Controlled Testing Environment for Measuring Larynx Phonation Pressure

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Whitney Johnson, Sarah Switalski , Kelsey Hoegh, Clayton Lepak, Jack Renfrew

Client – Jack J. Jiang MD, PhD
Department of Surgery and Otolaryngology

Advisor – Professor Thomas Yen

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Abstract

Dr Jack J Jiang has developed a device which non-invasively measures sub-glottal pressure, an essential factor in the evaluation in laryngeal health. In order to test this device an apparatus has been developed to test with an excised canine larynx. The larynx in this apparatus does not currently have a way to interface with the testing device. There are three design suggestions which could help to solve this problem and to create a more controlled testing environment: the "translating plate", the "rack and pinion", and the "complete enclosure." Due to the design specifications, each of these designs was based on the fabrication of a Plexiglas box which will be compatible with the current testing set-up. These designs, however, vary in the mechanism with which the larynx shape will be manipulated. After the relative strengths and weaknesses of each design option were considered, the translating plate was chosen for the final design.

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. Due to vocal efficiency's importance in evaluating laryngeal health, the client's device has strong diagnostic potential. Although there are other approaches for measuring subglottal pressure, these methods are either invasive 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 (see Fig 1). 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. The change in pressure is measured and used to calculate subglottal pressure. This straightforward method for

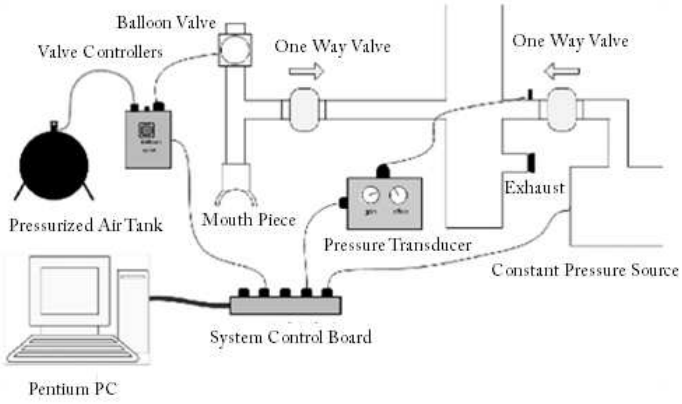


Figure 1. A schematic of the redirection system used in the client's testing procedure.

measuring subglottal pressure, requiring minimal patient and personal interaction, is essential to the development of the device.[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. When human testing subjects, a mouthpiece is used to create a continuous isolated airway between the gas chamber 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. This challenge is further intensified as a result of the volume constraint placed on the enclosure. 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 a maximum volume of 200 cm^3 and maintain an airtight seal while tests are performed and data is acquired. 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 the client uses 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 pressure measurement device. It must include a positioning system used to 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. Finally, the device is expected to withstand around 300 pressure ramps during each study while maintaining an airtight seal throughout each trial.

Current Devices

Currently, there are no marketable 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. 2a). Because this apparatus is unique, there are no current devices available that interface with the client's specific testing set-up. A transparent enclosure needs to be compatible with the setup and interface with the larynx tube and positioning system and prongs (Fig. 2b) in order to perform the function required by the client.

