Larynx Model

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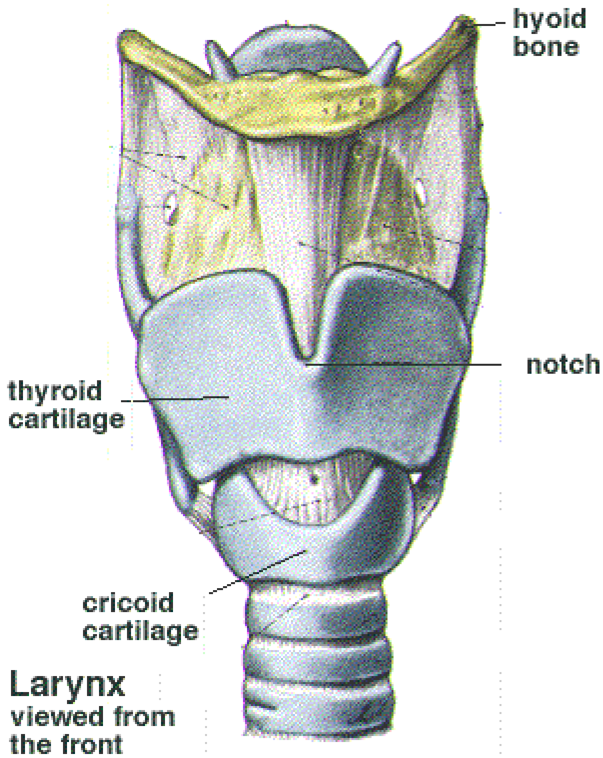

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Abstract

The goal of the project is to continue the development of a three-dimensional larynx model with moving cartilage and muscles. This device is intended to use as a patient educational tool for improved understanding of the laryngeal mechanics by exaggerating its subtle movements. We would like to demonstrate the relation between muscle and cartilage motions, and also apply automated cartilages to the model. The final design of the device consists of three motors that control the motions of the cartilage, and the muscle tissue associated with each motion. To test the efficacy of the model, a population of students was given a laryngeal anatomy presentation either with the aid of a static model or the prototyped dynamic model. The group presented with our dynamic prototype scored higher in our questionnaire compared to the control group presented with the static model. In the subsequent semester, we would like to introduce several laryngeal disorders into the model.

Background

Motivation

Speech pathologists see about 500 patients with laryngeal disorders per month, each of whom need to be educated about the larynx and their particular laryngeal disorder. Patients frequently face difficulty in comprehending laryngeal muscle and cartilage movements, even with the presence of a visual aid. Currently, the tool that our client uses to explain normal laryngeal function is a two-time life-size static larynx model. However, this model has a limited capability in illustrating laryngeal anatomy and essentially no ability to demonstrate the subtle and complex laryngeal muscle movements.

Due to the aforementioned limitations, our client proposed a three-time life-size laryngeal model with electronically controlled movable muscles and cartilages. The model is intended to accurately simulate intricate muscle and cartilage movement of the larynx so that the patients can have visual representation as well as auditory explanation of how the larynx works. Additionally, the model will also be used to demonstrate therapeutic measures on a dysfunctional larynx.

Larynx Anatomy and Physiology

The larynx is an organ located in the airway, lying immediately below the pharynx and above the trachea. The larynx houses the vocal cords that are essential during phonation or sound production. Six sets of laryngeal muscles control three different sets of cartilage that anchor the vocal cords. These muscles control the speed of vocal cord vibration as well as the pitch of the sound being produced. Three cartilages to which the vocal cords are attached to are thyroid cartilage, arytenoid cartilages, and cricoid cartilage, and are illustrated in Figure 1 below.

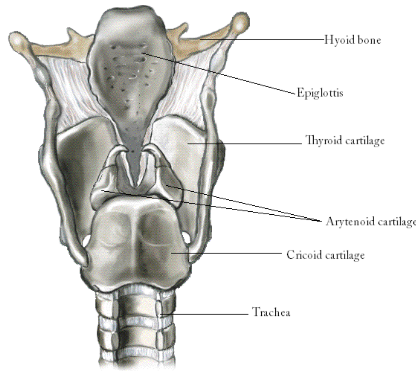


Figure 1. Cartilages of the larynx (facstaff.gpc.edu)

The six sets of muscles of the larynx are named after cartilages of which they are attached to and their functions are listed below.

