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Inguinal Hernia Model

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Abstract

An inguinal hernia is a protrusion of bowel in the abdominal cavity through the inguinal canal. This condition is very common and its repair is frequent. However, the procedure remains difficult to learn. We will create an inguinal hernia model that allows for the practice of open and laparoscopic surgery as well as teaching medical students and residents the anatomy. Our team considered different materials and ways to assemble the model, as well as client input, while developing a way to accomplish this goal. We evaluated the options giving us the most feasible and realistic design. Successful fabrication of the design will increase the accuracy and improve the learning process of medical students when performing open or laparoscopic surgery on patients.

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Background Information

Motivation

On average 600,000 hernia repairs occur each year and about one third of those are inguinal hernias. Inguinal hernias are very common and their repair has become one of the most frequently performed surgical operations. The chance of a male having an inguinal hernia in his lifetime is 27% while only 3% for females. While these surgeries are so frequent, the learning curve, or the number of times the surgery must be performed by any given doctor for him or her to master the technique, is said to be 250. Medical students, residents, and patients would benefit greatly from an inguinal hernia model that would allow laparoscopic and open surgery simulation with hopes to reduce the learning curve and increase the success rate of these surgeries (Rhodes, 2009).

Inguinal Hernia

An inguinal hernia is a protrusion of the bowel in the abdominal cavity through the inguinal canal. There are two types of inguinal hernias, direct and indirect, which can be identified by their relationship to the epigastric vessels. A direct inguinal hernia occurs medial to the epigastric vessels when contents of the abdominal cavity, or the hernia sac, protrude through a weak point in the abdominal wall. Causes of this type of hernia are often unknown, but lifting, straining, coughing, obesity, pregnancy, or constipation are often thought to increase the risk of occurrence. An indirect inguinal hernia occurs when the hernia sac protrudes through the inguinal ring, lateral to the epigastric vessels. This is the most common type of inguinal hernia and may occur at birth or later in life. Symptoms of an inguinal hernia may be gradual or sudden. They include a bulge in the groin or scrotum, discomfort, pain, and possibly a feeling of heaviness (Bupa, 2008).

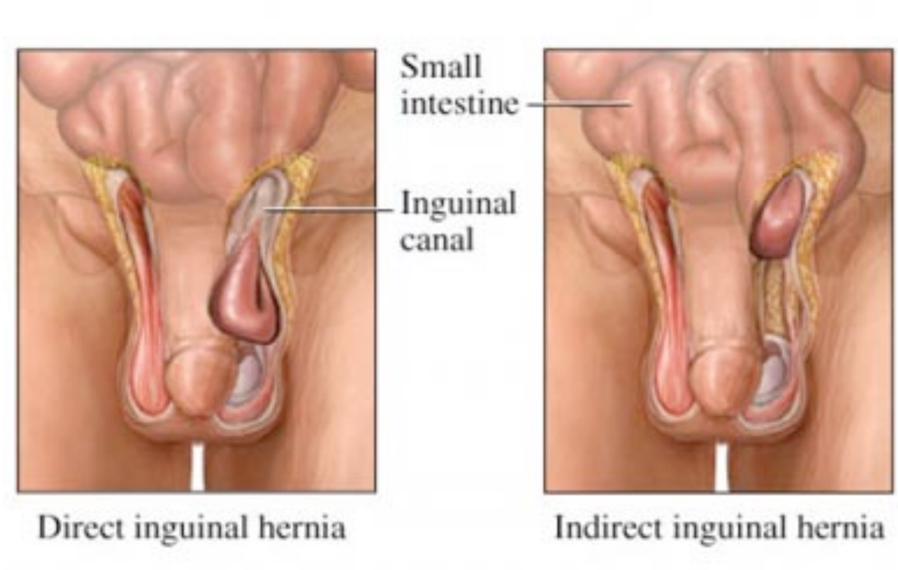

Figure 1. Direct and indirect inguinal hernias

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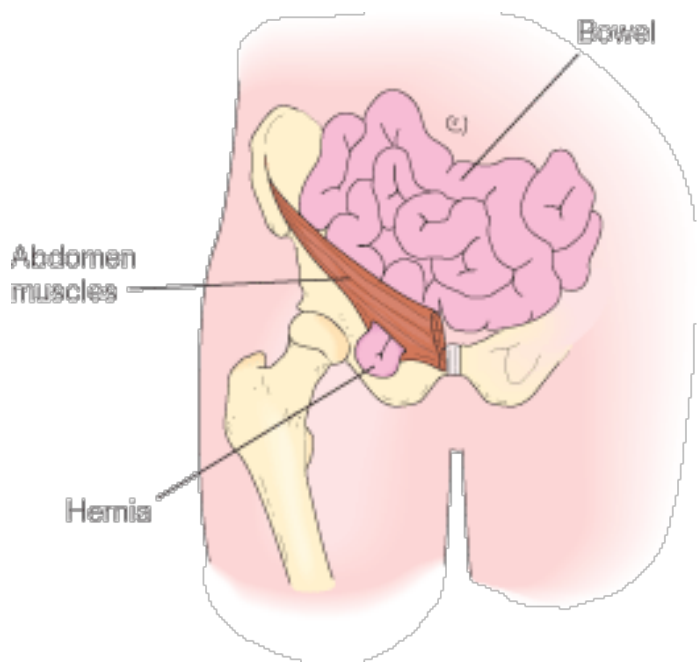

