while the other group used the 3D printed model. Students in both groups were given a list of anatomical structures and physiological actions to guide participation in the activity. Students in the web resource group clicked through various videos and images on the website for twenty minutes. Students in the model group assembled and manipulated the model for twenty minutes. The study team members were available for questions and demonstrations. After the twenty-minute activity the students had ten minutes to complete the post-test. The students assigned to the 3D model condition were also asked to complete an additional survey regarding the usability of the model as a form of consumer feedback.

2.3 Participants

Participants included a total of 14 students (8 graduate students and 6 undergraduate students). Eight students were assigned to the model activity and six students were assigned to the web activity. The undergraduate students were enrolled in an anatomy and physiology course for human communication. The study session was held two days before the laryngeal anatomy and physiology exam. The graduate students were first year graduate students in the speech language pathology master's program. The study session was held before the first meeting of the voice disorders course.

3. Results

An analysis of variance was calculate to evaluate the effect of study activity on test scores. Due to the small sample size and individual variability, there were no statistical differences in scores from pre-test to post-test across the two study groups. Some trends were revealed after review of descriptive data. Some students from both groups improved from pre-test to post-test. 62% of the students in the model group improved their score from pre-test to post-test while 50% of the students in the web group improved from pre to post-test (see Figure 3). The model activity resulted in increases in scores for physiology open-set questions (50%) and anatomy closed-set questions (50%) compared to the web activity (33% and 33% respectively). The web activity resulted in increases in scores for the anatomy open-set questions (33%) and physiology closed-set questions (83%) compared to the model activity (12% and 25% respectively).

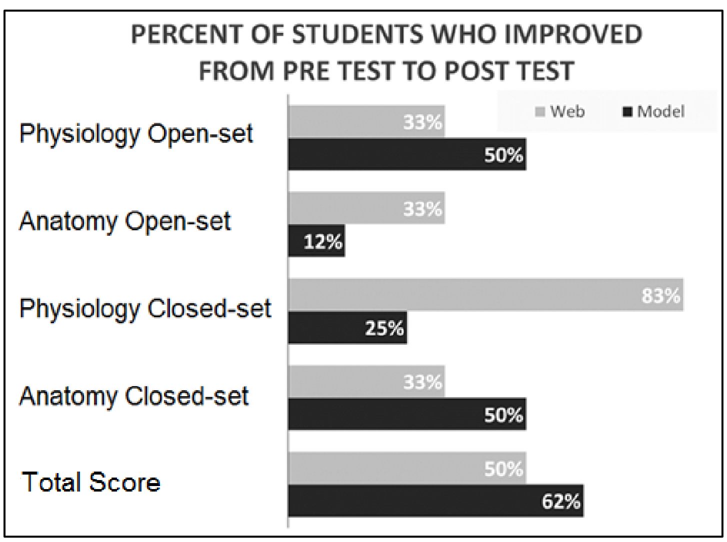

Figure 3. Percentage of students in each activity group that improved from pre-test to post-test. Grey bars represent students from the web activity. Black bars represent students from the model activity.

The surveys completed by the eight students who worked with the model revealed that the biggest concern with the model was durability (92%). Students were concerned that they may break some of the pieces specifically the pins that connected rigid structures. The majority of students reported the model improved their ability to understand laryngeal anatomy and physiology (57%). Students appreciated the functionality of the model (78%). For example, students reported that the model demonstrated movements of muscles and position of membranes that were previously miss-understood. 57% of the students surveyed enjoyed the tactile learning opportunity.

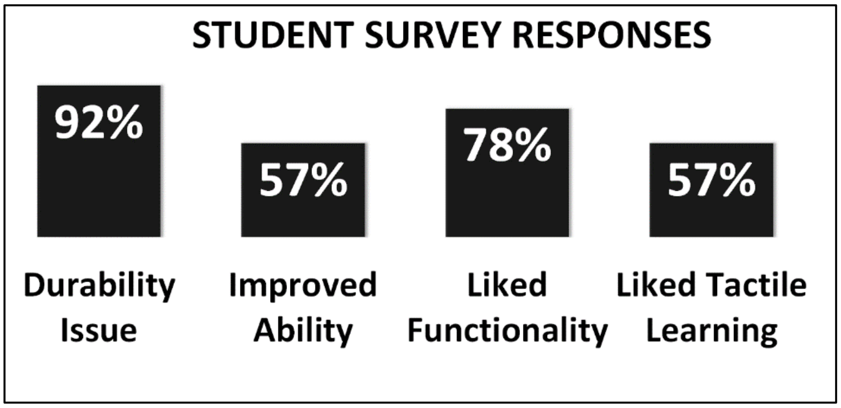

Figure 4. Results of product evaluation survey.

4. Discussion

Due to the lack of statistical significance, it is unclear if the 3D model was a superior study tool when compared to the web based study tool. However, the use of the model did not impede student learning and students who used the model reported enjoyment of the tactile learning opportunity. Given the results, it is likely that a combination of web based and physical based models would complement each other and support student learning.

The limitations noted of the 3D model included durability concerns along with statistically insignificant score improvement over the web materials. In regards to the durability concerns, future iterations of the 3D printed model may improve some of the major areas of weakness in the prototype. However, given the inexpensive replication costs of the 3D model, it is also feasible to print a new part if one breaks. In regards to the lack of significant changes in scores, the existing web materials may hold an advantage because the labels of each anatomical structure are easily mapped on the digital images. Currently, the 3D printed model does not have labels on the printed structures, but this feature could be added. At the very least, a clearly articulated assembly guide with pictures accompanying the model may improve student learning outcomes.

As expected, the model contributed to a greater proportion of students improving understanding of physiological open-set questions (although not statistically significant). This model likely facilitated manipulation of the muscles to serve as the agent of action which was a more realistic physiological experience. Demonstrating improved performance on open-set questions may lead to generalization and application of content. Research in other fields of inquiry suggests that open-set projects and activities facilitate broader application to various settings and assessment [9]. Data from the current study suggests that the 3D multi-material model may serve as a means to improve student learning and generalization. The model may be specifically useful for students in allied health and medical fields. These students are introduced to anatomy and physiology at the undergraduate level and must retain and apply the information in their graduate work and later professional practice.

The 3D printed mixed-material model not only has the potential to complement existing study tools, but also to serve as an educational tool beyond the traditional classroom. The model may improve compliance with Americans with Disabilities Act, allowing accommodations in the university classroom for visually impaired students to succeed in anatomy based courses. The model may aid in counseling and education of patients who need laryngeal procedures or are visually impaired. This may increase patient compliance and improve healthcare outcomes by reducing miss understandings or miss-communications. Lastly this model may serve as a catalyst for other anatomical models to improve the academic and clinical experience.

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