Kevin Hanson
Kenneth Roggow
Nick Ladwig
Jonathan Meyer
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The Larynx Model: contexts and concepts

Problem Statement

The goal of this project is to develop a physical 3D laryngeal model, with moving laryngeal cartilage, bones, membranes, and muscle to demonstrate nerve and muscle action and interaction in the larynx for voice, airway, and swallowing demonstrations. The model is to be used as a clinical tool for patient education for improved understanding of the laryngeal mechanism, and to plan treatment based on diagnosis of voice, airway, and swallowing disorders.

Background

Problem Motivation

Our client, Sherri Zelazny, is a speech pathologist at the UW-Hospital Voice and Swallowing clinic. Her office currently sees about 500 patients per month, including new and return patients. They come to her office for diagnosis and treatment of laryngeal diseases. She helps them understand what is wrong with their larynx and then presents a variety of treatment options to them. She would like functional model of the larynx to help her educate her patients. The larynx is part of the body that patients can't see and usually doesn't think about until they have to. It is a complicated and intricate instrument which the client says is difficult for her patients to visualize and understand. This lack of concrete patient understanding makes it difficult for our client to guide her patients through the treatment selection process. The model would also be useful for therapy demonstrations. Our client's patients find comprehending the larynx, along with the treatment exercises, difficult. Thus, the model will be used as clinical tool by our client to both improve the understanding of the larynx for her patients, and to help our client plan and explain treatment options to her patients. The client hopes that with a better understanding, her patients are more likely to complete their treatment exercises and have an overall greater satisfaction with the health care provided.

Larynx Mechanics

The human larynx, also known as the voice box, is a highly structured instrument in the body. It works through a variety of motions to generate the different pitches and volumes in voice production, known as phonation. This organ is made of cartilage, muscle, and soft tissues, which all work together in phonation, breathing, and swallowing. Hanging just below the hyoid bone in the upper neck, the larynx is located after the pharynx in the respiratory tract and sits atop the trachea (Thibealt). Here vibrates as air is exhaled from the body, thus generating sound. The vocal folds vibrate at an incredible speed of 100-1000 Hz (Titze). Using six major muscle groups, the larynx changes its shape and positions the vocal folds to create this broad range of vibration speeds. The vocal folds, composed of many layers of soft tissue, are connected to the arytenoid, cricoid, and thyroid cartilages. Cartilage in the larynx is rigid and acts much like bone does. Muscle groups are connected to these and other cartilages, which allow the cartilage to adduct or abduct, closing or opening the vocal folds. Abductor muscles separate the arytenoid cartilages and vocal folds for breathing, while the adductor muscles oppose the abductor muscles to position the