Figure 2. Protrusion of the bowel through the abdomen muscles.

http://drbhandari.com/images/inguinal_hernia.gif

Inguinal hernias do not always require surgery, though it is commonly recommended to avoid complications such as strangulation, or the loss of blood supply to the hernia sac. If a hernia sac in an adult can be pushed back or reduced, surgery can take place at the person's convenience. If it cannot, surgery must take place sooner.

The team's model will focus on two different types of hernia repair procedures, open and laparoscopic. Open surgery is the most common method of inguinal hernias repair. A single cut about 5cm- 10cm long is made in the groin. After the hernia is pushed back into place or removed, a mesh patch is sewn over the weakened area in the abdominal wall.

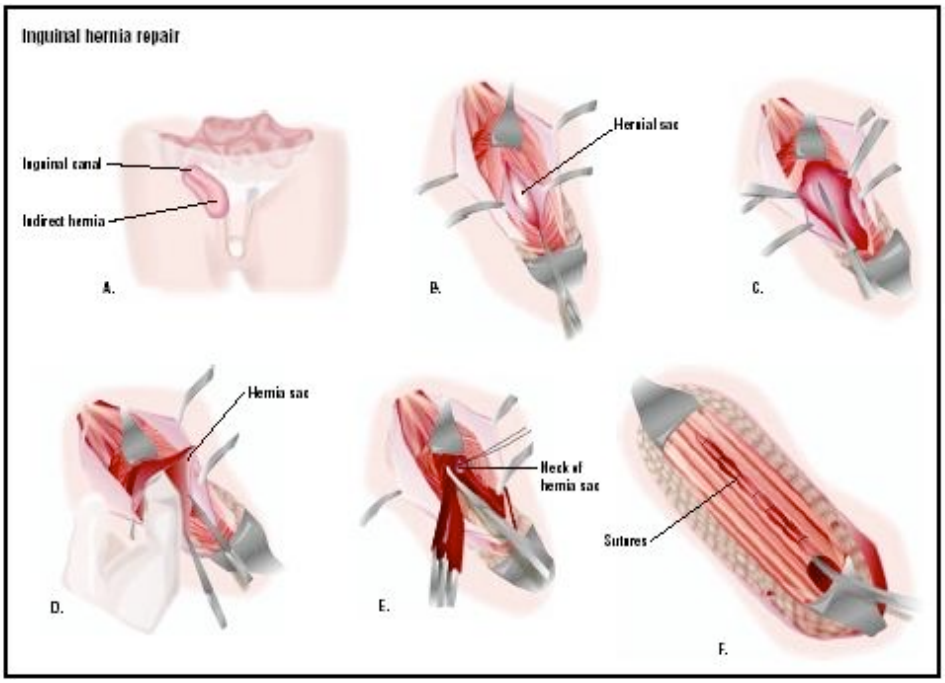

Figure 3. Open inguinal surgery repair.

http://www.surgeryencyclopedia.com/images/gesu_02_img0123.jpg

Laparoscopic surgery has some advantages over open surgery in certain situations. Studies show laparoscopic repair is less painful and allows patients to return to activities more quickly than after the open procedure (Rhodes, 2009). However, this type of surgery has a higher risk for serious complications. During laparoscopic surgery, the surgeon creates a small incision just below the navel. He or she places a balloon into abdomen, which is inflated with carbon dioxide so that the surgeon can see the abdominal organs. A laparoscope is inserted through the incision. The instruments to repair the hernia are inserted through other small incisions in the lower abdomen. After the hernia is pushed back into place, mesh is placed over the weakened area to reinforce the abdominal wall.

