Controlled Testing Enclosure for Measuring Larynx Phonation Pressure

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Abstract

Dr. Jack J Jiang has developed an airflow redirection device which non-invasively measures sub-glottal pressure, an essential factor in the evaluation in laryngeal health. Currently, this device noninvasively collects data from human subjects. In order to perform pressure measurements more directly, an apparatus has been developed to test with an excised canine larynx. However, the larynx in this apparatus does not currently have a way to interface with the airflow redirection device. The client needs a controlled testing enclosure that is airtight, is able to interface with the canine larynx and airflow device, and manipulates the larynx shape during testing. An airtight, transparent, acrylic enclosure has been fabricated. It includes a translating plate mechanism that is able to move the laryngeal folds in the x-y-z directions. This mechanism changes the shape of the laryngeal folds to produce various phonation sounds. Testing has shown that the enclosure has a final volume of 252.4 cm^3. In a submergence test, the average volume displaced before failure of the airtight seal was 566.83 ± 7.252 cm^3. Potential future improvements to the design include a more efficient hydration mechanism and integration of the client's current gear-based positioning mechanism.

Contents

Motivation

Laryngeal health is the basis of most vocal disorders. For this reason, the client has developed a device that measures subglottal pressure. Subglottal pressure, the pressure created by the lungs and used by the larynx to produce sound, is an indication of vocal efficiency.[5] Basic larynx anatomy can be seen in Figures 1 and 2. Due to vocal efficiency's importance in evaluating laryngeal health, the client's device has strong diagnostic potential. One specific case of this can be seen in its quantitative ability to differentiate between abductor and adductor spasmic dysphonia, a voice disorder involving involuntary movements of one or more muscles in the larynx during speech. A study in 1997 concerning patients with dysphonia concluded that the current indirect methods for measuring subglottal pressure had high rates of error, as much as 50% in some cases.[6] Through recent testing, it was concluded that the subglottal pressure measurement device proposed by the client could be a more accurate way in which to classify affected patients into the various spasmic dysphonia subtypes.[3]

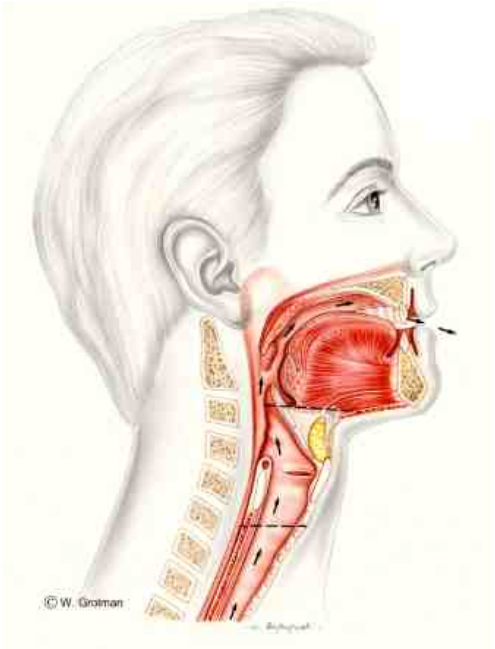

Figure 2. Position of larynx and direction of airflow inside the human body.[8]

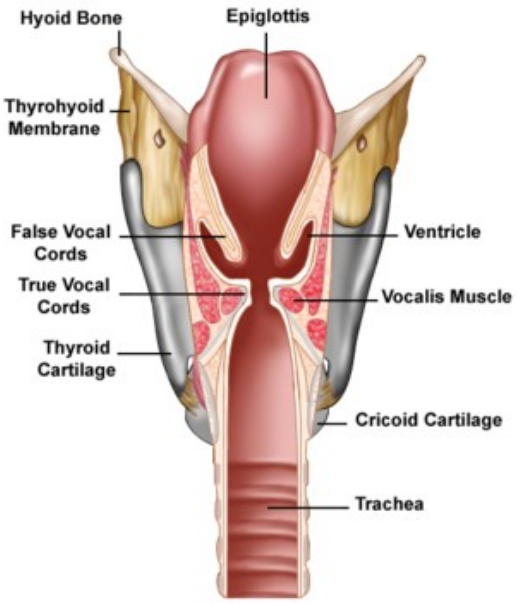

Figure 1. Diagram of human larynx and surrounding organs. Manipulation of the true vocal cords produces different phonation sounds.[9]

Although there are other approaches for measuring subglottal pressure, these methods are either invasive, preformed by puncturing the tracheal space just below the vocal folds[7], or require

extensive patient training before accurate results can be obtained. Also, aside from invasive procedures, there is no current method for obtaining quantitative measurements of subglottal pressure. Due to the ease of use, the client's device would allow for the efficient compilation of subglottal pressure readings on vocally impaired as well as healthy test subjects, ultimately leading to better diagnostic capabilities. It is for its ease of use that the client's device is such a novel idea, giving it the potential to be an essential tool for any physician specializing in vocal disorders.[1]