- *Thyroarytenoid muscle* – Attaches to the two arytenoids cartilages and the inner side of the thyroid cartilage, the thyroarytenoid muscle's contraction pulls the arytenoid cartilages toward the thyroid cartilage, causing shortening of the vocal cords.
- *Posterior cricoarytenoid muscles* – Attaches to the posterior of the cricoids cartilage and to the arytenoid cartilages, this pair of muscles is the main abductor muscle of the arytenoid cartilage. They are responsible for the rocking motion of the arytenoid cartilages which caused the abduction of the vocal cords.
- *Interarytenoid muscle* – Attaches to the right and left arytenoid cartilages, this muscle is responsible for the adduction of the arytenoid cartilages, and thus the vocal cords.
- *Lateral cricoarytenoid muscles* – Attaches to the lateral side of the cricoid cartilage and the arytenoid cartilages, this pair of muscles works with the interarytenoid muscle to rotate the arytenoid cartilages inward and thus adducting the vocal cords.
- *Arytenoid muscles (oblique and transverse)* – Attaches to posterior surface of one arytenoid cartilage and lateral border of the opposite cartilage, this set of muscles work with the interarytenoid and lateral cricoarytenoid muscles to adduct the arytenoid cartilages.
- *Cricothyroid muscle* – Attaches to the cricoids and the thyroid cartilages, the contraction of this muscle causes the tilting forward of the thyroid cartilage. In turn, the forward tilting of the thyroid cartilage lengthens as well as abducts the vocal cord. Thus, sound with higher pitch is created (Bielamowixz & Merati, 2006).

Competition

Currently, a static model is commonly used by speech pathologists to help educate their patients on larynx anatomy and physiology. The static model, although anatomically accurate, has limited capability in presenting larynx cartilages and muscle movements. This function is an integral component of patients' understanding of laryngeal function.

A second option is the widely available functional larynx model. Based on our research, currently available functional model only includes the rocking motion of the arytenoid cartilages. Additionally, these functional models lack muscle representation that responsible for movement of the cartilage. For this reason, patients are not able to observe the specific muscles responsible for cartilage movement.

Lastly, computer software and video recording have also been used as laryngeal functions teaching aids . It is difficult to understand the anatomy and physiology of the larynx through in-vivo video clips of a human larynx since the view is obstructed by enveloping connective tissue that enclose muscles and cartilages of the larynx.

Problem Statement

The goal of this project is to continue the development of a physical three-dimensional laryngeal model incorporating moving laryngeal cartilage, bones, membranes, and muscles. We would like to demonstrate laryngeal musculature and interaction in the larynx for voice production. The model is to be used as a patient educational tool for improved understanding of the laryngeal mechanism. It will also be used to plan treatment based on diagnosis of voice, airway and/or swallowing disorders. This semester, we will design a prototype that accurately demonstrates healthy laryngeal muscle movements. In the subsequent semester, we would like to introduce several laryngeal disorders into the model.

Design Requirements

Our design was constrained by two sets of criteria. These criteria include the correct representation of larynx anatomy and the automation of laryngeal movements.

First of all, the model must be three times larger than the actual size of an average human larynx. This requirement was given to us by our client based on her clinical experience. Since all the cartilages, muscles and connective tissues that make up the larynx are arranged in a complex fashion, a 3X scale model will allow for better visualization. In addition, the model must contain all the major cartilages and muscles. There are three most important cartilages (arytenoid, cricoid and thyroid) and six essential sets of muscles (thyroarytenoid, lateral crioarytenoid, interarytenoid, cricothyroid and posterior cricoarytenoid) that are responsible for the laryngeal movements. All of these anatomical components must be positioned and labeled correctly on the model.

Secondly, there are three major movements that require automation, two of which are the abduction and adduction of the arytenoid cartilage. It is crucial for the model to be able to demonstrate the rocking, rotational and lateral motions of the arytenoid cartilages. Moreover, the model must include the flexion and extension of the thyroid cartilage, which elongates the vocal fold and produces sound with higher pitch. All the muscles present must show the association with the cartilage motion, since in reality, it is the contraction and relaxation of the muscles that control the movement of all the cartilages.

Design Proposal

We focused our brainstorming on the mechanism of the arytenoid cartilages movement. The rationale being the fact that the arytenoid cartilages pose the biggest challenge due to their natural rocking, rotational, and lateral sliding motions. Three potential designs arose after the brainstorm session: rotational spring, ball and socket, and spring and track.