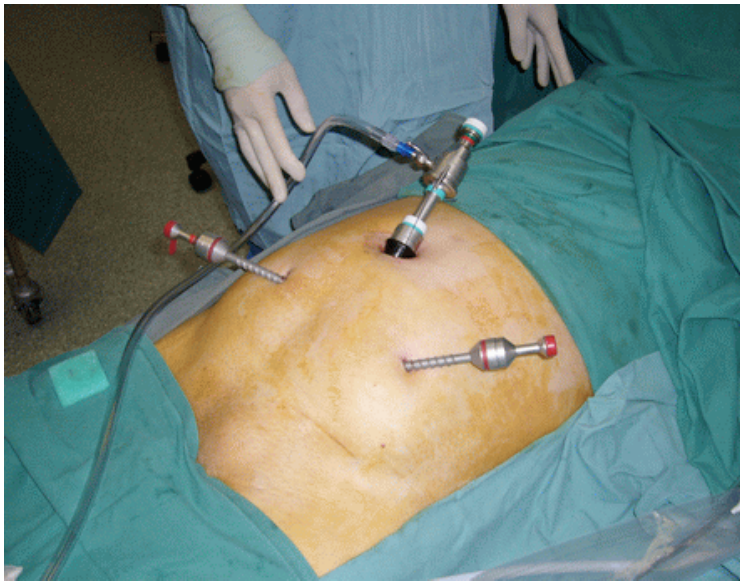

Figure 4. Laparoscopic inguinal hernia surgery repair, external view.

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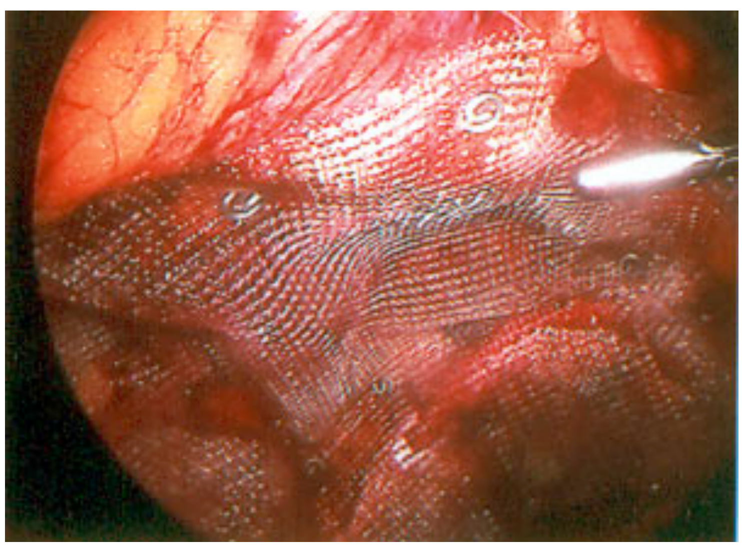

Figure 5. Laparoscopic inguinal hernia surgery repair, internal view.

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Client Information

Our client is Dr. Jon Gould who is an Associate Professor of Surgery at the UW School of Medicine and Public Health**.** He specializes in minimally invasive laparoscopic surgery of the foregut. In addition, he uses advanced minimally invasive techniques to treat acid reflux, obesity, and hernias.

Problem Statement

Dr. Jon Gould has requested a life-like anatomical simulation of inguinal hernia anatomy that can be used to train medical students and residents for both laparoscopic and open hernia surgical repair.

Hernia models that Dr. Gould has previously used did not have enough anatomical landmarks that are used to find specific nerves. The team's model will be made with materials that best imitate the appearance and feel of the body while having correct anatomy and including important anatomical landmarks.

Competition

Several models depicting inguinal hernias are currently on the market. Most models represent the defect in order to inform patients about their conditions, but there are few companies who make models that medical school students can practice the procedure of inguinal hernia repair.

Figure 6. Inguinal hernia model manufactured by Simulab (Simulab Corporation, 2010)6.

Simulab markets a model that is the most similar to this design project. This model, as shown in figure 5, shows students and doctors the anatomical landmarks used in laparoscopic repair while also showing the etiology of hernias. The trunk is covered with a removable skin, which has premade incisions that the procedure utilizes. This product also includes the following anatomical structures: pectineal ligament, transversalis fascia, external iliac vessels, inferior epigastric vessels, peritoneum, spermatic cord, and testicles. They have also created simulated bone landmarks including the anterior superior iliac spine and pubic symphysis. All layers can reflect to show deeper anatomy. This model depicts all three cases of inguinal hernias: direct, indirect, and femoral. Students can practice mesh placement multiple times on the various hernias. However, this model does not replicate the appearance of a human body. The model appears very stiff with unrealistic texture. In addition, medical students cannot create incisions, especially the cut through the fascia, an important aspect of the procedure. (Simulab Corporation, 2010).

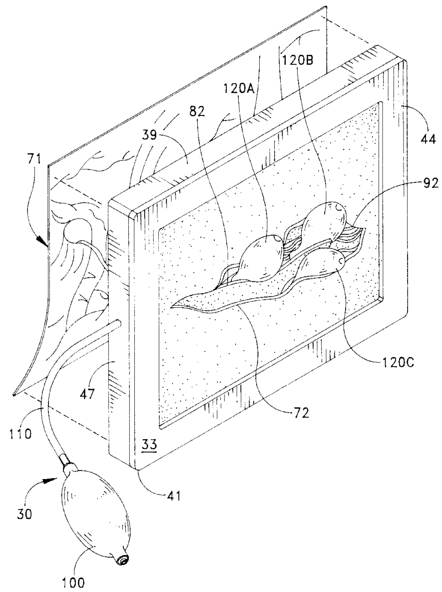

Figure 7. Inguinal hernia model patented by Goldfarb (1999).