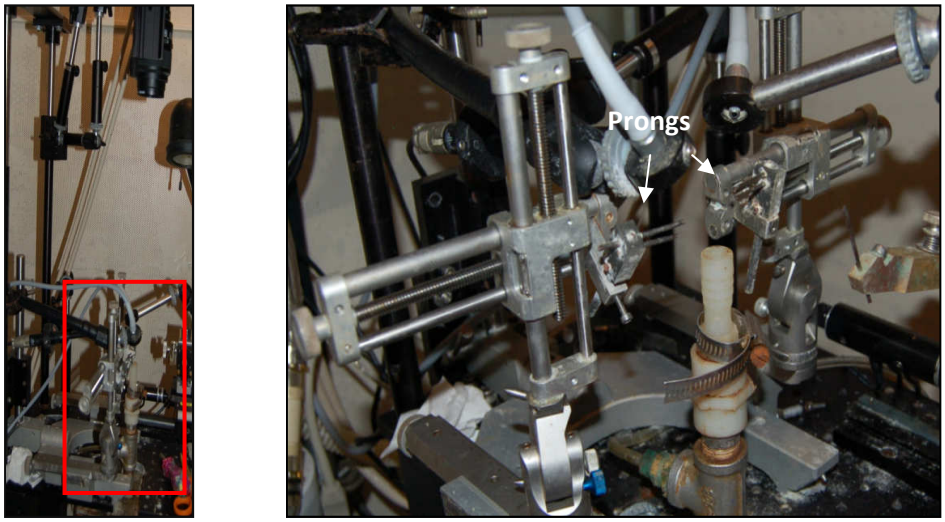
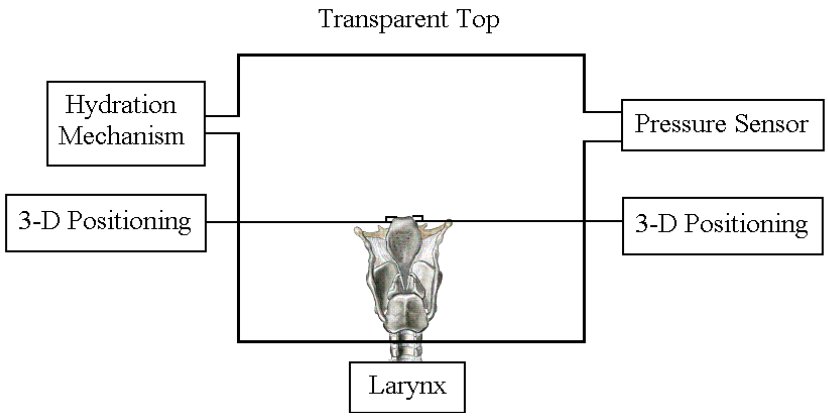


Figure 2. a (left) b (right) Client's testing apparatus. 2a shows the overall setup with camera viewing larynx from above and positioning system outlined in the box. 2b shows a closer view of where the larynx will sit and positioning system. Enclosure design needs to interface with plastic tubing and prongs.

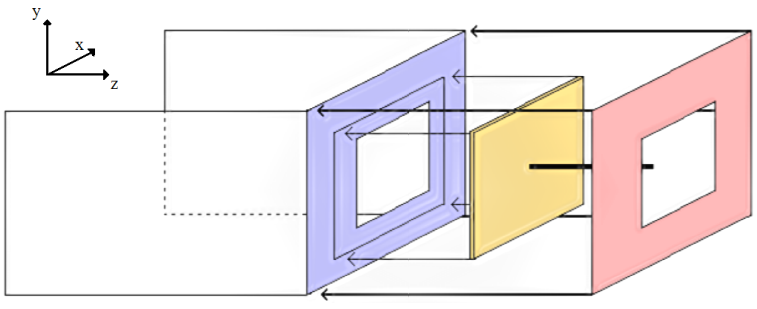
Design Ideas

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 3.



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. 4). 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



ɔox with the three Plexiglas

red layer are lined with rubber in order to keep the liquid from leaking outside of the box. Screws are placed as shown in Figure 5, 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.

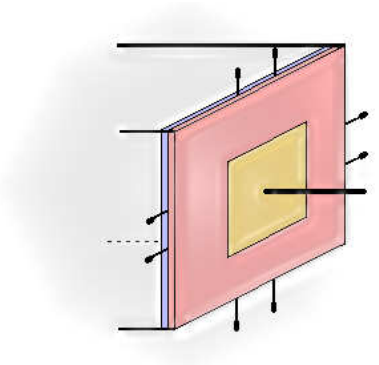


Figure 5. The condensed translating plate mechanism.

