Animatronic Tongue Model

Biomedical Engineering Design University of Wisconsin – Madison

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Client: Professor JoAnne Robbins, Ph.D.

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Abstract:

Dysphagia, the inability to swallow correctly, is a problem that can lead to a number of negative health conditions such as pneumonia, dehydration and malnutrition. The client, Dr. JoAnne Robbins, researches the causes of and treatments for dysphagia. Dr. Robbins requires a tongue model that can be used to test liquids and foodsboth accurately and precisely, and is compatible with the pressure measurement devices she wishes to examine.

The model proposed is a silicone tongue that features a 3-banded, T-pin design which utilizes computer-controlled servo motors for actuation. There will be a program written to allow for the client to manipulate the model as desired. After careful consideration, this was decided to be the most effective way to meet the client's needs and accomplish the tasks assigned, which also includes recreating the motion of the tongue during the different phases of swallowing. The next step in moving forward is to develop an oral cavity model and throat model around the current prototype, stabilize the servos, create java code for diseased states, and improve upon the movement of the model tongue.

Background:

Client

Dr. JoAnne Robbins is one of the foremost researchers in the field of dysphasia today. She focuses on the effects of behavioral interventions, such as physical therapy to increase muscle tone in the tongue and mouth. Her research also includes understanding the kinematics of swallowing, including pressure generation and the effects of food choices.

Dysphagia

Dysphagia is the inability to swallow properly. This can occur due to multiple reasons, such as sarcopenia (age-related loss in muscle tone), neurological disorders such as stroke, and muscle disorders. Dysphagia is detrimental to the patient's quality of life as he or she is no longer able to properly swallow all types of food. It can also lead to health concerns such as pneumonia (if food or liquid is aspirated into the lungs) or dehydration and malnutrition in extreme cases.

Swallowing

The actual swallowing motion is rather complex, and occurs in two phases: horizontal and vertical. During the horizontal phase the tongue creates a trough for the bolus and propels it from the front of the mouth to the back, by the throat. During the vertical phase, the soft palate is elevated to close the nasopharynx. The epiglottis is brought down to come in contact with the larynx, in order to close off the trachea and prevent aspiration. The bolus then moves down into the esophagus which propels it down into the stomach.

Tongue Structure

The tongue is one of the most complex aspects of the swallow. It has two groups of muscles: the extrinsic muscles, which are outside the actual tongue structure, and the intrinsic muscles which are inside the tongue.

The extrinsic muscles are what primarily contribute to the swallow. These muscles consist of the genioglossus, styloglossus, palatoglossus, and hyoglossus. The genioglossus is responsible for creating the trough of the tongue during swallowing and moving the tip of the tongue out of the mouth, backwards, and against the front roof of the mouth. The styloglossus is responsible for the tongue's upward and backward motion. The palatoglossus creates the grove in the tongue by pulling it back. The hyoglossus is responsible for the tongue's downward and backwards motion while also elevating the hyoid bone.

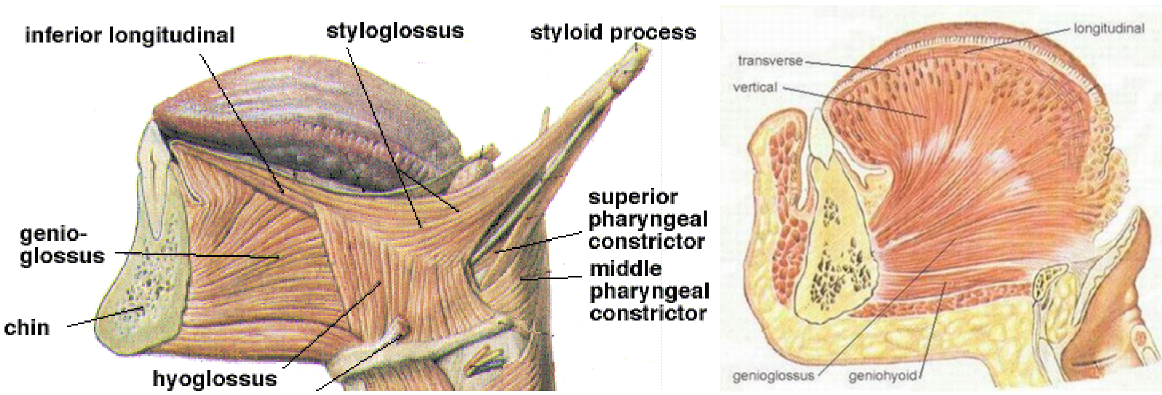


Figure 1. The extrinsic (left) and intrinsic (right) muscles of the tongue [I].