Rotational Spring

The rotational spring design is a modified version of the previous semester design. In this design, the arytenoid cartilage is inserted to the cricoid cartilage with a spring, instead of a pin as in the current model. A fishing line is attached to each of the arytenoid cartilages, which is responsible for controlling movements of the AC. As the fishing lines are pulled, the arytenoid cartilages move towards the direction of the line motion. While the lines are being pulled laterally away from the center of the arytenoid cartilages, the arytenoid cartilages tilt and open. The springs underneath the arytenoid cartilages are relatively flexible, thus they aid in the simulation the rocking and opening motions of arytenoid cartilages in a fixed position. However, there is no translational motion involved in this mechanism since the springs are stationarily inserted into the cricoid cartilage. This leads to inaccurate AC movements since it is important for our client to be able to show the exaggerated the lateral sliding of the AC on the cricoids cartilage to her patients. Yet, this design is quite simple, easy in fabrication and very feasible.

Ball and Socket

Ball and socket is the second design that is inspired by a ball-and-socket joint. A socket is implemented by drilling two long wells into the cricoid cartilage. The length of each well limits the distance that the ACs are allowed to translate during vocalization. The length of a well is approximately 1 cm. On the other hand, the ball portion is formed by attaching a rod to each of the arytenoid cartilages. Each rod is then inserted into its corresponding well and each rod is allowed to rotate in multiple degrees of freedom. Fishing lines are attached and stretched in a similar method as the previously mentioned rotational spring design. Once the lines are in tension, the arytenoid cartilages are free to glide along the socket, which simulates the opening motion; the self-rotation of the bars simulates the rocking motion of the arytenoid cartilages. Some blocking mechanism to prevent over-rotation of the arytenoid cartilages will be implemented inside the wells. The vision of this design is to create a model that depicts a multi-degree of freedom accompanied with a translational motion. It has a more accurate motion that better resembles the anatomy and physiology of the real larynx. However, the fabrication of the socket on the cricoids cartilage as well as the ball end of the arytenoids cartilages attachment can be challenging.

Spring and Track

The third design is spring and track model, which consists of a spring attaching the AC cartilages into the cricoid cartilage. The arytenoid cartilages are being placed along a track, located posterior to the cricoid cartilage. Similarly, fishing lines are attached to each AC and they are subjected to tension during arytenoid cartilages motion. As a result, arytenoid cartilages can glide freely along the track while the springs generate rocking motion. The track is implemented on the posterior side of the cricoid cartilage for the following reasons: 1) ACs will be placed at the more accurate location. If the track is superior to the cricoid cartilage, then arytenoid cartilages will be higher than they should be due to the length of the springs. 2) The posterior cricoarytenoid muscle is located at the position of the track, which helps to disguise the track. Again, the motion of this design might not be quite accurate because it is difficult to control how accurately the springs will rock, at what angles they are allowed to turn. However, it is easy to permanently attach a track onto the cricoid cartilage.

Design Selection

The design matrix serves as a decision-making tool for the three designs mentioned above. Four important criteria are included to determine which the design to pursue. The most weighted criteria are teaching effectiveness and motion accuracy. This device is intended to be a tool to aid patients and students in understanding laryngeal functions. The audience needs to be able to gain better understanding of the laryngeal system after utilizing the device. Thus, its teaching effectiveness is highly valued in selecting our final design. In order to achieve high efficacy, the accuracy of its motion should be largely considered. The prototype needs to be able to demonstrate cartilages and muscles movments correctly. Cost and feasibility are weighted the second. This is primarily due to their descending importance in contributing to the decision of the final design. Yet, they are still essential factors in this model. They are weighed equally because have equal input to the model and have equal importance in our design selection process... Based on the previous reasoning and different weightings according to their importance, we have concluded that the ball and socket model is the most suitable design to pursue for the arytenoid cartilages motions.

	Cost (2)	Educational effectiveness (3)	Motion accuracy (3)	Compatibility / feasibility (2)	Total (10)
String	2	1	1	3	7
Ball and Socket	1	3	3	2	9
Spring & Track	1	2	3	2	8

Table 1: Design Matrix

Final Design

The mechanically functional larynx model (three-time) was purchased for us by the client from the website www.einsteins-emporium.com. The epiglottis, vocal cords and arytenoid cartilages are movable by pulling the two strings that are attached to the bases of the arytenoid cartilages. Only rotational motion of the arytenoid cartilages was demonstrated by this model.