The Goldfarb's patented hernia model, as shown in figure 6, is used to inform patients about hernias and the surgical operation to repair them. It uses three balloons to show indirect, direct, and femoral hernias enclosed in a frame suspending four layers—the epidermis, external oblique fascia, and transverse muscle. This relatively low cost model depicts the external oblique fascia, the transverse abdominis, the spermatic cord, and illustrated epigastric vessels. However, this model appears inadequate for teaching medical students as the model lacks structural landmarks and anatomical features, including the ilio-inguinal nerve and pectineal and inguinal ligaments (Goldfarb, 1999).

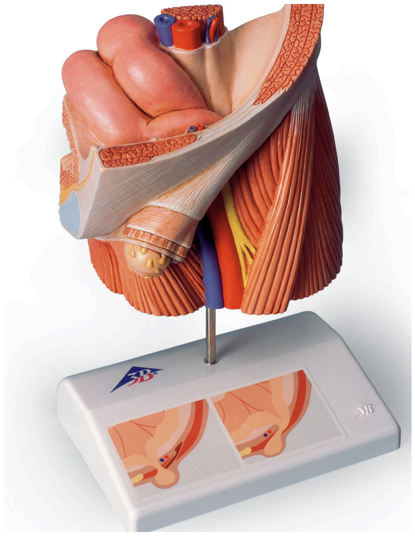

Figure 8. Inguinal hernia model manufactured by 3B Scientific (3B Scientific, 2002).

American 3B Scientific, as shown in figure 7, also produces a model directed toward patient education. The model depicts and compares indirect and direct hernias while also showing the major muscles in the pelvic region. In addition, the model shows the layers of the hernia sac and musculature. However, this model contains no removable parts as it is made from one solid piece of plastic, only showing deep anatomy by reflecting layers in the plastic. The texture and appearance are not realistic and would be of little help to a medical school student attempting to master the inguinal hernia repair procedure (3B Scientific, 2002).

Materials and Cost Analysis

Selecting the correct materials has proven to be one of the most challenging aspects of this design project. The model should consist of durable material yet exhibit the qualities of human tissue, including texture and color. After performing research, silicone, polyurethane, polyvinyl chloride, and latex seem to be the most effective materials to complete the design of the model.

Silicone is a polymer containing silicone, carbon, hydrogen, and oxygen (Greenwood & Earnshaw, 1997). Because this compound is highly inert, medical devices and implants commonly use silicone (Shin---Etsu Silicone, 2005). Silicone also shows flex fatigue resistance, which seems ideal for this application as students could practice multiple times on the same model (Shin---Etsu Silicone, 2005). The ease of fabrication is another benefit to this material, as silicone can be formed into virtually any shape. Greg Gion of The Medical Art Prosthetics Clinic, works with silicone because of its versatility and ease of fabrication. The prototype consists of $55.00 of silicone, which makes up all of the anatomical parts except the acrylic pelvis and aids in attachment. All vessels, nerves and oblique muscles were made with a typical silicone. The rectus abdominis muscles were made with silicone foam and covered with another type of silicone to make the muscles appear more realistic.

Polyurethane is another type of polymer commonly used in models. Because polyurethane remains durable and relatively inexpensive, it is commonly found in muscles and cartilage of many anatomical models. Polyurethane also comes in various textures and properties (McMaster---Carr, 2010). This creates the problem of finding the correct type of polyurethane for the desired texture. This also creates the problem of fabrication as the compound's properties vary, making polyurethane difficult to handle. However, polyurethane foam expands and sets rapidly, which became convenient in making the base of our model. Polyurethane foam is relatively firm, making the feeling realistic in comparison to a human abdomen.

Polyvinyl chloride (PVC) is yet another polymer found in anatomical models. This material is inexpensive and durable (McMaster---Carr, 2010). However, because of its hardness, PVC becomes difficult to mold and get the correct texture of the human body (Gion, 2010).

Latex is another polymer used in modeling that is normally filled with another material to achieve the proper texture. Because of this, the appearance of the anatomy could easily be replicated. Latex also proves to be tear resistant with high abrasion resistance (Hygenic Corporation, 2008). This material is relatively inexpensive. However, allergic reactions to latex are relatively common; occurring in about one in one thousand people. Allergic reactions range from mild to severe (Asthma and Allergy Foundation of America, 2010). Our model will come in contact with many people, eliminating latex in the final design.