The intrinsic muscles include the inferior and superior longitudinal muscles, the transverse muscle, and the vertical muscle. These muscles primarily affect the shape of the tongue. The placement of the tip of the tongue is affected by inferior and superior longitudinal muscles. The transverse muscle affects the width and length of the tongue, and the vertical muscle changes the shape of the surface of the tongue by depressing it.

Current Devices

There is currently no device on the market for the specific purpose of studying dysphagia. There are, however, other animatronic devices that attempt to mimic human mouth movement.

In Japan, recent advances have been made in the field of robotics, such as the Showa Hanko 2, a dental training dummy. The Showa Hanko has human-like movements and reacts to pain similar to a real patient. However, the robotic tongue displays limited movement, allowing only two degrees of motion.

Figure 2: The Showa Hanko 2, a dental training dummy marketed in Japan [V].

Another device of note is the Animatronic Model of a Human Tongue and Vocal Tract, or Anton, developed at the University of Sheffield in England. This model has a functioning tongue, jaw, and vocal tract, and has been able to produce sounds comparable to human speech. However, this model only mimics speech patternsand is not currently commercially available.

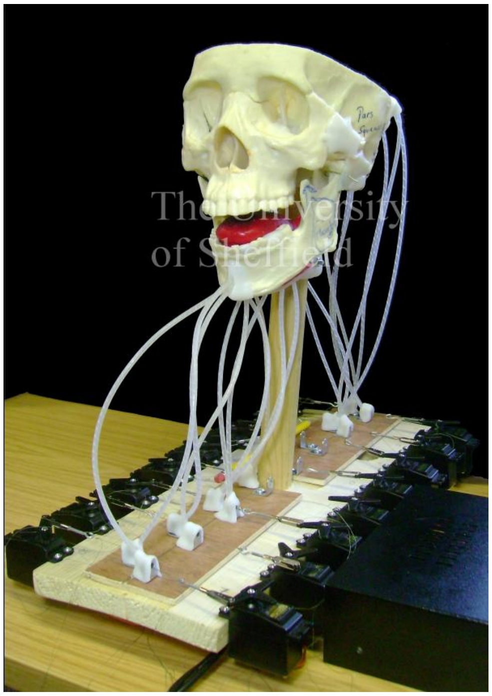


Figure 3: The Anton, a speech model created at the University of Sheffield [IV].

Problem Motivation:

Dysphagia, or difficulty swallowing, has potential to affect a large number and a wide variety of people. It can occur due to sarcopenia (loss of muscle tone due to age), neurological disorders such as stroke, or muscular disorders. . Dysphagia is detrimental to the patient's quality of life as he or she is no longer able to properly swallow all types of food. It can also lead to health concerns such as pneumonia (if food or liquid is aspirated into the lungs) or dehydration and malnutrition in extreme cases.

There are no devices currently on the market that have the purpose of studying dysphagia or the swallowing process. The ultimate purpose of this project is to construct a 3D model of the mouth and tongue that will accurately mimic the human swallowing motion, in addition to the weakened swallowing characteristic of dysphagia patients. The goal for this semester was to design an animatronic model of the tongue that would be able to perform the complete motion of a swallow.

Problem Statement:

The goal of this project is to develop an actuating tongue model. This tongue model needs to accurately emulatethe motion of a tongue during a swallow. It must go through the full range of action required to carry the bolus through the horizontal phase of the swallow and into the vertical phase. The tongue should apply equivalent pressure to the bolus and the oral cavity as an actual human tongue. In this way it can provide accurate pressure measurements under testing conditions.

The tongue should be able to imitate a number of dysphasia conditions in which the patient has difficulty swallowing. As some of these conditions are caused by dysfunction of specific muscles of the tongue, the model must be able to temporarily stop the movement of specified regions. By doing this, the tongue should be able to demonstrate the overall effect on the swallow resultant from the degradation of a particular set of muscles.

Design Requirements:

The tongue model will be made to accurately mimic the movements of the human tongue during swallowing. In order to achieve the complexity of motion necessary, a functioning animatronic model of the tongue must be created. In addition to accuracy of motion, the tongue must also be capable of applying appropriate pressure distribution, and must do so without breaking down or failing. This tongue will be used with various pressure testing devices and determine the ease of swallowing various foods under different neuromuscular conditions.