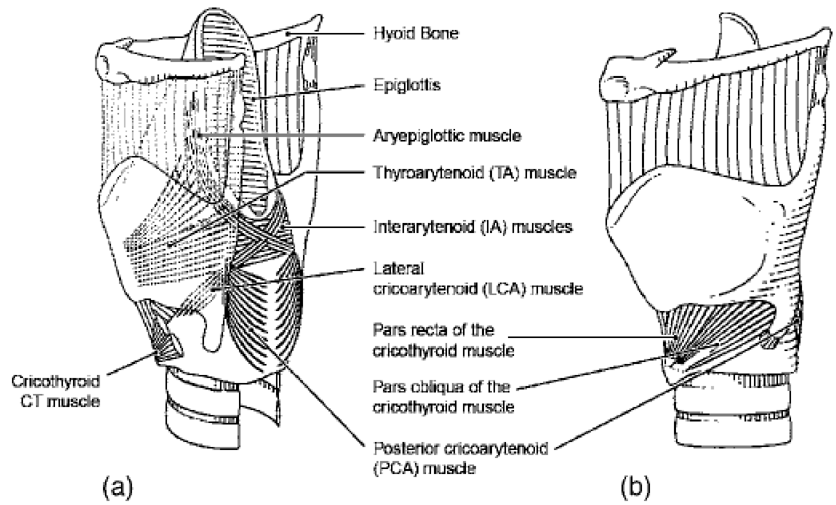

Figure 2: Anatomy of the larynx

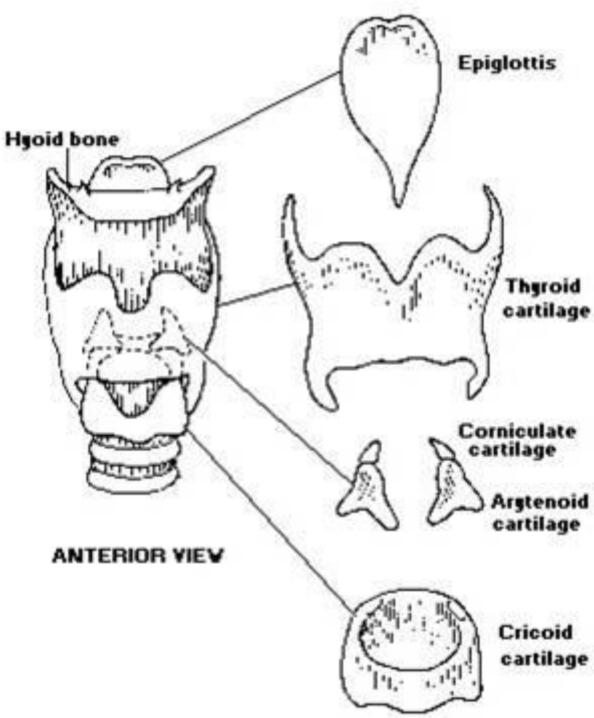

Figure 1: Cartilages of the larynx

arytenoids together for phonation. Vocal folds elongate and tighten with glottal tensors, and shorten and relax by opposing relaxers. This is important in the vocal folds' vibrational behaviors. Two other muscle groups rock the thyroid cartilage back and forth on the cricoid cartilage to elongate and shorten the vocal folds. These muscles are the cricoarytenoid and thyroid muscles; they work as opposing abductors and adductors, respectively, to move the cartilages (textbook of Laryn, Thibealt).

Larynx Diseases and Disorders

The client sees patients when something has been damaged, usually by injury or infection. Many things can cause the larynx to improperly function. Symptoms include hoarseness, loss of voice, throat pain, and swallowing difficulties. The client most commonly sees patients with vocal fold paralysis, arytenoid cartilage dislocation, and general vocal fold flexibility loss (Zelazny). Vocal fold paralysis results from tissue infections and can affect one or both sides of the larynx. Arytenoid cartilage dislocation is the complete separation of the cartilage from the joint space, resulting from injury or intubation trauma (emedicine.com). Loss of vocal fold flexibility creates a symptom of "low pitch" voicing. The patient is unable to elongate the vocal folds, thus cannot produce high frequency vibrations. This disorder is caused by underuse, aging, swelling, and scarring (voicedoctor.com). Muscles in the larynx act much like other voluntary muscles in the body and can be repaired through rehabilitation exercises. The client teaches patients how to complete disorder-specific exercises in an effort to help them recover lost laryngeal abilities. She hopes that this model will aid her in teaching her patients these exercises.

Figure 3: A model of the cartilages of the larynx

Existing Models

Currently, models exist that provide a valuable illustration of the cartilage and bone framework of the human larynx. These models consist of a completely rigid representation of the cartilage and, therefore, offer very little insight into the way the muscles are attached to the cartilage, let alone the movement of the larynx for normal function. An example of this static model is shown to the right. Lacking the muscles of the larynx, this model offers little benefit to our client.

Other existing models have improved upon this static design in a number of ways. Some models simply added plastic, rigid muscles to the static models. Though this addition creates a clearer illustration of the anatomy of the larynx, it lacks the motion that is vital to our client's needs.

In an attempt to recreate the movement of the cartilage in the larynx, models are now created that use a drawstring mechanism to allow the user to move the cartilage as if the muscles were doing it.. Although these models can mimic the motions that certain cartilages undergo, they cannot offer a realistic representation. When a human pulls on the strings, there is no consistent regulation of speed, range of motion, or accuracy in the model. In addition, there is no muscle included in these model types, which makes it difficult to understand the actual mechanism of laryngeal motion.

Figure 4: A movable larynx model

Client Specifications

Because our client is not satisfied with any existing models, there are certain specifications that we must follow to create the most useful model possible.

1. Size: The model must be three times life size or greater

This will give a clear view of the anatomy as well as the mechanism of muscle contraction driving the movements in the larynx.

2. Transportability: The model must be movable by one person from room to room without too much difficulty.

Our client will need to move the model between rooms within the clinic that she works in and, potentially, to other buildings for educational purposes.

3. Anatomy Included: The model must include the area between the hyoid bone and the second tracheal ring.

The model must also include the motion of the thyroarytenoid, cricothyroid, and interarytenoid muscles to demonstrate vocal cord movement.

4. Timing: The movement controlled by the muscles must take no less than two seconds to repeat one repetition.

This delayed timing will slow down the motion of the larynx, giving the user a clear view of the mechanics of motion in the human larynx as well as an isolated view of each muscle as it moves. This provided the best environment for a patient who may not know anything about laryngeal motion to learn about the controls of vocal cord movement.