Fabric was also utilized in the design as an attachment method and to create a more realistic appearance. Silicone only bonds to itself, so cotton fabric embedded with silicone was attached to the anatomical parts. To make the abdomen look more realistic, a pink polyester fabric was used as a peritoneum, the deep border for the model. The fabric also is stretchy, making the peritoneum more realistic in appearance. Nylon was utilized in creating the aponeurosis covering the muscles. As it is translucent and stretchy, the nylon exhibits the qualities of the transversalis fascia as well. These layers cover the hernia sac; therefore, the material needs to exhibit some stretch and fatigue resistance while maintaining a realistic appearance.

An aluminum bar is also utilized to mimic inflating the abdomen with carbon dioxide during the laparoscopic procedure. Aluminum is a nonmagnetic, soft, durable, lightweight, and malleable metal. As we wanted to create a custom shape and keep the prototype relatively light, this metal was chosen.

Total expenses this semester (Table 2):

Item	**Cost**
Modeling clay	$21.37
Model Magic	$18.92
Model of Pelvis	$56.38
Screws/ Velcro/ Metal support bar	$10.98
Strapping Tape	$5.38
Super glue/ fabric	$11.05
White nylons	$5.28
Silicone/ polyurethane foam	$77.00
Total	$206.39

Table 2. Total expenses. Materials purchased from January to May 2010.

Initially, modeling clay and Model Magic were purchased to create different parts of anatomy. Once anatomy pieces were replicated using Model Magic, Greg Gion remade them using silicone. From there, other parts were purchased to act as other features of anatomy including the peritoneum, apaneurosis, and attachment methods.

Total cost for a single prototype (Table 3):

Item	Price
Model of Pelvis	$56.38
Silicone	$55.00
Screws/ Bolt	$1.59
Coloring Dye	$2.00
Nylon	$1.76
Aluminum Support Bar	$0.90
Magnets	$14.00
Fabric	$2.00
Velcro	$0.72
Polyurethane Foam	$10.00
Total Cost	$144.35

Table 3. Total cost of one prototype.

Design Matrix

In order to compare the advantages and disadvantages of the materials, we have developed a design matrix. The design matrix evaluates four different types of materials: silicone, latex, polyurethane, and polyvinyl chloride. The categories that we used to evaluate the materials were determined from our client specifications.

Design Matrix for Materials

	Weight	Silicone	Latex	Polyurethane	Polyvinyl chloride
Cost	0.25	1	3	3	4
Durability	0.85	3	3	4	4
Appearance	1	4	4	2	1
Realistic texture	1	4	4	2	1
Feasibility	0.5	4	3	2	1
Safety	0.75	4	1	4	4
Diverse application	0.45	4	3	3	1
TOTAL		17.6	13.9	13.5	10.35

Table 1. Design Matrix.

The material design matrix is shown in Table 1. The categories chosen to evaluate the materials include cost, durability, appearance, realistic texture, feasibility, safety, and diverse application. We weighted these categories by ranking them on a scale from 0 to 1, with 1 being the most important. Each material was given a score from 1 to 4 relative to each other, with 0 being the worst and 4 being the best. Silicone was the rated the best material with a total of 17.6 points. The runner up was latex with 13.9 points.

The cost category was weighted 0.25 because we have a budget of $500 with potential for larger funds if necessary. Durability was weighted 0.85/1 because our model needs to be able to be used multiple times to teach many students. All of the materials that we looked at were relatively durable. The next category was appearance. Appearance is a very important category and was given the full weight. Silicone and latex were both received a 4 for appearance because these materials are easily manipulated into different colors, textures, and consistencies.

Realistic texture is also an important aspect of the design. Many other models have a realistic appearance but not texture (i.e. composed of hard plastic). Our challenge is to use durable materials that have a realistic texture so that the medical students and patients using the model can understand what the organs look and feel like. Again, silicone and latex were both ranked at 4 because they can be easily manipulated and patterned to get the different textures to mimic the different organs of the body.

We defined the feasibility category as how readily available the material is, how well it molds, and how easy it will be to manufacture. Feasibility was weighted 0.5 because it is important to select well-known materials, but not as important as the appearance of the model. Silicone scored highest in this category since Dr. Greg Gion, a materials expert, has offered to help us acquire the materials. He has also provided his knowledge to assist us in making different textures and shapes out of silicone.

Safety is very important for our model. Surgeons will be using sharp scalpels to cut through different layers of the model. All of the materials were ranked 4 for safety except latex since it elicits potentially severe allergic reactions.

Diverse application was ranked 0.45 because it will be useful and more convenient to make many different parts out of the same material. Silicone is the most versatile because we are able to manipulate the material to alter the flexibility, hardness, texture, and color.

Overall, silicone won as the material to use in our model because of its appearance, realistic textures, feasibility, and safety.