The model must be sturdy enough to allow for daily use. This includes being able to withstand the vast amount of water and edible food to which it will likely be exposed, as well as other fluids such as saliva. For the purposes of liquid studies, it must also be made of waterproof material. Because the model will be for demonstration purposes, sterilization is not an issue. However, due to its frequent exposure to foods and fluids of all kinds, the model must be relatively easy to clean.

In addition to the above, the model must also be able to swallow both hot and cold foods. The range of temperature for foods it must be able to swallow is 15-40 degrees Celsius. There are no real requirements for types of materials used, with the exception that the material be stain-protected. The material should be as close to the human tongue as possible.

In general, the client's top priority is accuracy. The model should be capable of mimicking human swallowing movements as closely as possible. The forces exerted by the animatronics should be similar to the force exerted by a human tongue, and the model itself should be able to move in a way that reasonably simulates the motions of a human tongue during swallowing. The model should be as close to a human tongue as possible in appearance, as well. There is also an emphasis on the reproducibility of the motion- the model must be capable of remaining accurate through repeated daily use.

Design Alternatives:

Mesh Design

This design alternative makes use of a silicone tongue, which provides both the firmness required as well as a degree of flexibility, allowing the model to be flexed and yet bend back into shape. This tongue is imbedded at various points with a screen meshwork, placed at the attachment points of essential extrinsic muscles used in the swallow. Attached to each of these mesh segments are cables, which then run out of the tongue along the line of action of the extrinsic muscle it is acting as. By controlling which and to what extent the cables are pulled taught, different movements of the tongue can be produced.

One of the major benefits of this design is that it more or less follows the lines of action actually present in the tongue, as opposed to equivalent motion being provided by some other means. As such, the tongue is able to move in the required directions.

However there are some downfalls to this design as well. Though it can move in the directions needed, the extent of movement is limited. It is quite possible the meshwork will only apply force on its specific region of the tongue, while the desired deformity of the rest of the tongue remains minimal. This would prevent the tongue from giving a full range of motion. As a result, the tongue itself might also be limited in its ability to provide the appropriate amount of pressure on both the bolus and oral cavity.

Plated Tongue

This design is made of one, solid plastic piece embedded in a silicone tongue. This solid piece resides at about the midpoint of the thickness of the tongue. It also is in the shape of the tongue, roughly, and has three T-pins attached to it. The T-pins are solidly fixed at the end of the plastic plate nearest the throat, about a third of the way towards the tip from the first T-pin, and at the very tip of the plastic plate. The silicone tongue is molded around both the plastic plate and the T-pins.

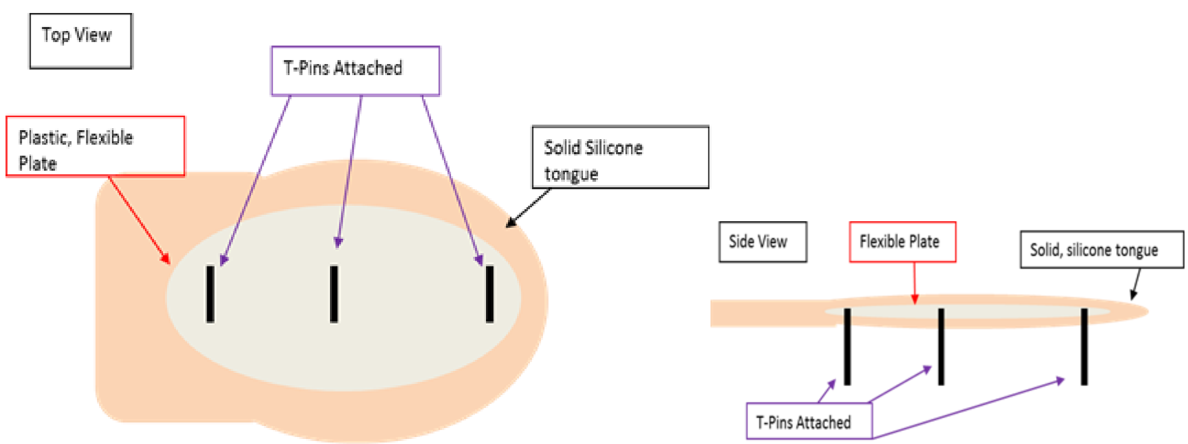


Figure 4: Side and top views of plate model.