The ease of use of the client's subglottal pressure measurement device, which is an essential driving force for its development, is mainly due to the minimal effort needed by both the test subject and the testing personnel. In order to use this device, the test subject phonates at a certain frequency into a mouthpiece that is open to the outside environment (Fig. 3). This phonation is fed into a computer that gives constant feedback to the patient allowing them to adjust the frequency at which they are phonating to the frequency needed for the test. When the patient is phonating at the correct frequency, the airflow to the outside is randomly interrupted and redirected into a gas chamber for short durations of time, between 100-200 ms.[4] Change in pressure is measured and used to calculate subglottal pressure. This straightforward method for measuring subglottal pressure, requiring minimal patient and personal interaction, is essential to the development of the device.[2]

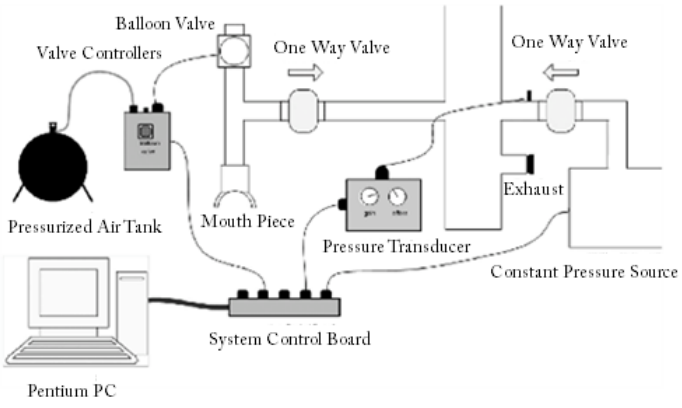

Figure 3. A schematic of the redirection system used in the client's testing procedure.[2]

The client has, for the purpose of studying the phonation process, created a testing apparatus that is used to mimic phonation on excised canine larynxes. In order to use this apparatus in conjunction with the pressure sensor, an enclosure must be designed as an interface between the two. With human testing subjects, a mouthpiece is used to create a continuous isolated airway between the pressure sensor and test subject's larynx. This airtight area is essential to the testing process, which poses a significant problem in the case of an excised

canine larynx. On an excised canine larynx, the correct frequency needed in the testing process must be created via manual manipulation of the vocal folds. Since the enclosure must create a controlled testing environment representative of an actual phonation tract, its volume must also correspond to actual volume of the phonation tract. Creating an airtight enclosure that allows for manipulation of the larynx's vocal folds while conforming to the volume constraint is the basis of this project.

Design Specifications

The device needs to have an approximate volume of 200 cm^3 and maintain an airtight seal while tests are performed and data is acquired. A volume of 200 cm^3 was determined because this is similar in size to the actual phonation tract in humans. Also, changes in pressure are not instantaneous, but occur over a time interval defined by a time constant τ, much like a capacitor. If the enclosure has a large volume, this would increase τ, which would prevent the client from accurately detecting sensitive pressure changes. However, a small volume of 200 cm^3 would decrease τ and make the pressure measurements more accurate. The enclosure must also remain airtight because the data being collected is change in pressure, and any loss of air would affect the pressure readings and, subsequently, the client's data.

The device must be rigid and accommodate a pressure up to 100 cm H_2O, which is the maximum pressure that is used during testing. The enclosure needs to be transparent and cannot have any obstruction on the top surface so that the larynx can be recorded by a high speed camera from above. The enclosure must be made of a material with minimal glare to avoid interference with the camera. In addition to camera considerations, the enclosure must also be compatible with other elements of the client's current testing apparatus. For example, the device must form an airtight seal around the tubing where the larynx sits and around the mouthpiece that interfaces with the airflow redirection device. It must include a positioning mechanism that will hook into the larynx and manipulate the shape of the laryngeal folds up to 3 cm in the x-y-z directions.

The device should be capable of withstanding 2-3 hours of testing at a time for five day increments. An opening must be accessible to hydrate the larynx with a saline solution approximately every 30 seconds during the testing process. Finally, the device is expected to

withstand around 300 pressure ramps during each study while maintaining an airtight seal throughout each trial.

