Background Information

Every year millions of animals and human cadavers are used in medical training and research settings, driving up the costs of medical discovery and creating controversy among animal rights groups. Anthropomorphic phantoms provide a cheaper, reusable option. Physical models of organs can provide safe, repeatable testing and training of endoscopic tools and techniques. Currently, colorectal phantoms for colonoscopy device testing are not widely available, and upper gastrointestinal (GI) phantoms for endoscopy device testing do not exist. Thus, our goal is to create two GI phantoms for endoscopic and colonoscopic device testing: one of the upper GI tract, which will include the esophagus, the stomach, and the upper third of duodenum, and another of the lower GI tract, including the colon and the rectum. We will also embed targets in these phantoms in order to allow for testing of both devices and techniques.

Gantt Chart for Completion of Project Components

Table 1. Gantt Chart.
Discussion of Achievements, Problems, and Work that Lies Ahead

Since our previous report, we have attached all eight printed segments of the plastic colon mold to one another. Initially, we did experience a few difficulties. Our first plan was to attach the pieces using acetone; however, we quickly determined that acetone did not aid in the formation of a covalent bond between our plastic pieces. We realized that although acetone can form a covalent if used in conjunction with other types of plastic, the type of plastic that we used in order to print our pieces at the Vanderbilt design studio does not react with acetone. Instead, we used cyanoacrylate (super glue), which worked nicely.

Another problem that we had in gluing the pieces together, however, was that some of the pieces did not align perfectly to one another, and it was difficult glue two pieces together once the surface of the plastic had reacted with the superglue. Thus, in these cases, we used Lysol wipes in order to remove the superglue from the surface of the plastic, and we did our best to copy the picture of the .stl file in order to achieve the best alignment.

Now, that the pieces are joined, all the remains is painting them with EcoFlex in order to yield our final colo-rectal phantom.

In the last two weeks, we have assembled a rotating device to hold the 3D printed model of the lower GI tract. This device is used during the EcoFlex curing process. The 3D mold is tethered to and suspended from a rod which is then hooked up to a motor. While the motor is spinning, approximately 6 rpm, the 3D mold is coated in EcoFlex following the established curing protocol. Following each layer of coating, the device continues to rotate for approximately two hours to ensure even layers. Currently, we are on working on creating the finalized EcoFlex colon. We have six layers on the current mold and
simply need to fill in any gaps in the material when the new EcoFlex arrives. We have yet to test the removal of the cured EcoFlex to the entire colon; to date, we have only cured to and removed the EcoFlex from small portions of the 3D mold. Ability to remove will affect subsequent models. If removal is difficult, we will perhaps need to use a non-stick spray or Vasoline to help separate the 3D model from the cured EcoFlex. In the upcoming weeks, we will be working to finish the lower GI tract model, including adding a flesh-tone colored dye to give it a more life-like appearance. We will also be adapting the magnet and EcoFlex polyps to ensure they capture the essence of true polyps found in the colon.

Fig. 1. The fully conjoined plastic colon on the rotating device, being painted with EcoFlex.

This week, we also made progress on our stomach phantom. When we last met with Dr. Obstein, our advisor, he told us that our current stomach model was accurate in terms of dimensions, but that it should be more collapsible, be able to stretch to 150% of its size, incorporate inner gastric folds, and also be a fleshy tone of pink. With these criteria in mind, we made our second stomach prototype. For elasticity, we used one initial layer of dragon skin and then four layers of EcoFlex 0010, containing the dye. This was a reduction in number of layers of dragon skin as well as a reduction in the total number of layers cured (5 instead of 6). We made the folds by hot gluing insulated wires to the outside of the prior mold, and we altered the material properties by only using five total layers of painting, one of Dragon Skin followed by four of Ecoflex. The coloring was accomplished with pink dye. When we presented the updated version to Dr. Obstein, he was pleased with the presence of the folds and the texture, but not as pleased with the shade of pink. Although we have currently hit a roadblock with ordering more Ecoflex, we hope to soon make the pink shade more realistic in future models, and attach a new duodenum to the current model.
In a second iteration of our esophageal model, we have made several advancements in our two-piece mold. Per the request of our advisor, Dr. Obstein, we reduced the diameter of the outer portion of the two-piece mold from 2” to 1.25”, while maintaining the inner mold’s diameter of 0.75”. Hence, the final thickness of the phantom esophagus is 0.25”. Additionally, we applied a liquid-rubber coating to the inner wooden dowel rod to add ease to the removal process once the mold has set. Also, in our first model, we included a ring of paper towel at the upper opening in the esophagus to model the increased rigidity at the throat-esophagus entrance. However, this addition was rendered not feasible because some of the instruments to be used in the phantom model trials have a larger cross sectional area than the inner diameter of our phantom and require the normal elasticity observed in a pure EcoFlex model. Lastly, we added a pink dye to the EcoFlex in order to more closely resemble human tissue. In the future, we may try to use a different dye, or at least a different quantity, in order to achieve a color that resembles the human esophagus even more closely.