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. 6). 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 x-axis, and will

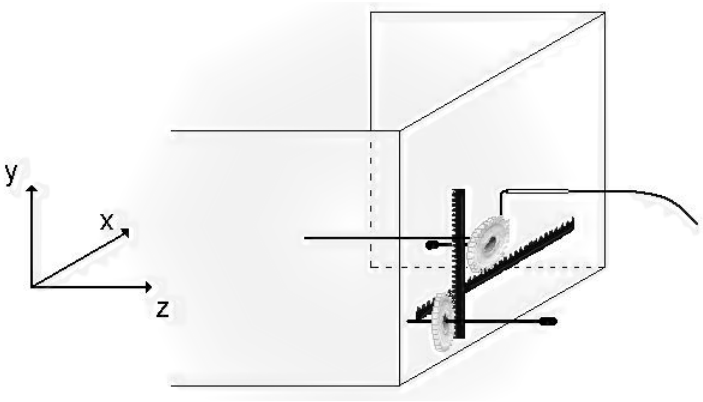


Figure 6. A layout of the Rack and Pinion model.

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. 7). 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.

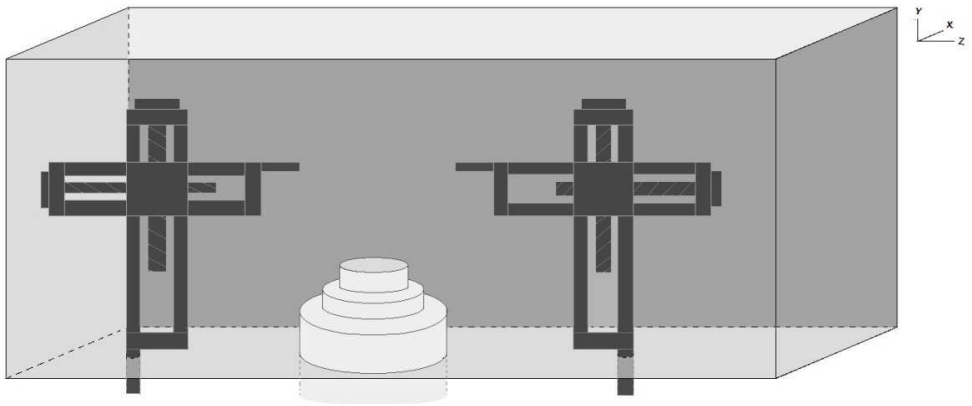


Figure 7. A layout of the complete enclosure design.

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 (see 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, are 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 than for 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 Plexiglas that will have to be cleaned off and reapplied regularly. 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 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. 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 will consist of five core components: an airtight interface with the pressure sensor, an airtight interface with the larynx, an opening for hydration, an effective translation mechanism for the manipulators and laryngeal manipulators.

The components of the design deal with penetrating the testing environment while maintaining the airtight seal. The interface between the pressure sensor and the enclosure will be made of a fitted rubber seal. This will be cost effective and easy to use. The rubber seal will be easily removable by the client, which is beneficial as the pressure sensor will be needed elsewhere during other experiments.

The interface between the larynx mount and the enclosure will be handled in the same way. In an effort to minimize volume we will interface the enclosure with the larynx mount as high as possible. Unfortunately, the larynx mount itself is made of semi-plastic, so an airtight connection with a rubber seal may be hard to achieve. If this is the case, the enclosure must be lowered on the larynx mount, where the larynx mount is more rigid. This will increase the volume of the design, but ensure a good seal.

The hydration lid must allow the client to pour a saline solution over the larynx once every thirty seconds during testing (see Fig. 8). This means it must be easily removable, yet airtight in between testing. A simple hinge mechanism will be attached to the enclosure along with a fitted lid. When closed, the lid will rest on an inset portion of the main Plexiglas body. This will allow for hand screws to tighten the lid to ensure it does not open under the pressure of testing.