Current Testing Apparatus

Currently, there are no commercially available devices that fit the client's needs because the design is specific to the client's testing procedure and method of data collection. The client performs his testing with an apparatus consisting of parts purchased and assembled by the client (Fig. 4a). Because this apparatus is unique, there are no current devices available that interface with the client's specific testing set-up. A high speed camera records the larynx from above (Fig. 4a), and the larynx is mounted on and secured to the plastic tubing by a metal band (Fig. 4b). The larynx mount is connected to a device called a pseudo-lung, which mimics the function of a human lung by pushing air through the larynx and inducing phonation. Two sets of metal prongs hook into the larynx and are moved in the x-y-z directions by a positioning system of threaded rods (Fig. 4b). The movement of the prongs manipulates the shape of the laryngeal folds, which mimics the movement of vocal cords to produce different phonation sounds. Ultimately, the team's transparent enclosure needs to be compatible with the setup and must interface with the larynx mount as well as include some variation of the given positioning system in order to perform the function required by the client.

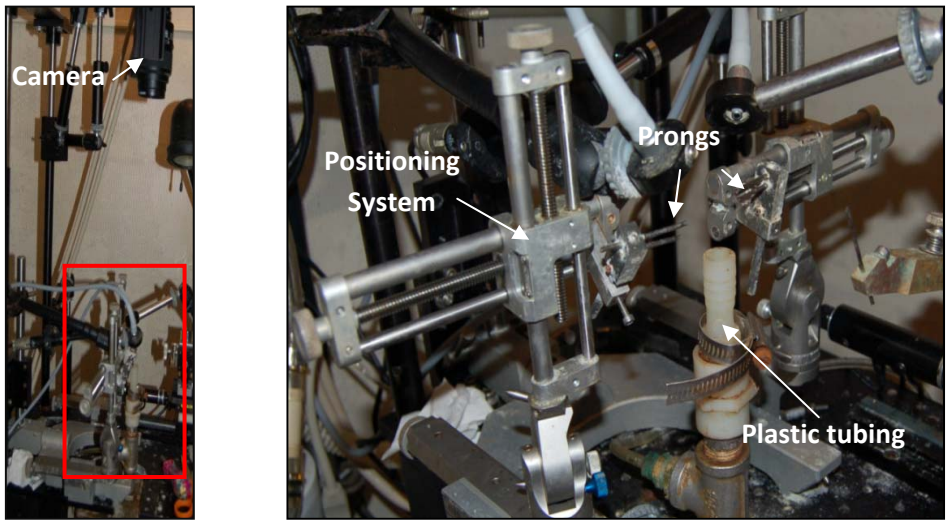

Figure 4. a (left) b (right) Client's testing apparatus. 4a shows the overall setup with camera viewing larynx from above and positioning system outlined in the box. 4b shows a closer view of where the larynx will sit and positioning system. Enclosure design needs to interface with plastic tubing and prongs.

Design Ideas

Due to very specific design specifications, all three of the design ideas are centered around the construction of a Plexiglas box that will fit in with the current testing design. This box will interface with a hydration mechanism, the pressure sensor, and the larynx. As these mechanisms are all stationary, simple rubber-lined connections will suffice to maintain airtight seals. The main challenge considered in the design ideas is the fabrication of a 3-D positioning mechanism that fits with the client's specifications. A schematic of components included in the final design can be seen in Figure 5.

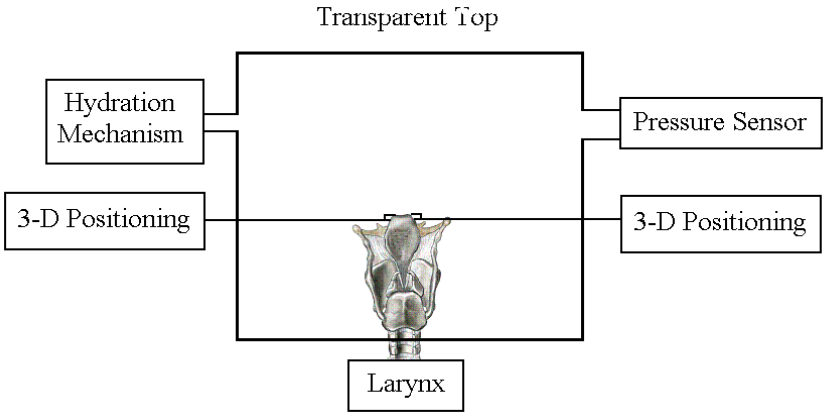

Figure 5. A schematic of the components that will be integrated into the final design.