After brainstorming further and experimenting with the ball and socket model, we found a more feasible alternative for the mechanism of the arytenoids cartilages motion. This design allows the same advantages of the ball and socket design yet allows for easier fabrication. In our final design, two wells (width 5.5mm, length 10mm, depth 20mm) are milled in the cricoid cartilage and served as two tracks that guide the lateral movement of the arytenoid cartilage. Two small tubes (diameter 3.5mm, length 15mm) move laterally inside of the sockets, onto which the two pins on the bottom of the arytenoid cartilages are inserted upon. In order to retain the rotational motion of the cartilages, the tubes were designed such that the cartilages could rotate 180 degree maximally.

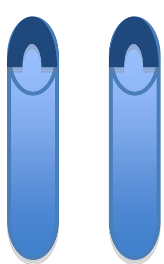


Figure 2: Sketch of two tubes inserted into the wells

The tubes are positioned permanently inside of the sockets by two pins that penetrated the sides of the cricoid cartilage, through the tubes at the position of 5 mm from the bottom of the tube and inserted in to the other side of the sockets. The rocking, rotational and lateral movements of the arytenoid cartilages when abduction and adduction occur are controlled by two separate sets of lines. Since the vocal cord was attached to the two arytenoid cartilages, it opens and closes respective to the abduction and adduction motions.

In order to manage the tilting movement of the thyroid cartilage, it is attached to the hyoid bone by a set of springs with 3 mm diameter. It is also attached to the cricoid cartilage by nails that serve as joints. The joints served as the pivot points that allowed the tilting motion. One fishing line was connected to the bottom of the thyroid cartilage and pulled it anterior to the cricoid cartilage by a rotational motor. The springs were stiff enough to act as a mechanism that pulls the thyroid cartilage upward to the normal position.

Muscle tissue was created with the help of Greg Gion, a Madison based medical artist. Mr. Gion assisted in the creation of a negative plaster mold to shape the silicon muscles. The mould was created by first making wax models of the muscles as best fit the laryngeal cartilage, then using the wax mould to create a negative plaster mould. The plaster mould was then filled with a silicone gel called PlatSil, and pressed with a tile. The muscles created were flat on the back, and could be adhered to the cartilage model. After the silicon set, the mould was removed and the muscles were cut away from the excess silicone gel. The vocal cord and thyroarytenoid muscle had to be created in a 3-dimensional manner. Thus a separate mould was founded around a 3-D wax model. The male plaster mould was shaped like a cone, and fit into a female mould to create a consistent muscle thickness.

As indicated in the design specification section, six sets of muscles were present on the model. They were custom made of PlatSil Gel 10 polymer, with mixture ratio of 1 part A : 1 part B : 1 deadener to provide the desirable flexibility and stiffness. The muscles were attached and labeled correctly onto the model as specified by the larynx anatomy given by our client. The muscles were attached by Epoxy onto the cartilages such that the association of motions between them and the cartilages could be easily identified. Figure 3 below depicts our final prototype.