In order to replicate the rolling motion of the tongue, the model is designed to arch/undulate in response to T-pin movements. By moving the T-pins and changing their relative heights, the plastic plate can be manipulated to create macro movements of the tongue. Through planned precise movements of the T-pins, an accurate representation of the motion of swallowing can be produced by the model tongue.However, since there would only be 3servo attachment points, accuracy might be an issue for this design.

3-Banded Tongue

This design consists of three separate plastic strips that extend lengthwise down the tongue. The strips are located in three different places looking from above; the center, and to either side of the center equidistantly from the centerline. When looking from the side, all three strips reside at about the mid-level of the tongue. At three different points along each plastic strip, a T-pin is attached. The locations of the T-pins along the strip are as follows: the throat end of the tongue, about a third of the way from the throat end, and at the very tip. These T-pins are fixed to allow vertical movement in either direction of the plastic strips. The actual model tongue is made from silicone molded around the plastic strips and the T-pins.

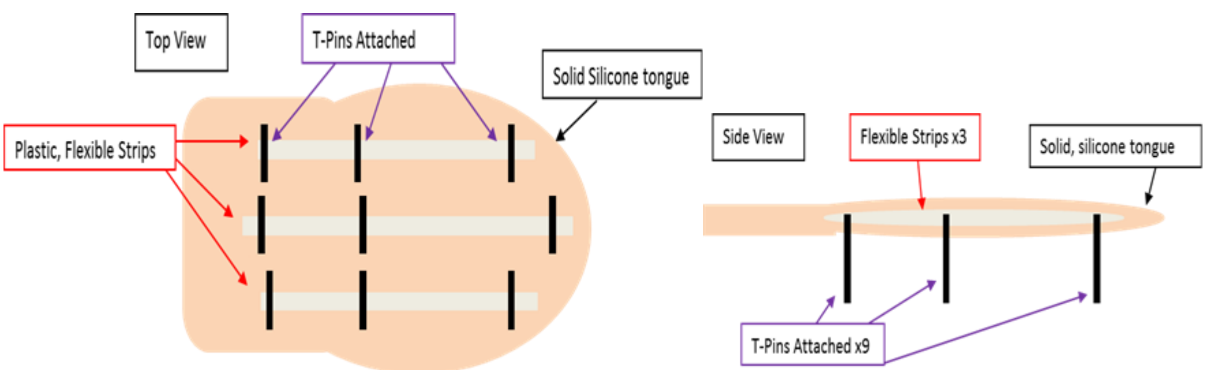


Figure 5: Side and top views of 3-Banded tongue design.

This model is designed to replicate both the rolling motion of the tongue and allow for a greater amount of freedom of manipulation of the tongue. With three separate bands, each with three separate T-pins, there are many different ways to control the tongue. The plastic strips are there to provide a solid arch/backbone that will move the body of the tongue in response to finite and precise manipulation of the T-pins. Each plastic strip can be made to arch up and also to undulate towards the back of the throat by varying the heights of the T-pins relative to each other.

Design Matrix				
	Designs:	3 Band	Plate	Mesh
accuracy	0.35	9	7	8
precision	0.3	9	7	8
ease of fabrication	0.1	7	9	5
durability	0.15	6	7	3
simplicity	0.05	5	8	3
cost	0.05	9	9	9
total	1	8.15	7.35	6.75

Accuracy

Accuracy refers to the models ability to generate movements and pressures that are close to that of an actual tongue. This is essential as the client will be using the model to simulate the tongue under various health conditions, and if useful results are to be obtained, the model must be able to provide realistic action and force. Due to it’s importance, this section had a weight of 35%. The 3-banded model scored best in this category, as it can provide a more complex movement and as a result can most closely emulate the motion of the tongue. The mesh design scored slightly less and the plate scored the least.

Precision

Precision in the ability of the model to produce consistent movements and pressures depending on its setting. This too had a fairly high weight of 30%.

Because this model will be used for testing purposes, it must be able to provide reproducible functions. The 3-banded design scored best in this category, each region of the tongue can more exactly be controlled with the increased bands and T-pins. Again, the mesh design scored slightly less and the plate scored the least.

Ease of Fabrication

The ease of fabrication refers to how easily the design can be manufactured. It had a weight of 10%. The plate design scored highest in this category, as it contains the fewest separate parts that need accurate integration. The 3-banded design scored below this, followed by the mesh design.