In an attempt to design an alternate stomach model, a two-piece mold was developed. Plaster of Paris, a quick-setting plaster product, was purchased and mixed in a 1 cubic foot container. The mixing protocol required 2 parts dry plaster to 1 part water by volume. A 3-D CAD model of the stomach was obtained and converted to an .stl file for 3D printing. Two stomachs were printed: one at regular human size, and another enlarged by 1 cm at the cross-section. The larger model was used to create the outer plaster mold. The larger stomach print was glued to the side of the container at a point so that the entirety of the stomach would be at least 1” from each wall. Half of the mold was poured and let solidify. Then, non-stick plastic wrap and lubrication was applied to the remaining half of the stomachs surface area and the exposed portion of the plaster. Then, the second-half of the plaster mold was poured and set until solid. This allowed us to have a two-part outer shell for the stomach. Once the plaster mold was set, the normal-sized stomach model was set in the center of the plaster mold using EcoFlex spacers that were approximately 1cm x 1cm x 0.5cm (thickness) at enough points on the inner stomach mold to ensure equal spacing at all points across the stomach. EcoFlex was poured into the opening of the mold and allowed to cure. Unfortunately, this model did not yield a
stomach with equal distribution of EcoFlex across its entire surface area. We believe that EcoFlex is too viscous to fill such a small area of air space because the air could not escape the mold at a fast enough rate. While the two piece mold initially proved successful in the esophagus model, we have decided not to continue to explore it as an option for the stomach.

Final steps were taken to ensure EcoFlex is compatible with electrical components of the phantom, specifically light-dependent resistors (LDR's). Previous optical tests were repeated to ensure transmittance of light through updated dyed EcoFlex is still sufficient, and no significant change from the uncolored material's transmittance was noticed, confirming LDR's as compatible. Additionally, LRD's were cured in EcoFlex formed by putty molds to make preliminary LDR modules that can be cured to the surface of a stomach phantom. Finally, concerning electrical components, two modes of endoscope tracking were researched. Video-based tracking with MATLAB image processing would allow for tracking of light emitted by an endoscope or other instrument when navigating the phantoms. A second option for similar light-based tracking would be installing several more LDR's and outputting signals to a physical model with LED's or a computer model to allow the user to better visualize and quantify surface area seen within the phantom. Previously, processing speed and power of MATLAB were making 3D model live tracking an unlikely option; so, now we are researching different 3D rendering software to enable our goals.

Additionally, some work that remains is to somehow sustain our phantom so that it does not collapse upon itself. Our most recent thought is to suspend it in memory foam, and one of the members of our group has already begun to purchase the foam for us.

Assessment of Whether We Will Meet the Objectives Proposed

As for the generation of a phantom of the upper gastrointestinal tract, we anticipate that this will be completed very successfully. Our first models of the esophagus, the stomach, and the upper third of the duodenum were received very well by our advisors, and our second prototypes seem even better. Now, virtually all that remains for the completion of this portion of the model is achieving a more realistic color and incorporating our electronic tracking (LED) system directly into the model. We anticipate that once we receive our next shipment of EcoFlex, this will be completed very quickly, well in advance of design day.
We anticipate that the completion of the phantom of the lower portion of the gastrointestinal tract will also occur well in advance of our schedule. Now that the plastic mold is completely finished and has been painted with EcoFlex, all that remains is to change the color of the phantom, as we see necessary, and to finish incorporating “polyps” and our Arduino system. Surely, this will be completed very soon.

Once the model has been completed, all that will remain will be to suspend it in foam. As we have already begun to purchase the foam, all that we will have to do once it arrives will be to cut a hole in the foam of the exact size of our phantom and to attach the phantom, itself. We are sure that our design will be completed on time and that it will be very successful, and we are excited to see it through.