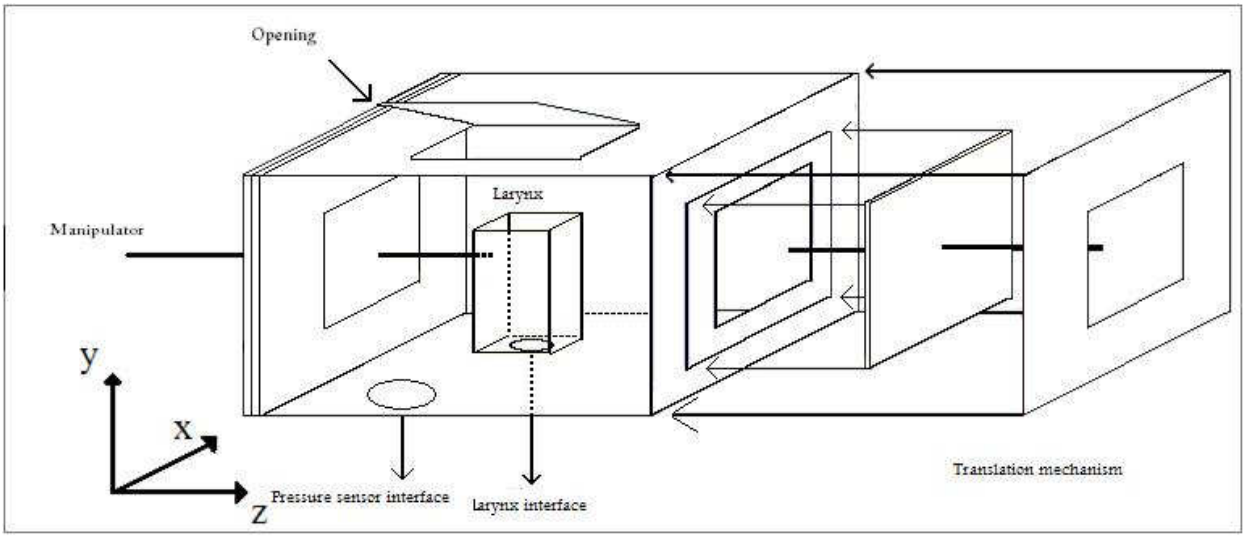


Figure 8. An overall view of our final design.

The translation mechanisms will be identical to that of Design 1. There will be two translating plate mechanisms on either side of the larynx. The translation will be accurately moved by the screws shown in Figure 5. The central Plexiglas sheet of the translation mechanism must be of adequate thickness to seat the screws. With the correct screws, the middle panel can be 1/4 in. thick Plexiglas. All other Plexiglas can be held at 1/8 in. thick.

The manipulator will penetrate the translation plate without causing significant amounts of air to escape during testing. A syringe is favored for this application because it will have a

small cross sectional area, leading to a smaller amount of air escaping during testing. The syringe also solves the problem of moving the manipulator in the "z" direction (see Figure 5). Movement in the "z" direction is required by the client during testing, and would be hard to acquire with most other manipulator devices. The volume displaced by the plunger of the syringe must be negligible to ensure quality testing.

Future Work

Next in the design process is to determine the average laryngeal volume of a canine larynx. This is necessary because the client specified a strict volume limit of 200 cm^3. Since the design will enclose the canine larynx during testing, the volume of this larynx can effectively be subtracted from the total volume of the design. After we find this volume, final dimensions of the design will be determined.

Research must be conducted on the viscous liquid that is integral to the translating plate mechanism. This liquid must be inexpensive and replaceable. It must also allow for free translation of the surrounding Plexiglas plates as well as maintain an airtight seal. Vegetable oil is a substance we are considering for preliminary testing. If there are no problems, this liquid will pass on to the prototype.

The most difficult component of the design to manufacture will be the translating plate mechanism. For this reason, we will create a prototype of just this mechanism, without all the other components of the design, to ensure it is feasible. This will include ordering Plexiglas and cutting it according to the translation design. If this goes well, the syringe will be incorporated as a manipulator. The device will then be given to the client for additional testing for accuracy and functionality.

References

1. Baggott C, Yuen A, Hoffman M, Zhou L, and Jiang J. Estimating Subglottal Pressure via Airflow Redirection. *Laryngoscope. 2007; 117:1491-1495*.

2. Rieves A, Regner M, and Jiang J. Phonation Threshold Pressure Estimation Using Electtroglottography in an Airflow Redirection System. *Laryngoscope. 2009; 000: 1-6*.

Appendix

Larynx Adapter Product Design Specifications

October 15, 2009

Whitney Johnson, Kelsey Hoegh, Clayton Lepak, Sarah Switalski, John Renfrew

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.