Durability

The durability, the longevity of the model, was also taken into account. Durability is required, as the model needs to be used frequently without wearing down. It was weighted with 10% of the total score. The plate design scored the highest in this area. The plate has fewer parts that can break down and inhibit the function of the tongue. The 3-band design scored below this, and the mesh design scored the least.

Simplicity

Simplicity of design refers to the overall design, including the number and interaction of parts, as well as their eventual integration with the servomotors. It was given a weight of 5%.

Again the plate design was given the most points, as it has the least components and the fewest servos required to control it. The 3- banded design and mesh design scored below this due to their many parts and greater number of servos required for their function.

Cost

Cost was weighted with 5% of the total. Every design did equally well in this category. The 3-banded, plate and mesh designs scored high, as none of them are particularly expensive to manufacture.

Total Scores

By totaling the weighted scores for each design, the 3-banded design was chosen with a score of 8.15, while the plate design had a score of 7.35 and the mesh design had a score of 6.75 out of 10.

Final Design:

For the final design, the 3-banded tongue was deemed to be the best choice. This was shown in the final design matrix. In order to build the 3-banded tongue model, there are two parts that need to be created—the tongue model itself and the servo motor system to control it. The model is formed through a complex molding process. First, the plastic strips must be measured and cut to size. Then, the T-pins must be firmly attached to the plastic strips in the final positions desired. Next, a negative mold is created for the silicone to be poured into. This is done by molding some alginate around a clay, life-size tongue replica in a large beaker.

Once the alginate has solidified, the alginate is removed from the beaker and cut lengthwise around the middle (top to bottom) so that the cut follows the mid-line of the tongue as viewed from the side. Each half of the alginate mold is pulled apart and the replica is extracted. Each of the plastic strips with the T-pins is aligned and inserted into the alginate mold that contains the bottom half of the tongue to the required depth. This fixes the strips and T-pins in the desired positions for the final mold. The two halves of the alginate are put back together, and the silicone is prepared for molding by slowly stirring the two ingredients together with some pigment added. The alginate mold is also prepped for pouring by the addition of air holes at the top. This helps minimize the amount of bubbles caused by trapped air in the final silicone model. The silicone is then poured into the alginate space until completely filled. After this the silicone is left to solidify and, once completely solid, is removed from the alginate.

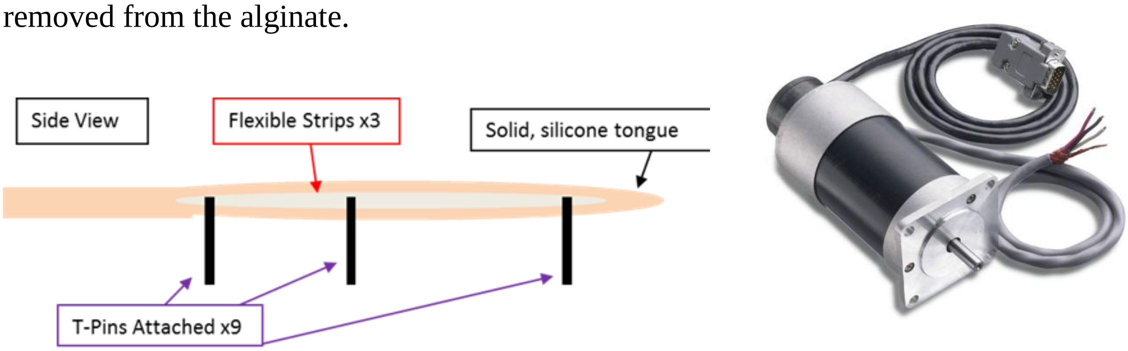


Figure 6: side view of final design and example of servo motor [VI]

The servo system consists of seven servo motors each connected to a T-pin. Though the original 3-banded design calls for nine t-pins and servos, the final design was revised to seven. This is because the servo controller that was purchased is only capable of controlling up to eight servo motors at once and spatial limitations. The final design may have a little less movement than the nine servo design, but this should be minimal. Theseven servo motors will be connected to a computer that will be able to control each of them independently at the same time. The computer will allow for complex tongue movements to be pre-programmed and run. These movements can range from normal swallowing to movements that incorporate swallowing disorders. One of the important aspects that needs to be considered however, is the relative strength of the servo motors and the resultant forces that the model can generate compared to normal human tongues. This will have to be looked at experimentally and adapted so that the model performs as close to normal values as possible. Currently, the final design has servo motors that were chosen based on cost and ability to generate moderate amounts of torque.