Proposed Designs

To meet these specifications, we have developed the following designs:

1. Piezoelectric Circuit System

Piezoelectric material changes its shape and volume when placed in an electric current. This design option uses a piezoelectric material to form the moving muscles in our model (i.e., the cricothyroid, thyroarytenoid, and interarytenoid muscles). In order to have each muscle respond independently, each muscle is integrated into its own circuit, yielding three separate circuits in the model. Each circuit is composed of a voltage source and the respective muscle connected with wires. When the user wants to contract one of the three muscles, the voltage source would be turned on, sending a current through the piezoelectric material. This would change the volume of the material, replicating muscle contraction. In order to return the muscle to its original position, the voltage source would be turned off and the piezoelectric

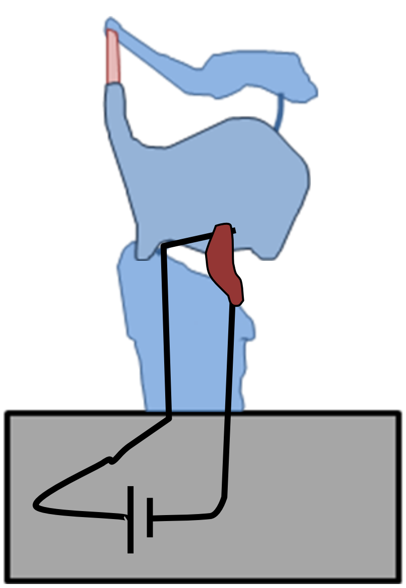

Figure 5: Illustration of the pneumatic actuator system, showing a voltage source connected to the muscle via two wires

material would return to its original shape, representing muscle relaxation.

2. Pneumatic Actuator System

Pneumatic actuators use an air flow source to change their volume and the volume of materials surrounding them. They can regulate this air flow in order to expand and contract on command. This design option incorporates five separate actuators into the model, with each located inside one of the three muscles being replicated (two of the muscles are bilateral). Each of the muscles would be made of silicone, which would stretch or contract when the actuator inside of it expanded or contracted. Activating the actuators with air flowing in one direction would decrease the volume of the actuator and the muscles surrounding it, representing muscle contraction. When the air flow was reversed, the actuator volume would increase, and the volume of the surrounding muscle would return to its original state, representing muscle relaxation. This design would require an airflow source alongside the model at all times in order to function.

Figure 6: A linear pneumatic actuator, with two ports (top and bottom) for air connections

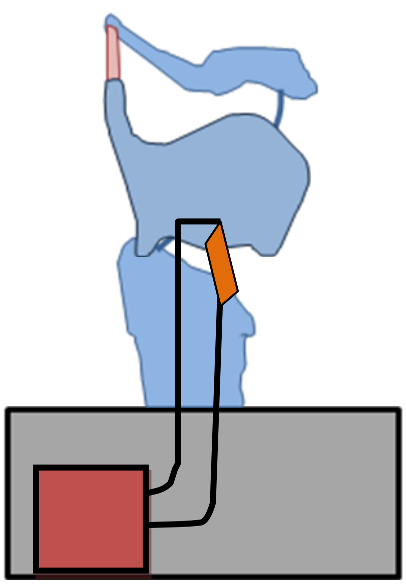

Figure 7: Illustration of the pneumatic actuator system, showing an air controller (air source not shown) connected to the actuator via two air hoses

3. Precision Motor System

The precision motor system design uses three reversible electric motors (i.e. stepper motors), similar to the motors found in remote control cars, to induce muscle movement in the larynx model. These motors can be activated in both the forward and reverse directions, which is necessary in our model because we need to replicate muscle contractions and relaxations. In addition, the motors vary in speed, which will allow us to adjust their speed until the desired muscle movement is achieved. Attached to each motor axel is flexible wire that is integrated into the inside of one of the three replicated muscles. When a motor turns in the forward direction, its wire will wind around its axel, creating a tensile force on the muscle that it is attached to. This tensile force will pull the respective muscle into its contracted position at which point the motor will be stopped, no longer winding the wire around its axel. In order to return the muscle back to its relaxed position, the motor will be reversed, and natural rubber elastic attached from the solid model base to the muscle's cartilage will provide the tensile force needed to pull the muscle back to the relaxed state.

The motor housing would consist of a plastic box containing three motors (one for each muscle group mimicked), upon which would be mounted a plastic model of two of the tracheal rings, the cricoid cartilage, and the hyoid bone. These cartilages would be combined to form a single plastic piece, and would serve as a foundation for the moving thyroid and arytenoid cartilages. The thyroid and arytenoid cartilages would be held in place with imitation muscles, made from silicone formed around a natural rubber or flexible rubber base. The wires connecting the movable muscles with the motors would be threaded through holes in the plastic cartilages, and would thus be hidden from observers. The entire model would then be covered in a series of colored elastomeric membranes to mimic the membranes in the larynx, and dyed or painted as necessary to make them look realistic.