Design 1. Translating Plate

The translating plate design consists of having two opposite faces of the Plexiglas box be constructed from three separate layers (see Fig. 6). The inner and outer layers, represented by the blue and red colors, respectively, are attached around the outside of the enclosure. This seal creates an empty space throughout which the center orange plate can translate in the x and y directions. Injected into this volume is a viscous fluid to maintain the airtight qualities of the enclosure. The inner edges of the square cut out from the red layer are lined with rubber in order to keep the

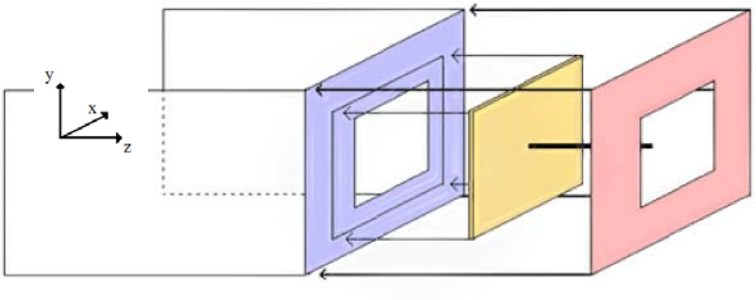

Figure 6. Shown is one face of the box with the three Plexiglas layers separated.

liquid from leaking outside of the box. Screws are placed as shown in Figure 7, which can be tightened around the position of the translating plate to fix its position. The z-axis is positioned by a mechanism resembling a rod threaded through a hollow tube. The rod is connected to the focal folds and can be translated along the z-axis.

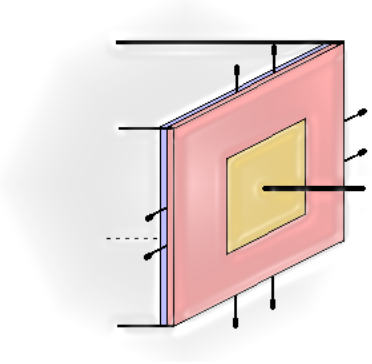

Figure 7. The condensed translating plate mechanism.

Pros

- Able to obtain the small target volume
- Easy to manufacture materials
- Easy to reach positioning system

Cons

- Slow lubricant leak would likely require regular cleaning and upkeep
- Tightening screws may slow testing process

Design 2. Rack and Pinion

The second design contains two gears that rotate on their corresponding axis in the x and y directions (see Fig. 8). Both axes are completely enclosed by the Plexiglas. The x-axis is controlled by a knob on the inside of the box and is fixed to the y-axis. Therefore, when the y-axis is positioned from a knob located on the outside of the box, the entire x-axis translates vertically. A string is attached to the vocal folds and threaded through a rigid tube fixed in the box face. The string is attached to the gear on the

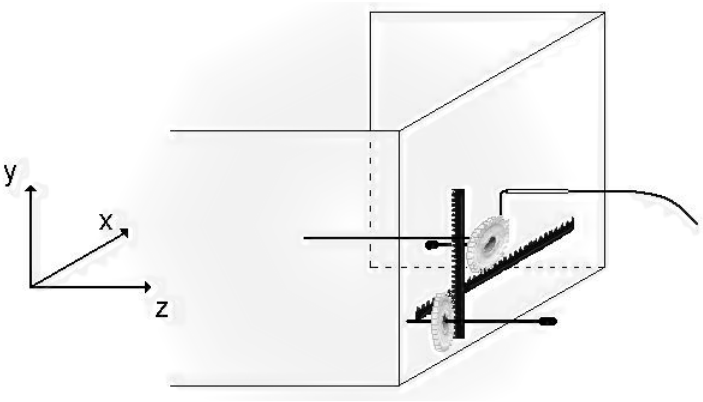

Figure 8. A layout of the Rack and Pinion model.

x-axis, and will therefore translate with the entire gear mechanism. This way, the string can be pulled to make adjustments in the z-direction.

Pros

- Easy to create precise movements in the x and y directions
- Would not require maintenance
- Does not have large areas needing to be sealed

Cons

- Very difficult to manufacture
- Would require operator to open box in order to position x-axis
- Z-positioning via string would only provide tension in the positive z-direction

Design 3. Complete Enclosure

This design is a large box that completely encloses the current larynx manipulation system (see Fig. 9). The enclosure will interface with the base of the current 3-D positioning mechanism. Positioning the system will include opening the enclosure and manipulating the threaded rods from the interior.

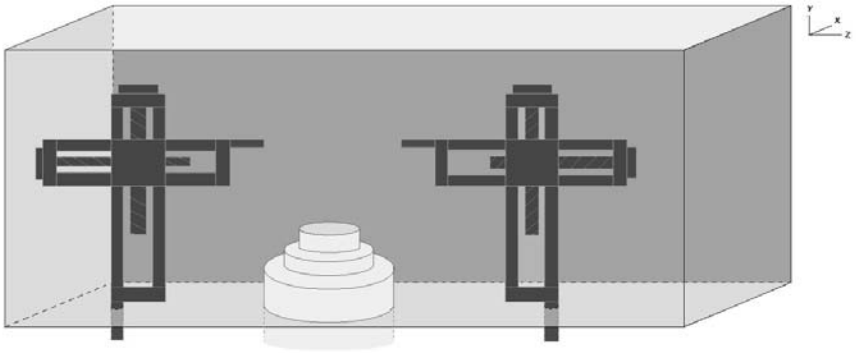

Figure 9. A layout of the complete enclosure design.