Final Design

Many properties of silicone are easily manipulated, which allows the material to be used in many diverse applications. This made it the clear choice for the final design of the inguinal hernia model. Other key features include thermal stability and low levels of chemical reactivity and toxicity. The flexible synthesis of silicone is useful for the replication of the various anatomical features of the hernia model. For example, small fibrous fishing wire was embedded in the silicone as it cured to replicate the appearance and texture of the illioinguinal and femoral nerves.

To realistically simulate the anatomy, a skeletal model of the pelvis has been used as a base for the final prototype. By using a realistic bone structure, the relative positioning of key components of the anatomy is more accurate. The bone structure provides an accurate portrayal of the pubic symphysis and anterior superior iliac spine (ASIS), which are both critical landmarks for the initial incision of the open repair. Furthermore, by using a skeletal base, the anchorage and suspension of the model's components has been achieved in a more life-like manner.

Several methods of attaching anatomical components to the pelvis skeleton have been implemented including Velcro, magnets, screws, and superglue. Securing the components via Velcro and/or magnet attachment incorporates the idea of detachable parts into the prototype. During the open surgical repair, the surgeon must descend and cut through the external, internal, and transverse abdominal oblique muscles. To avoid replacing the oblique muscles each time, our Velcro attachment mechanism allows the oblique muscle layers to be peeled away instead of incised. The specific fabrication and attachment method of the different components are discussed below:

Vessels

The various vessels of the design including the femoral artery and vein, epigastric vessels, spermatic cord, femoral nerve, and illioinguinal nerve were formed from silicone. Their shape was achieved using medical tubing of different diameter to replicate the unique size of each. Silicone was mixed, colored using oil paints, and poured directly into the tubing, which was capped and allowed to cure. After several hours the silicone was pulled from the tubing revealing the final product.

The attachment of the vessels to the pelvic base was slightly more complicated. Due to its limited strength, a screw would simply tear through the silicone. For this reason, we chose to reinforce the silicone using cotton fabric. Wrapping a small extension of fabric around the ends of the vessel and applying a thin layer of clear silicone remedied this issue. The thin layer of silicone embeds in the fibers of the fabric and also to the original vessel, consequently, forming a strong bond between silicone and fabric. Once in place, a single screw was placed through the fabric and into the pelvic base, securing each vessel in its desired location.

Ligaments

Ligaments in the model include the inguinal and pectineal ligaments. The fabrication of these materials is similar to that of the vessels. The thin, flat shape of the inguinal ligament was modeled from Model Magic and used to form a plaster mold. White silicone was then poured into this mold and allowed to set. Since this ligament also requires strong elastic strength, fabric was embedded in the silicone. The fabric makes the silicone more resistant to stretching and consequently more durable. The smaller, less complex pectineal ligament was shaped by hand from mixed, white silicone.

As a client requirement, the inguinal ligament attachment at the pubic tubercle was to be removable. With this in mind, we were able to drill a small cavity in the relevant pubic tubercle and install two small neodymium magnets using superglue. The corresponding magnet was embedded in the cup-shaped end using the previously discussed technique of fabric reinforcement to prevent silicone tearing. With this end magnetically connected, the opposing end was secured with a single screw into the anterior superior iliac spine of the pelvic base. Since superglue does not bond directly to silicone, the pectineal ligament was lined with a small layer of fabric using the technique of embedding silicone. The ligament was then secured in place via superglue attachment to the fabric on the lateral edge of the pubic tubercle.

Rectus Abdominals

The two rectus abdominis muscles were formed from silicone foam using plaster molds of Model Magic replicas. Upon lining the molds with mixed, colored silicone foaming agent, a plastic brace was set on top of the mold and clamped in place. This limited the expansion of the foam so the desired thickness of the muscle was not exceeded. Upon curing, the foam muscles were painted with a thin layer of silicone in which vertical striations were carved with a knife.

The lower portion of each muscle is attached with a single screw to the posterior of the respective pubic tubercle. However, the backside of the rectus was first fabric reinforced to prevent tearing and dislocation of the silicone. Furthermore, additional silicone was applied between the tubercle and muscle to limit the potential of silicone tearing. By client requirements, the rectus abdominals are to be reflectible. To achieve this, a curved aluminum support bar was installed to maintain proper positioning of the rectus abdominals. This aluminum bar was cut to size, curved, and its ends modified to fit the contour of the anterior superior iliac spine. The bar was then secured in place with two screws into the pelvic base on both sides of the model. This bar serves as the upper attachment point of the rectus abdominals as well as simulating the space inflated by surgeons in the laparoscopic procedure. Using the fabric reinforcement technique, a single neodymium magnet was fitted into the upper backside of each muscle. Since the aluminum bar is not magnetic, corresponding neodymium magnets were glued in place underneath the support bar. With this mechanism, we have achieved a very elegant and convenient method of muscle detachment.