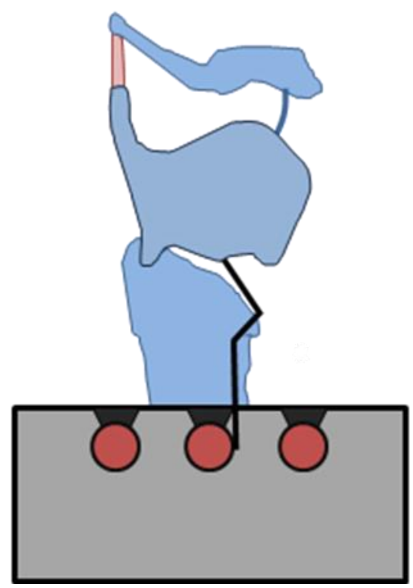

Figure 8: Illustration of the precision motor system, showing a motor connected to the thyroid cartilage via a flexible wire

Design Selection

The three designs were evaluated using a design matrix, which is shown in Table 1. The primary factors considered in evaluating the designs were realism (i.e. how realistically the model mimicked the larynx) and feasibility (i.e. how probable it was that the project could be successfully completed in one semester). Other factors considered included how easy the design would be to operate, how much the design would cost, and how easily the design could be expanded in the future to include other movements and functions.

Table 1: Design Matrix

Design Option	Realism 0.3	Feasibility 0.3	User Friendliness 0.15	Cost 0.1	Durability 0.1	Future Expandability 0.1	Total
Precision Motor	**4** 1.2	**5** 1.5	**4** 0.6	**5** 0.5	**4** 0.4	**5** 0.5	**4.45**
Pneumatic Actuator	**3** 0.9	**3** 0.9	**2** 0.3	**3** 0.3	**4** 0.4	**2** 0.2	**2.9**
Piezoelectric	**5** 1.5	**1** 0.3	**4** 0.6	**1** 0.1	**5** 0.5	**4** 0.4	**3.2**

Despite its realistic appearance and high user friendliness, the piezoelectric system was rejected, primarily due to its high cost. Mere membranes of piezoelectric materials that offered a large enough change in volume (about 20% of their size) cost approximately $75. The feasibility of forming a realistic muscle out of the material was also a concern.

The pneumatic actuator design was also rejected, primarily due to its low user friendliness, high cost, and low expandability. A pneumatic actuator system requires a constant supply of compressed air, which is frequently unavailable in a clinical setting, and could require the operator to carry around a tank of compressed air. The system's high cost stems primarily from the fact that it would require an actuator in each of the movable muscles. Linear pneumatic actuators cost several hundred dollars each, so if more muscles were added to the design in the future, the cost would quickly become prohibitive.

The precision motor system was selected as the final design primarily because of its high realism and feasibility, and its low cost. Electric reversible motors (i.e. stepper motors) can be easily and precisely controlled, allowing for an accurate depiction of the muscle movements. At only about $20 apiece, they are also relatively inexpensive, allowing the model to be easily expanded in future semesters.

Problems on the Horizon

The primary anticipated problems this semester are muscle construction, muscle attachment, and motor selection. These are problems because they rely on testing, which isn't possible until the model is constructed.

We anticipate that muscle construction will be difficult to accurately accomplish because our current construction method has to be done on site. We plan to form the muscles by coating wire or natural rubber attachments between the cartilages with silicone. Thus, we will probably have difficulty keeping the silicone coatings from sticking together as we make them. We may be able to solve this problem by forming the muscles off-site, and then attaching them to the model.

We also anticipate that attaching the pre-formed muscles to the cartilage will be difficult. Glue has a limited lifespan, and may not be very durable, so we hope to find a mechanical means of attachment. One option involves embedding wires into the muscles, which would then hook into wire attachments embedded in the plastic cartilages, or thread through them to attachment points on the cartilages' exterior.

Finally, we anticipate that motor selection will be a problem this semester, primarily because we can't calculate the force required to move the thyroid and arytenoid cartilages the required distances. The cartilages will be attached to numerous retaining muscles, formed from wire and rubber cores coated with silicone. Thus, we won't know how much elastic force will resist the motor's force until we build the model and measure its elastic resistance. This makes motor selection difficult, as one of the key specifications of a motor is the force it can apply. We may be able to calculate a reasonable approximation of the required forces by treating the muscles as if they were made completely from silicone or rubber, but we plan to consult with a materials specialist and a motor specialist before attempting this.

Conclusion

In conclusion, we have selected a basic design for a motorized larynx model that will demonstrate the movement and function of the thyroarytenoid, interarytenoid, and cricothyroid muscles. Although several problems remain unresolved, we hope that by the end of this semester, we will have a useful model for patient education.

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Figures

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Figure 2: Hennessey R. (2003). "Larynx". Anatomy Website of the University of Pittsburgh Nurse Anesthesia Program. Accessed March 12,2008, at http://www.pitt.edu/~anat/Head/Larynx/Larynx.htm

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