Pros

- Simple to manufacture
- Minimal Maintenance
- Used preexisting positioning mechanism

Cons

- Does not meet volume requirements
- Inconvenient large size
- Requires operator to open box to manipulate all aspects of the positioning system

Design Matrix

The design matrix displays the strengths and weaknesses of the three designs (Table 1). There were five categories in which the designs were scored: small volume, maintenance of an air tight seal, ease of manufacture, ease of use, and maintenance and durability. The relative weights of these categories, out of 100, were 25, 25, 20, 17, and 13 points respectively (Table 1, column 1). The translating plate scored the highest out of all three designs in the two highest weighted categories – small volume and maintenance of airtight seal. The volume for the translating plate design is able to be smaller and much closer to the approximate 200 cm^3 than either of the other options because the entirety of the larynx manipulation system is accessed from outside the box.

The translating plate design does not require the box to be opened to manipulate the shape of the larynx. Thus, if it became necessary to adjust the shape of the larynx during testing the airtight seal could still be maintained, whereas the rack and pinion and the complete enclosure require opening the top of the box for manipulation – a clear failure at keeping the airtight seal. The most noticeably low scoring category for the translating plate is the maintenance and durability category. This is due to the requirement for a lubricant between the

layers of acrylic that will have to be cleaned off and reapplied regularly. The translating plate design would not require expect skill to fabricate. The greatest difficulty would be maintaining the airtight seal between moving plates. Thus, the translating plate scored 15 out of 20 points in this category. The translating plate also scored slightly higher in the ease of use category than the other designs (16/17 compared to 14/17 for both alternate designs). This is due to the fact that the box would not need to be opened to operate the larynx manipulation system.

The rack and pinion design scores moderately well in all categories with the exception of ease of manufacture. This design is by far the most complicated, as it requires gears as well as multiple points of access to initiate shape manipulations. The level of complication that this possesses caused the overall score of the rack and pinion design to suffer significantly. The rack and pinion design will allow for a much smaller volume than the complete enclosure design but it must be large enough to allow for the client's hands to manipulate gears from within the box. This requirement results in a score of 18/25 points in the small volume category. A few points were taken from the rack and pinion design in the maintenance and durability category because the gears involved would require some maintenance to continue functioning properly in the long run.

The greatest weakness of the complete enclosure is shown by its exceptionally low score in the small volume category. The client specified that the design should have a total volume around 200 cubic centimeters. The complete enclosure would require a minimum volume of almost 3 times this. The complete enclosure would maintain an airtight seal very well, except when the box must be opened to manipulate the larynx. The current larynx manipulation system would be used and thus this design scored a solid 14/17 points in the ease of use category. The complete enclosure would also be very easy to maintain, as there are no moving parts in the design and no lubricants would be required for use.

Overall, the translating plate design received the highest total score with 82 points out of 100 compared with 75 points out of 100 for the rack and pinion and 67 out of 100 for the complete enclosure.

Table 1. The design matrix used to determine final design.

Category	Design 1 "Translating Plate"	Design 2 "Rack and Pinion"	Design 3 "Complete Enclosure"
Small Volume (25)	25	18	5
Maintains Airtight Seal (25)	20	22	18
Ease of Manufacture (20)	15	10	17
Ease of Use (17)	16	14	14
Maintenance and Durability (13)	6	11	13
Total Score (100)	82	75	67

Final Design

The final design consisted of a 5 cm x 5 cm x 11.15 cm inner box made of acrylic with a width of 0.22 in (0.5588 cm). A further breakdown of dimensions can be found in Appendix B. Five core components were integrated into the design: a set of translating plate mechanisms, a PVC piece to interface with the airflow redirection device, a PVC tube to create dead space within the box, a removable, air-tight lid, and a larynx mount piece. All components were completely rigid and uphold the air-tight qualities of the inner box. The final design can be seen in Fig. 10.