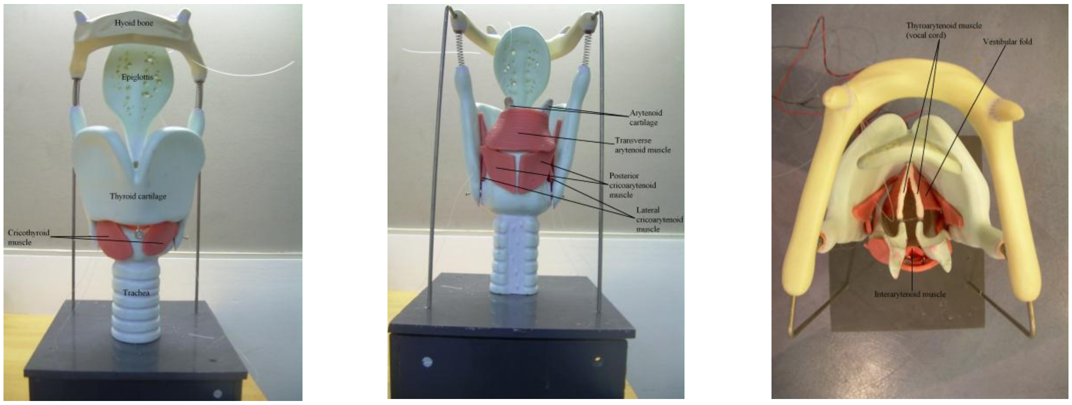


Figure 3: Anterior, posterior, and superior view of final prototype

Following the attachment of muscle, the mobile aspects of the model were animated with clear line. Four lines in total were attached for motion. The first line attached to the bottom of the thyroid cartilage, and was responsible for pulling the cartilage downward so as to increase the length of the vocal cords. The second and third strings were anchored to the junction of the arytenoids and vocal cord, and were responsible for laterally abducting the arytenoid cartilages. The fourth line looped around the two junctions of the arytenoids and vocal cords and abducted the cartilages much in the way a lasso or snare encloses.

Upon completion of the muscle tissue and line positioning, the model was assembled on top of a PVC box. The PVC box contained three 9-18V motors to tense cords attached to the cartilage in order to automate the puppeteer lines. The motors were powered by an Agilent +/- 25V power supply. The cords were anchored to points on the arytenoids and thyroid cartilage to animate motions. One motor was responsible for pulling the thyroid cartilage downward, opposing its elastic attachment to the jaw. The other two motors were assigned to opening and closing the arytenoid cartilage respectively. One motor pulled the cartilage laterally in an abduction motion, and the other motor opposed its motion by adducting the arytenoids.

Testing and Results

In order to test the efficacy of the automated laryngeal model, we conducted an experiment involving twenty UW Housing residents with no prior enrollment in college level anatomy or physiology course. They were divided into two groups, with ten students in each group. The control group was presented with a static laryngeal model that does not show any muscles or cartilage movement, whereas the variable group was presented with the developed automated model. Both groups received a short presentation regarding larynx anatomy and physiology from a member of our team. All subjects were exposed to the same presenter in order to minimize variability in presentation style. After the presentation and explanation of the laryngeal functions, both groups received the exact same survey to examine their understanding in laryngeal anatomy. Survey used in this experiment is included as appendix 1. The survey consists of six laryngeal anatomical questions and four muscle movement questions. After the subjects have completed the surveys, the questions were grade based on correctness that worth one point each for each question. A t-test is conducted to compare the mean of the two sample groups, and the result is presented in table 1 below.

	Static model (n= 10)	Automated model (n = 10)
Mean	3.4	5.3
Standard deviation	1.26	2.58
p- value	0.028 (< 0.05)	

Table 2: Summary of the statistical analysis performed on the data obtained from the testing is presented above.

The p-value obtained from the t-test is 0.028, which is less than 0.05 – the standard 95% confidence interval for one-tailed test. This indicates that there is a statistically significant difference between the mean scores of the two groups. Thus the improvement in the average score of the automated model is not merely due to some random chance.

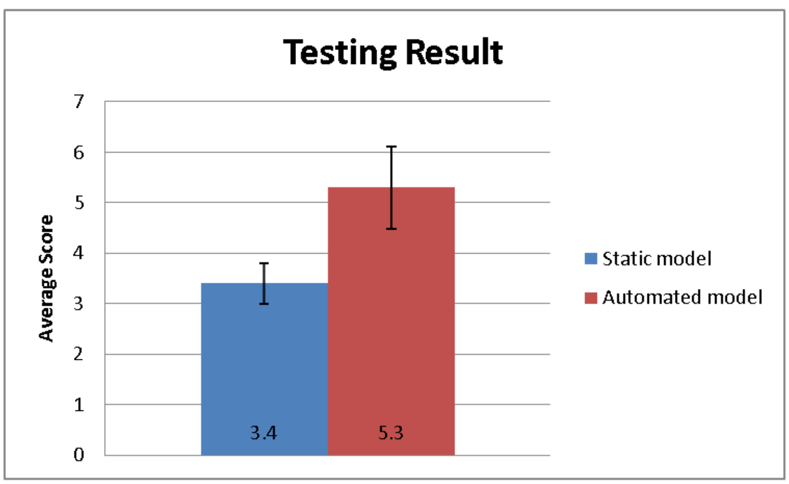


Figure 4: This graph illustrates the average score of the two groups, with the automated group that scored higher (mean = 5.3) than the static group (mean = 3.4).