Design Progress:

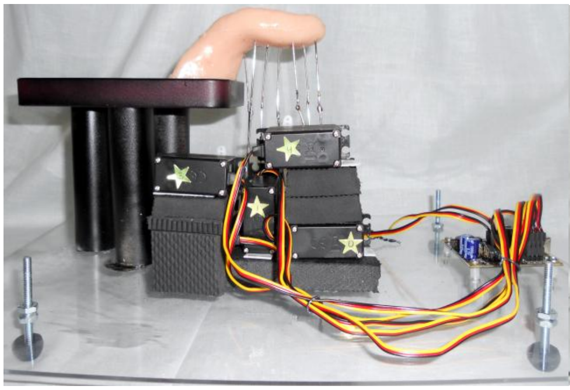
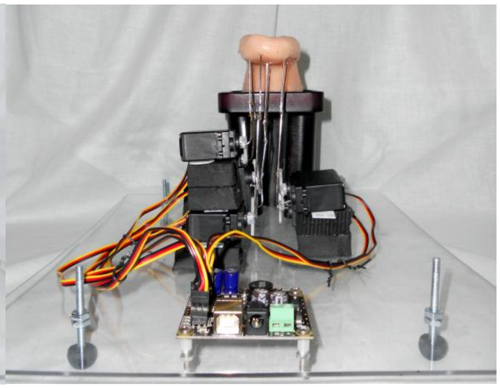
As stated in the design alternatives and final design, it was decided that the mesh and cable design needed to be dropped in favor of a t-pin and reinforcing strip design. The methods for forming the negative alginate mold and forming the silicone gel were also revised. This helped give the final prototype more stability, better aesthetics, and improved functionality. The first factor that improved the physical mold of the silicone was the use of Ecoflex 00-10 supersoft silicone—which is more flexible and life-like. There was also flesh toned pigment used to give it a more realistic appearance. Another important factor was an improved clay tongue used to make the negative mold—also thinner than the original—that incorporated more realistic texturing and eliminated some unnecessary structures. As far as pouring the mold, new precautions and steps were taken to minimize the amount of air bubbles in the silicone such as slower mixing and air holes for gases to escape the mold.

The t-pin design allows for more site-specific control of the tongue's movements as it progresses through the swallowing motion. Having the separate sections and t-pins be independent gives the user more control over the model. The user can move specific parts of the tongue together or at separate times. Having each side independent also allows the model to simulate diseased conditions, such as partial paralysis. There are a total of seven t-pins used in the final design: three along the middle, and two along each side. The three in the middle are connected by a thin, plastic strip that runs lengthwise down the tongue; the two on each side are also connected similarly. This gives the model extra support, increases the effect of each movement of the t-pin, and helps give the silicone a more realistic arching motion when the t-pins are being manipulated.

The automation of the tongue model is done by a system of seven servo motors. This system was constructed and attached to the model on a solid base with foam securing blocks, screws, superglue, PVC piping, and sticky pads. The system includes: the servo motors, the silicone tongue model, the servo controller, the t-pins and the base. The purpose of the base is to help to stabilize the prototype during use. The servo motors are controlled via the central servo controller which is capable of controlling up to eight servos. The servo controller is connected to a computer with a USB cord and to an outlet with an a/c power adapter. A program was written in Java to allow the client to use the model as desired and to command the servo controller. It is coded with functions for moving specific servo motors individually or multiple servo motors in concerted movements. The client asked for a realistic swallowing motion, which is replicated in a concerted movement. To improve accuracy, the client can also change the code if she desires at a later time. As of now, the code relays data to the client in a text-based manner and takes input in the form of integers for the identification of servos to move and positions to move them to. The code has the following options: individual control of each servo, a setting all servos to their default positions, a complete swallow, a slowed-down swallow, and a slow-motion swallow.

The servo motors were chosen based on cost and torque generation ability. The t-pins were attached to the servo motors by soldering additional cut t-pins to the ends of the existing t-pins. These were then bent at the end in order to slide into the servo motor's actuating arms. When needed, additional solder was added to the ends of the t-pins to hold them in place in the servo motor arms.

Results:

As seen above, the model is fully built and functional. A text-based program was written in Java that allows the model to make an arching swallowing motion in 0.5 sec, the time specified by the client as the duration of a swallow. The program can also move servos individually or in basic concerted movements. However, more must be added to the program to allow for the diseased states that the client wishes to study.