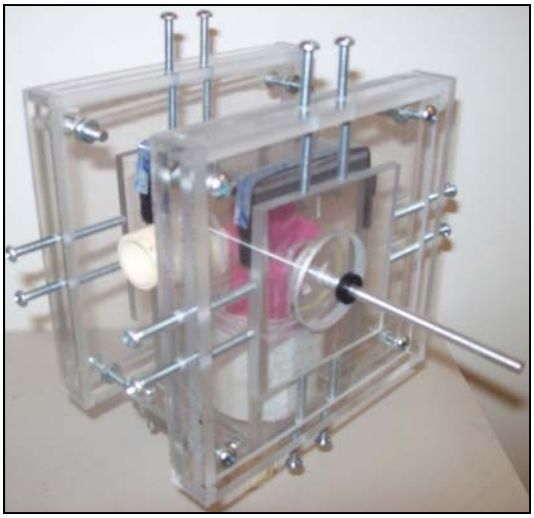

Figure 10. Overall view of final prototype, highlighting the translating plate mechanism.

Translating Plate Mechanism

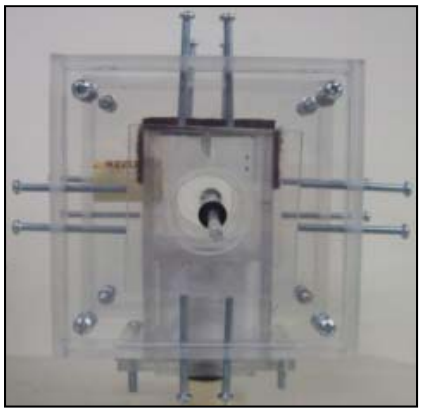

Figure 11. Translating plate mechanism.

In order for the researcher to manipulate the shape of the vocal folds during testing, the translating plate mechanism described in Design 1 was implemented into the prototype (see Fig. 11). Changes made to the design include increasing the overall size of the mechanism. As the client's design process required 3 cm of freedom in the three orthogonal directions, extending the plates beyond the borders of the inner box provided extra space for this extended motion. Another change to the original described design was the removal of the rubber gasket system on the center plate. This aspect was eliminated from the design because a viable, repeatable mechanism for the insertion of lubricant to the desired area between acrylic plates could not be found. Instead, a viscous water-based lubricant was used to create the air-tight seal between plates which did not required addition containment. In order to accommodate this lubricant, the outermost plate in each mechanism was made to be removable. This allows the researcher access to the three plates in order to clean the mechanism and replace lubricant as needed. A schematic of the translating plate mechanism along with final dimensions can be found in Appendix B.

Transparent Lid

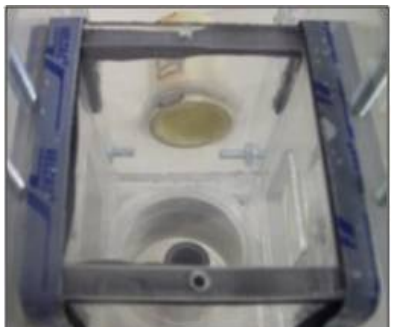

Figure 12. An overhead view of the transparent lid sitting on top of black weather stripping.

The lid of the box is removable to allow a mechanism to hydrate the larynx (see Fig. 12). This must be done approximately every thirty seconds, and therefore it would be preferable for the lid to be easy to remove and to replace. To achieve this, strips of Velcro were attached along the edges of the lid that attach to the upper portion of the box. In order to create an airtight seal along the non-solvated edges weather stripping was placed between the box and the removable lid.

Removable Bottom

The bottom of the box is removable because it would be very difficult for the client to reach their hands into the very small box to attach the larynx. With the removable design, the larynx can be placed on the larynx mount, then the box can be placed over the larynx and the two pieces can be screwed together (see Fig. 13). Again, there is a layer of weather stripping between the removable bottom and the bulk of the box in order to maintain an airtight seal where the pieces are not solvated together.

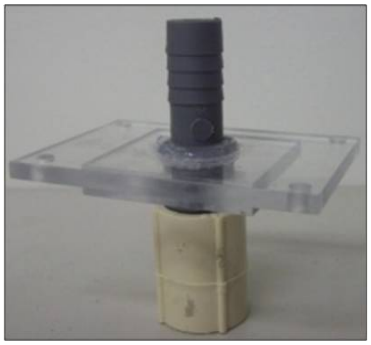

Figure 13. The removal bottom incorporates the larynx mount into the design.

PVC Piping

The last two important features of the design are the two PVC pipes that are integrated into the box. The first PVC pipe is solvated onto a side of the box not containing the translating plate mechanism to create an airtight seal. This is the interface between the box and the client's airflow redirection mechanism. The second PVC section is found and attached inside the box. The PVC blocks off peripheral space, reducing the total volume of the box and bringing it closer to the 200 cm^3 volume requirement specified by the client. The final cost for the manufacture of the prototype was approximately $99.41. A breakdown of the final cost analysis can be seen in Table 2.