Further t-test is performed on the mean scores of the anatomical questions as well as the muscle movement separately. The t-test conducted compared the mean of the anatomical scores of the two sample groups is presented in table 3 below (Table 3).

	Static model (n= 10)	Automated model (n = 10)
Mean	2.60	4.00
Standard deviation	0.97	2.16
p- value	0.1554 (> 0.05)	

Table 3: Summary of the statistical analysis performed only on the anatomical scores obtained from the testing is presented above.

The p-value obtained from the t-test is 0.1554, which is greater than the standard 95% confidence interval for one-tailed test. This indicates that there is not a statistically significant difference between the mean anatomical scores of the two groups. This can be explained by the fact that the two models do not differ in the teaching ability of the laryngeal anatomy. Yet, the mean of the automated model is greater than the static model. In other words, the automated group exhibited a greater comprehension in laryngeal anatomy even though the improvement in average score was not statistically significant.

The third t-test is performed between the muscle movement scores of the two groups, and the t-test results are listed in Table 4.

	Static model (n= 10)	Automated model (n = 10)
Mean	0.90	1.60
Standard deviation	0.99	0.97
p- value	0.2556 (> 0.05)	

Table 4: Summary of the statistical analysis performed only on the anatomical scores obtained from the testing is presented above.

The p-value obtained from the last t-test is 0.255, which is greater than the standard 95% confidence interval for one-tailed test. Similarly, there is not a statistically significant difference between the mean muscle movement scores of the two groups. However, the muscle movement mean score of the automated group is greater than the mean score of the static group. It is possible that the difference between the means could be caused by chance, not by the actual improvement in the knowledge of the students. Thus, in order to ensure that there is a significant improvement in individual sections of the survey, more questions need to be developed. To achieve this goal, at least twenty questions relating to muscle questions must be presented in order to sufficiently test the comprehension of the test subjects about the larynx anatomy and physiology. Also, more comprehensive questions should be worked, rather than quizzing the subjects with multiple-choice questions.

Future Work

In the next semester, several avenues will be pursued. Three main areas in focus are automation, visualization and synchronization with sound. The primary area of improvement will be in the implementation of motors. The motors did not function comprehensively on the model and are in need of modification. A less powerful motor will be used in the next revision, as the current motors have proven to snap lines and break parts. The static resistance of the motors is currently difficult to surmount, and thus causes unnecessary tension in the lines. There will be additional circuitry needed as well to ensure the motors are not overpowered. Computer implementation will allow for greater control of muscle movement, and could potentially be used to govern the range of motion.

In terms of visualizations, LED lights are under consideration to indicate activated muscles. This demonstration would allow a user to see the muscles that are working to move the vocal cords, as the silicone is incapable of contracting. The LEDs would be wired to the motor movements so that accurate representation is shown. Once visualizations and automation are completed, computer control will be investigated. Using a computer to control motion and visualization could also create room for synchronization to sound. This synchronization would allow a user to hear what tones are made based on the position of the cartilages and vocal cords, and bring the demonstration full circle.

References

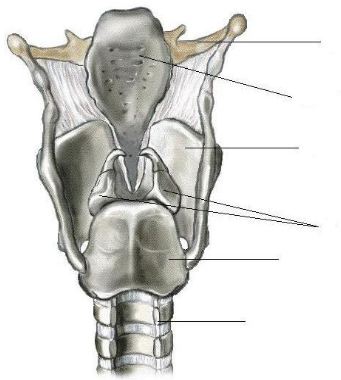
Armstrong, Eric. Voice and Speech Source. Retrieved December 12, 2008. http://www.yorku.ca/earmstro/index.html

Bielamowicz, S. and Merati, A. (2006). Anatomy of the/ larynx and physiology of phonation. In *Textbook of Laryngology* (pp. 34 – 39). Plural Publishing Inc.

Retreived December 3, 2008. http://facstaff.gpc.edu.

Appendix A: 3D Larynx with Moving Parts Quiz

Part A. Please label the following parts of the larynx. You may use the word bank.