The base on which the model rests is fairly sturdy but the servos need a different mode of attachment for client use. More secure attachment could be achieved by using either metal brackets or by making custom plastic brackets, possibly using a 3D printer.

Solder was used to extend the pins to reach the servos; however, this provides weak points where the pins could break. This could be fixed by either welding the pins to make them longer, or using a solid piece of metal (which would require remolding the tongue).

The tongue creates a plunging motion backwards and downwards to complete the swallow. This was not possible to do with the current setup of servos and pins, but the addition of a pin oriented diagonally towards the back of the tongue should provide the desired movement.

Using ecoflex 00-10 supersoft silicone in the final design was beneficial to the success of the design. The tongue had good range of motion and did not exhibit any excessive stretching or tearing. The addition of texture and pigment to the tongue helped make it more lifelike, which is important to the client.

Testing:

A video demonstration of the tongue model was sent to the clients for evaluation. They responded with feedback to ensure qualitative accuracy.

"I think it looks really amazing. Your team did a great job this semester and brought the project forward nicely with innovative ideas." *Jackie Hind*

"Nice job! Would like to see base/back of tongue have a little more range of motion....

You have made it 'come a long way'." *JoAnne Robbins*

The above are direct quotes from our clients. They validate that the model portrays an accurate swallow, but could use more backwards motion for the "plunger" effect.

Future Work:

The next step in the continuation of this design project will be to develop a model of the oral cavity to house the tongue in, as well as a model of the upper portion of the throat. Both of these components will be required for the complete demonstration of a swallow. The materials used should provide realistic tissue qualities comparative to the actual mouth and throat.

In conjunction with the construction of the oral cavity, further testing should be done on the tongue functionality. Pressure against the model mouth can be measured to better determine tongue accuracy. With the completion of the oral cavity varied food substances can then be tested within the model as well.

With regards to the tongue itself, its mobility should be increased to more accurately represent the swallow. This can be achieved though the addition of an actuation point at a 45% angle to the back of the tongue and the attachment of an additional servo motor. With these changes, the tongue will be able to push back and down towards the throat to a much greater degree. Also, stable housing for the servos should be designed as well as more solidly attached pins.

The java program which runs the tongue can also be further developed. Disease model swallows should be input into the program so the tongue can perform a swallow with varied degrees of paralysis and force. User interface will also be streamlined, providing buttons to initiate tongue actions as opposed to requiring inputs.

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Appendix

Developing a 3D model of the Tongue and Mouth to Assess Pressure Generation When Swallowing

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Armand Grabowski
Nick Schapals

Function:

The device must be a physical 3D model of the tongue, mouth, and throat that closely mimics the mechanism of human swallowing. This semester's design will focus on creating a functioning, mechanical tongue that have the ability to realistically mimic swallowing motions of an adult, human tongue. The synthetic tongue will need replicate proper pressure distribution and mechanics. It will be used to test different pressure testing devices and also to determine the ease of swallowing different foods and liquids under different neuromuscular conditions.

Client requirements:

- A sturdy design to allow for daily use
- Waterproof material for liquid studies
- Easy to clean (Sterilization not necessary)
- Ability to be swallow hot and cold samples
- Stain-protected material

Physical and Operational Characteristics

Performance Requirements:
The product must perform the functions of the tongue, specifically the swallowing mechanism. In order to fully model and replicate swallowing and the fluid dynamics of the human mouth, the product will be required to: transport the bolus from the anterior to

posterior oral cavity for passage to the pharynx, simulate epiglottis down-folding, perform top to bottom contractions of pharyngeal constrictor muscles, and ultimately relaxation of the cricopharygeus muscle. In order to achieve this, a functioning, animatronic tongue will be needed. The mechanical tongue will be required to make all necessary movements in a life-like manner, as well as create proper pressure distribution. Additionally, the product will need to perform these tasks on a daily basis and interact successfully with both hot and cold food, as well as liquids.

Safety:

The product should be made to be very user friendly. This requires all proper safety factors including safety guards for any hydraulic systems and smooth surfaces on exposed parts to prevent injury. All air compressed powered hydraulic and electrical systems need to properly labeled with necessary warnings. Again, to ensure safety and functionality, all animatronics cables need to be imbedded in material, properly covered, and properly secured to the base structure. Servomotors, circuit boards, and other animatronics mechanisms need to be securely mounted to a base structure and covered. Additionally, non-allergenic materials should be utilized.