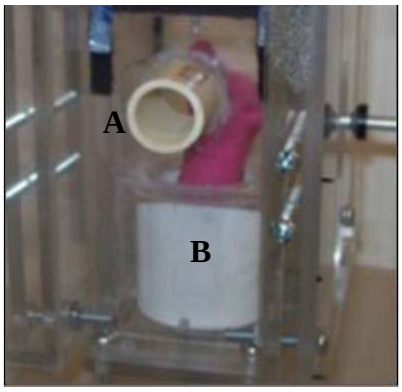

Figure 14. The mouthpiece PVC (A) interfaces the airflow redirection mechanism to the design, and the other (B) creates dead space.

Table 2. Cost Analysis

Item	Cost ($)
Acrylic Sheet	39.97
Screws	7.85
Adhesive	22.84
Lubricants	8.04
Velcro	1.88
PVC	3.83
Washers	9.03
Gasket Material	5.97
Total:	**99.41**

Construction of the final design

The fabrication of the chosen design also had significant impacts on its final structure. One problem that arose during fabrication was the inability to mill a hexagonal piece to fit around the larynx base mount. No available tool had the precision to cut the hexagon originally designed to fit over the base mount and create a temporary airtight seal. This led to the permanent implementation of the larynx mount directly into the removable bottom, creating the airtight seal with epoxy and caulk and also increasing stability of the overall enclosure.

Another problem that arose dealt with the lubricant used. Since the translating plate mechanism was built out of acrylic, no petroleum-based solvent could be used due to its abrasive quality towards acrylic. Therefore, water or silicon based solvent was needed. The original assumption was that the solvent's viscosity was irrelevant and that the airtight seal would be created mainly by the acrylic-acrylic interaction between the interior stationary plate and the translating plate. This was proven wrong during testing. Our original solvent, being less viscous, did not create an airtight seal. This led to the use of a much more viscous water based lubricant in the translating plate mechanism.

A third problem that arose was the failure of the nylon screws to adequately secure and seal the enclosure. The original design specified that nylon screws secure the top and bottom. Through experimentation it was concluded that not only would the screws be insufficient in creating an air tight seal, but tightening took too long to be a practical method of securing the top. This led to the idea of using Velcro and weather-stripping for the top and metal screws and weather-stripping for the bottom.

Because the device does not deal directly with human subjects, there are no ethical principles to consider. The device does not change existing testing procedures and therefore does not influence the treatment and acquisition of testing materials.

Testing

The team performed two separate tests with the final prototype, one test to determine the final volume of the enclosure, and one test to determine the pressure required to compromise the airtight seal of the enclosure. These tests were chosen because these two aspects of the design were rated with the highest importance in the decision matrix (Table 3). For complete test results, refer to Appendix C.

To test the volume of the prototype, water was used to fill the enclosure, and the mass of the water was taken using a balance. Using the conversion that 1 gram of water = 1mL = $1cm^3$, the average volume of the prototype was calculated to be 252.4 ± 0.447 cm^3. This volume, however, included the PVC mouthpiece and the larynx, which is not part of the vocal tract. The PVC mouthpiece had a volume of approximately 7 cm^3, and the average canine larynx volume was estimated to be approximately 30 cm^3. By subtracting this volume from the previously calculated value, the average volume of the prototype was 215.4 ± 0.447 cm^3 (Table 3).

Table 3: Volume of Prototype

Total Volume [cm3]	(Total Volume – Larynx) [cm3]
252.4 ± 0.447	215.4 ± 0.447

To test the pressure required to compromise the airtight seal, the prototype was submerged in a water bath up to the depth where the airtight seal visibly failed. The depth at which the prototype was submerged was measured, and this depth was used to calculate the total volume of water displaced. The average water displaced was 566.83 ± 7.252 cm^3.

Future Work

Because the hydration of the larynx occurs every 30 seconds, the device must be conducive to efficient hydration. Currently, the Velcro strips must be removed and put back for every hydration cycle. This creates more work for the client then is necessary. To avoid this,

Figure 15. Example of one-way valve (www.lifemedicalsupplier.com)

a hydration valve will be installed. A one way valve will provide easy hydration (see Fig. 15). The size and shape of the valve must accommodate the client's current hydration bottle. The saline solution being applied must hit the laryngeal vocal folds, at the top of the larynx. However, the client's camera prevents mounting the valve on the top plate of acrylic. Because of this, the valve will be installed on the available side plate of acrylic, but above the larynx, to let the client effectively hydrate the larynx.

An adaptation of the translation mechanism will provide increased usability. An interface between the translating plate and the client's translation mechanism (the gear system) will help integrate the device into the client's current apparatus. In addition, this will make operation of the device virtually identical to the operation of the current apparatus, using the gear system to control manipulator placement both with and without the airtight environment attached.