Oblique Abdominals

Using Model Magic to determine the proper size and shape of the muscles, we were able to form plaster molds. From these molds, colored silicone muscle prototypes were formed. Simple silicone versions were chosen since the desired thickness was difficult to achieve with the silicone foam. After molding, colored silicone was applied to incorporate muscle striations similar to the rectus abdominals. Upon curing, each oblique muscle was cut to a more specific shape. To replicate the terminal aponeurosis of the muscle that serves as a form of attachment, we incorporated nylon fabric. The nylon was cut to size and attached to the underside of the each muscle by embedding silicone in its fibers and to the silicone muscle.

Lateral attachment of the oblique muscles was accomplished using a single nut and bolt. Bolt was threaded through each muscle layer and secured onto the support bar just above the anterior superior iliac spine. To prevent silicone tearing, the site of bolt penetration of each layer was fabric reinforced and washers were placed on either side of the bolt. In actual anatomy, below the arcuate line the aponeurosis of each muscle layer attaches at a medial point between the two rectus abdominal muscles. However, this degree of realism is irrelevant and unnecessary in our model. Therefore, for the strongest means of attachment, we chose to stretch each aponeurosis around the far rectus muscle. A thin, Velcro strip is attached to the lateral underside of the rectus muscle. Corresponding Velcro tabs were attached with superglue to the nylon ends. This tabular form of attachment is a simple and convenient way to peel back the muscle layers to view the underlying anatomy.

Peritoneum

To fill the unneeded underlying space of the model, polyurethane foam was used. By lining the pelvis with plastic sheeting and incrementally adding foaming agent, we formed an accurate foam imprint of the pelvic interior. This foam was later carved to meet the specific size requirements of the client. Covering the space filling foam with thin, pink polyester fabric more accurately portrays the peritoneum lining.

Bowel and Fascia

The most critical feature of the model is the replication of the actual hernia. Thin, tubular silicone has been used to recreate the herniated bowel. A plaster mold was created using a thin plastic tube as an imprint. Silicone was then colored, poured into the mold, and left to cure. Several attempts were needed to achieve a bowel with the necessary capacity to realistically stretch and bend. Replicating both direct and indirect hernias will involve several small openings in the abdomen wall through which the silicone bowel may pass. However, this prototype includes only a single opening that replicates an indirect hernia.

Using nylon leggings, a tube of nylon approximately an inch in diameter was reinforced at the seam and sewn to a corresponding circular opening of a small nylon sheet. This structure reasonably represents the transversalis fascia, which lies between the transverse oblique muscle and peritoneum. It is through this tubular opening that the spermatic cord, vas deferens, and indirect herniated bowel descend toward the scrotum. This nylon tube was set to pass through the relevant portion of muscle and aponeurosis of each oblique abdominal layer. The bowel is held in place by this passage. Furthermore, the thin nylon sheet was then spread across the peritoneum and secured.

Obstacles

Our group encountered a few obstacles along the way of designing our model. The first obstacle was that the inguinal ring was hard to simulate because the inguinal ring stretches and expands depending on how much bowel is in the hernia. Our model used silicone, which is sticky and so the hernia had problems smoothly getting in and out of the inguinal ring. In the future we will fix this by using a silicone gel.

The next problem that we encountered was how to suspend all of the anatomy pieces while still maintaining the realistic look. We overcame this obstacle by using silicone, neodymium magnets, Velcro, nuts, and bolts. These methods were all concealable by covering the attachment sites with silicone and attaching the anatomy pieces to the bottom of the pelvis.

Ergonomics

Although the realistic representation of hernia anatomy is the most critical design requirement, the model should ideally be easy to maintain. Limited maintenance is necessary for the user to enjoy repeated use. Therefore, attention was given to the durability of our model. We used silicone, which is very durable, while still having a realistic texture. We also used an aluminum bar to support the rectus abdominis, thus providing maximum strength. In order to secure all of the anatomy parts we used high strength neodymium magnets, screws, nuts, bolts, and superglue. Our model should not require any maintenance after purchasing it.

Ethical Considerations

In choosing our final material for our model we accounted for some ethical considerations. Latex is very durable and can be molded into many different shapes and textures. It also comes in many different colors and densities. However, we chose silicone as our final material because not only is it durable and moldable like latex, it is also inert and non-toxic. As many people are allergic to latex, we did not want to include it in our final design.

Future Work

Though the inguinal hernia model functions well to display correct anatomy and improve knowledge of the surgical operation, several further steps need to be taken in order to make the inguinal hernia model more realistic and beneficial.

Appearance

For our final design, we used silicone to fabricate most pieces of anatomy. One problem with silicone is that it has a very tacky texture. This is not ideal since the organs of a body typically have a moist texture. We would like to improve upon the realism. To do so, the silicone material would need to appear moister. One option would be to coat everything with a silicone gel that would reduce the friction of the silicone and give it a more realistic appearance.