Accuracy and Reliability:

This product will need to have a great deal of precision (repeatability) in the movements and replicated swallowing fluid dynamics it will provide. Furthermore, the product will need to accurately simulate the swallowing mechanism of the tongue. To model the most typical case, the design should mimic an adult's tongue as closely as possible. In order to ensure accuracy and reliability the tongue will be mounted to a model lower mandible/jaw and rest inside a scale model mouth. The proper mouth specification (both size and function) should be designed as close to a typical adult's as possible.

Life in Service:

The product will need to be used daily for multiple demonstrations by various users. This continuous use should be able to persist for several years without any deterioration of materials and with sustained mechanical efficiency.

Shelf Life:

While in storage, the product should be able to withstand temperature changes from a range of 15° C – 40° C. The product will use servomotors and electricity to power its functions. Consequently, the shelf life of batteries and other powering sources do need to be taken into consideration. The materials the product will be comprised of will need to have shelf life of 5 – 10 years, so the product can be cost effective and have proper usage.

Operating Environment:

The device will be exposed to a great deal of water and anything edible during its time of use. It will need to operate with both hot and cold food (15°C - 40°C). The product also be required to endure frequent contact with fluid (i.e. water, other consumable fluids, saliva), vibrations (i.e. air compressor), and specific parts of the model will need to endure pressure conditions created by the physiology of swallowing. During storage, the model will need to be able to be exposed to dust, dirt, humidity, and extended non-use. Because of the nature of this device – modeling – the product will be exposed to extended handling and use.

Ergonomics:

This device will need to be very user friendly. The forces exerted by the pulling and pushing of the animatronics system used will be similar to the force exerted by the typical human tongue during swallowing. Ideally, the product should be light enough to be easy and straightforward to transport by a single individual.

Size:

The size of the product should be similar to the dimensions of the typical human mouth and jaw, while being easy to transport. This will require a degree of portability and limitation of additional components besides the model mouth itself.

Weight:

The maximum weight of the product is 50 lbs. to ensure ease of transportation and there is no minimum weight for the design. A lighter product would be ideal; however, weight is a low priority consideration in this design.

Materials:

Materials that will resemble the human figure should be used for the product. There are no specific materials that should not be used. All synthetic material and animatronics cables and motors need to be of a durable nature.

Aesthetics, Appearance, and Finish:

The product should resemble an actual human tongue as much as possible. There should be proper color and texture to the design that will resemble the tongue in order to suitably depict adult, human swallowing movements and feel. The client has requested to avoid red materials and utilize materials that do not absorb dye.

Production characteristics

Quantity:

The client has requested a single model for use in the lab. If the project is successful, more could be produced for labs elsewhere.

Target Product Cost:

The cost of the materials used to construct the prototype should not exceed $300, in order to fit the budget provided.

Miscellaneous

Standards and Specifications:

The device is not drug related so therefore doesn't have to be approved by the FDA, but could possibly have to undergo some other inspection in order to be used by businesses. Mainly, the students building the model will set the standards for this project.

Customer:

The product's most important use will be to serve as a testing subject for the pressure sensors developed, The Madison Oral Strengthening Therapeutic (MOST) device and

The Iowa Oral Performance Instrument (IOPI). The main use of the device that will be focused on is recreating the pressure and swallowing motion created by the tongue. The highest priority for the customer is ensuring accuracy in this regard.

Patient-related Concerns:

Because its purpose is outside of clinical contact with human subjects, the device does not necessarily need to be sterilized between uses, but will need to be easily cleaned to avoid mold and rotting food particles building up.

Competition:

Currently there are few devices resembling the proposed design, and none meant to study swallowing. There is, however, one line of devices that will be considered while designing the prototype. The dental community has innovated several versions of mechanical, interactive robots for clinical practice. The animated robots are, in various combinations, capable of "feeling," wincing, vomiting, and moving its tongue all in response to the practicing dentist's ministrations. The device uses some of the same ideas put forth by this team in creating a replica of a human mouth, notably, air powered "muscles." The most significantly similar technology is the functional tongue. It may not be capable of the fine motions necessary to mimic swallowing however. In addition, a team of researchers in Britain is designing a model of the mouth that can actually speak, utilizing a tongue that is very accurate in its human-like movements. However, Anton, as a research project, is not likely to be commercially available for some time, and is not designed to do the swallowing motion this project needs.