Additional research of lubricants must be conducted. Lubricants that are less expensive, cleaner, and create a better seal are of interest. Additionally, these lubricants will be tested against acrylic over a prolonged exposure. This will ensure that the selected lubricant will not have any degrading chemical effects on the acrylic casing over time.

Installation of lubricant gaskets will improve the usability of the device. Currently, lubricant is applied to the inside of each translating plate to provide an airtight seal. A gasket, likely made of weather-stripping, installed against these translating plates will help localize the lubricant. In addition, the gasket will provide an additional seal, should the lubricant seal fail for any reason.

A storage container for the device will increase its usability. Because the device will not be mounted on the client's apparatus for all testing, a clean, safe storage space should be provided in the interim. A box with several layers of soft foam, possibly shaped polystyrene, would be ideal for housing the individual components of the device.

Conclusion

An airflow redirection mechanism has been developed as a test of sub-+glottal pressure, which can be a measure of vocal health. In order to develop a controlled testing environment for this device, and interface was needed to connect the device to an apparatus, which has a pseudo-lung pumping air through an excised canine larynx. The interface design needed to be transparent, rigid, airtight, and allow a mechanism for manipulation of the vocal cords of the canine larynx. Three designs were considered to solve this problem: the translating plate mechanism, the rack and pinion mechanism, and a complete enclosure design. After scoring each design in a decision matrix, it was determined that the translating plate design would most closely meet the client's needs. The translating plate was able to move in two of the three Cartesian planes, and a retractable rod was used to control movement in the third Cartesian plane. Interfaces were added to the design to connect it to both the larynx mount on the testing apparatus, and the airflow redirection device. This design was fabricated and tested for volume, and allowable pressure. The design satisfactorily met all necessary requirements.

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Appendix A: PDS

Larynx Adapter Product Design Specifications

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Problem Statement:

There is a testing apparatus which uses an excised canine larynx to measure sub-glottal pressure, and indicator of vocal health. Our objective is to create an airtight, rigid, and transparent enclosure to obtain a more controlled testing environment; this enclosure will interface between a pressure measurement device and the canine larynx

Client requirements:

- Airtight
- Must accommodate pressure up to 100cm of H_2O without changing shape
- Transparent
- Max volume = $200cm^3$
- Compatible with current larynx testing apparatus set-up
- Larynx must be accessible between tests without removal of enclosure
- Needs a system to manipulate the larynx shape up to 3 cm in 3 Cartesian directions

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: The device will be used for 5 days every 3-4 months. The device must withstand testing for 2-3 hours at a time with an accessible opening to hydrate the larynx every 30 seconds. The enclosure must withstand up to 300 pressure ramps during each study while maintaining an airtight nature in each trial.

b. *Safety*: Must avoid latex as a material if possible.

c. *Accuracy and Reliability*: The device must withstand 10-15 pressure ramps for each larynx tested. The positioning system must move up to 3

cm in each Cartesian direction, but it must move on a scale of millimeters during testing (accurate measurements not necessary because larynx shape is qualitative.)

d. *Life in Service*: Does not need to be portable. Not used for extended periods of time.

e. *Shelf Life*: Stored in testing lab at room temperature and standard pressure.

f. *Operating Environment*: Experiments will be recorded with a high speed camera which requires bright lights that must not glare off the box. The device must handle 0-100 cm H_2O of pressure without failing in airtight connection. The device must rest on shelf of current testing unit.

g. *Ergonomics*: Must have an accessible opening to keep the larynx hydrated during testing. Positioning system must be accessible to the human hand.

h. *Size*: Maximum volume of 200 cm^3.

i. *Weight*: N/A

j. *Materials*: Must be transparent, cannot allow glare, and must maintain shape under pressure. Possible materials include: Plexiglas, acrylic, latex, leather.

k. *Aesthetics, Appearance, and Finish*: N/A

2. Production Characteristics

a. *Quantity*: One.

b. *Target Product Cost*: No cost specified, funding available from grant.

3. Miscellaneous

a. *Standards and Specifications*: N/A

b. *Customer*: N/A

c. *Patient-related concerns*: N/A

d. *Competition*: No, device is highly specific for the client.

Appendix B: Schematic with Dimensions

Appendix C: Testing Data

Volume Test Data

Trial	Mass of Water (g)
1	254
2	252
3	252
4	252
5	252

Airtight Seal Data

Trial	Depth of Submergence (cm)	Volume of Displaced Water (cm^3)
1	8.4	547
2	8.7	568
3	9.0	589
4	8.6	561
5	8.9	582
6	8.5	554