Another option would be use a different material other than silicone, which will be discussed later.

Another change that could be implemented to create a more realistic looking model would be to use duller colors for the vessels and muscles. In the model, the colors are very vibrant and bright. In reality, this is not the case. This could be done easily by using a different colored mixture to dye the silicone.

Furthermore, the outside appearance could be changed as well. Though the main focus of our model is the inside anatomy, having a realistic outside appearance would contribute to having an overall realistic effect. This could be done by having an outer layer of removable skin. The skin would be fabricated using silicone or a different material and would really bring the project together.

Mechanism for Protrusion and Retraction of Bowel

When trying to simulate an inguinal hernia and the surgical repair, the protrusion and retraction of the bowel is a large part. Currently, one can manually protrude and retract the bowel with effort. This is due to the friction of the silicone in addition to the tight material that is used to represent aponeurosis. Ideally, the model would include a mechanism for easy protrusion of the bowel to simulate the inguinal hernia, and also less friction so that the bowel could be put back into place without as much effort while performing the surgical operation. This could be potentially be done by using a pneumatic mechanism to push the bowel through the inguinal ring and removing air when returning the hernia to its original position.

Material Changes

During design refinement, some material changes can be made to enhance the durability of the model. Currently, vessels and other anatomical features are attached by screwing fabric-covered silicone into the pelvis model. This is not ideal because neither the silicone nor fabric are very reliable and tear easily. Finding an adhesive that would stick to both the anatomical features and the pelvis model would solve this problem. Another feature that could be changed to increase strength is the aluminum support bar. With repeated use, this bar may become weak and not serve its proper function. Replacing this bar with a stainless steel support bar would deter any worry of this ever happening.

As noted before, the anatomy should appear moist not tacky. A different approach to using silicone gel would be to use a new material altogether. Plastic could be used as a material with less friction.

Further Testing

Besides the short-term evaluations we have received from doctors, it would be beneficial to perform long-term testing on our model to determine if it has helped improve the knowledge and awareness of the anatomy and surgery for medical students. Ideally, the model would be implemented in an educational setting. We would like to collect data of how current medical students learn and compare the learning strategy with medical students that would use our model. Analyzing test scores and the learning curve would give us a much better idea of what other features could be improved.

Conclusion

The creation of an inguinal hernia model will allow medical students and residents to practice the procedure of an inguinal hernia repair, increasing their awareness of the anatomy involved in the surgery, and therefore increasing their confidence and skill. The design, fabrication, and testing of the inguinal hernia model shows promise in providing this awareness. Though further testing must be performed to ensure effectiveness, not only will this be to the benefit of medical schools, doctors, and residents, but to their future patients as well.

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Appendix A

Project Design Specifications

#24- Life-like Anatomical Simulation of Inguinal Hernia Anatomy

March 1, 2010

Team: Carmen Coddington, Bryan Jepson, Laura Platner, Taylor Powers

Client: Dr. Jon Gould

Advisor: Professor Thomas Yen

Function:

Dr. Gould has requested a life-like anatomical simulation of inguinal hernia anatomy that can be used to train medical students and residents in anatomy, for laparoscopic surgical simulation, and for open hernia surgery simulation.

Client Requirements:

- Life- like internal and external appearance
- Interactive learning model
- Male model
- Life- size
- Materials realistically replicate anatomy
- Indirect and direct hernia
- Open and laparoscopic surgery

Design Requirements:

1) Physical and Operational Characteristics

    a) *Performance requirements*

        i. Interactive model.

    b) *Safety*

        i. No negative biological effects.

c) *Accuracy and Reliability*

i. Must accurately portray inguinal hernia and surrounding anatomy

d) *Life in Service*

i. Daily use for 5- 10 years

e) *Shelf Life*

i. 15-20 years

f) *Operating Environment*

i. In contact with surgical tools and hands.

ii. Must operate from 15^{o} to 30^{o} C

g) *Ergonomics*

i. Easily maintained.

h) *Size*

i. Dimensions of an average male from lower abdomen to upper thigh

ii. 14 x 10 x 10 in.

i) *Weight*

i. 15lbs- 30lbs

j) *Materials*

i. No latex

ii. Silicone

k) *Aesthetics*

i. Must naturally portray hernia and anatomy

2) Production Characteristics

a) *Quantity*

i. One model.

b) *Target Product Cost*

i. $500- $1,000

3) Miscellaneous

a) *Standards and Specifications*

i. FDA approval is required if placed in the market

b) *Customer*

i. Medical schools

ii. Hospitals

c) *Patient-related concerns*

i. Not applicable.

d) *Competition*

i. Inguinal Hernia Model (Patent number 5,908,302)

ii. SimuLab Product number HTM- 30

iii. American 3B Scientific Inguinal Hernia Model