- Arytenoid cartilage
- Cricoid cartilage
- Epiglottis
- Hyoid Bone
- Thyroid cartilage
- Trachea

Part B. Muscle Identification. Please choose the best choice. If you do not know, then indicate "I don't know"

1. Which muscle is responsible for the forward tilting of the thyroid cartilage?
   a. Cricothyroid muscle
   b. Thyroarytenoid muscle
   c. Posterior cricoarytenoid muscle
   d. Interarytenoid muscle
   e. I don't know
2. Which muscle is responsible for the adduction of the arytenoid cartilages?
   a. Cricothyroid muscle
   b. Thyroarytenoid muscle
   c. Posterior cricoarytenoid muscle
   d. Interarytenoid muscle
   e. I don't know
3. Which muscle is responsible for the shortening of the vocal folds?
   a. Cricothyroid muscle
   b. Thyroarytenoid muscle
   c. Posterior cricoarytenoid muscle
   d. Interarytenoid muscle
   e. I don't know
4. Which muscle causes the rocking motion of the arytenoids cartilages which leads to the abduction of the vocal cords?
   a. Cricothyroid muscle
   b. Thyroarytenoid muscle
   c. Posterior cricoarytenoid muscle
   d. Interarytenoid muscle
   e. I don't know

Appendix B: Product Design Specifications

Physical 3D Larynx Model with Moving Components

December 10, 2008

Team Members: Rexxi Prasasya, Chou Mai, Karen Chen, Jason Tham

Problem Statement:

The goal of this project is to continue the development of a physical 3D laryngeal model with moving laryngeal cartilage, membranes and muscles. We would like to demonstrate nerve-muscle action and interaction in the larynx for voice production. The model is to be used as a patient educational tool for improved understanding of the laryngeal mechanism. It will also be used to plan treatment based on diagnosis of voice, airway and/or swallowing disorder. This semester, we will design a prototype that accurately demonstrates a healthy laryngeal muscle movements. In the subsequent semester, we would like to introduce several laryngeal disorders into the model.

Client Requirements:

1. The model must be three times the size of an adult human larynx

2. The model must contain the section of the larynx opening from the hyoid bone to the first two tracheal rings and show soft tissues, major muscles and cartilages.

3. Cartilage movements and associated muscles that need to be included are:

•Abduction and adduction of the arytenoid cartilage

•The rocking of the arytenoids cartilage

•Flexion and extension of the thyroid cartilage

•Oscillation of the thyroarytenoid muscle

4. The model must be presentable and functional

5. The model must be easily transportable

Design Requirements:

1. Physical and Operational Characteristics

a. Performance Requirements- The model must demonstrate the muscle and cartilage movements, as well as the proper anatomy of a healthy larynx. The model must be properly labeled to indicate components of the larynx.

b. Safety- The detachable part of the model must be designed to avoid choking hazard. All electrical components must be housed within proper insulator.

c. Accuracy and Reliability- The model should be 3 times the size of an adult human larynx. The model should create the correct muscle and cartilages movement (e.g. contraction, abduction, adduction, tension, etc.).

d. Life in Service- The model needs to operate for at least five years of constant usage. This may include sudden on and off switching, withstand short and long distance transportation.

e. Shelf Life- 10 years with only minor repairs required.

f. Operating Environment- The method must be compatible with hospital environment. Also, the device has to be operable by users who do not have full knowledge of the larynx.

g. Ergonomics- N/A.

h. Size and Shape- The model should represent the larynx at three times the actual size. The base dimensions should not be in excess of 25x25 cm and the height not exceeding 50 cm.

i. Weight- Less than 1.0 kg

j. Materials- The model must be prepared from a material that is widely accepted by the users, not rejected by the users' skin (e.g. allergic if made from latex). The material of the model needs to withstand transportation and ware from constant operation and articulation. The base of the model needs to be strong enough to support the model, as well as supporting the embedded circuits and motors.

k. Aesthetics- The model should be presentable. Each component of the larynx needs to be uniquely color coded to ease patients' observation of movements within the larynx. The rest of the model should also be accurately colored in order to provide a good approximation of the physiology. The aesthetics should cater to an educational need.

2. Production Characteristics:

a. Quantity- One working and well-tested prototype by the end of the semester.

b. Target production cost- $700 for the original prototype.

c. Testing procedure- Testing will be done to test the patient's understanding on how the larynx works before and after demonstration of the prototype.

3. Miscellaneous:

a. Standards and Specifications- The model can be used for educational purpose worldwide.

b. Customer- LED lights and sound system maybe integrated into the functioning model if time allows

c. Patient-related concerns- N/A

d. Competition- Non-automated functional larynx models and Visual software programs.