Small bowel anastomosis simulation in residency training

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Abstract:

Background: In the last few decades, residency programs and medical schools have used cadaveric animal tissue to teach surgical procedures. Cadaveric animal tissue has become increasingly costly and unavailable, and currently there is a demand for more realistic models that accurately replicate the *human anatomy.* This project focuses on creating an affordable, accurate synthetic small bowel on which residents and surgeons can practice as well as be assessed on techniques such as resection and anastomosis. Currently, there are three human synthetic small bowel products on the market, but they offer no increased accuracy or anatomical complexity that promote their use over animal tissue. **Methods:** Therefore, to meet this demand, a novel synthetic small bowel was created using an innovative fabrication protocol called "The Nesting Dolls Technique." This product uses a cotton fiber mesh as a scaffolding matrix and cellulose fiber sheets and Smooth-On products to model the surgically-identifiable small bowel layers. Medical personnel performed a surgical simulation on the prototype and evaluated its performance. **Results:** The elongation at failure average of the synthetic bowel of 67.5% compares well to the literature-proven elongation at failure average for small bowel of 62%.[11] Qualitatively, the resident's survey of the prototype was positive for aesthetics, feel, and procedural capability. **Conclusion:** Overall, the finished product offers more simulation advantages than the current products on the market with its high degree of anatomical and mechanical accuracy, ease of fabrication, and overall decrease in product cost.

Introduction:

The educational approach to surgical training has changed significantly over the past few decades. While apprenticeship used to be the sole model of training, students are now also acquiring professional training by utilizing surgical skills laboratories.[1] Animal tissue simulations are the current method and are very useful because of their genuine anatomical attributes, but samples can be costly, unavailable, and short-lived.[2] The use of and demand for cadaveric animal tissue has therefore drastically increased within the surgical-training field to assess various surgical techniques. Due to a shortage of adequate material to practice and learn surgical procedures, it is of great concern to find a realistic alternative. The simulation of small intestine gastrointestinal procedures, particularly resection and anastomosis, is of particular interest to this project. Currently, it is common to use horse and rodent bowel tissue as practice for these surgical procedures.[3] With medical error being the third leading cause of death in the United States in 2013, residents and tenured surgeons alike cannot afford to translate animal tissue practice incorrectly to surgical procedures on humans.[4]

Globally, penetrating abdominal trauma results principally from military actions and wars, with 69% resulting from gunshots or shotgun wounds, and the remaining 31% from stab wounds. In penetrating abdominal wounds, the small bowel has the highest incidence of perforation at 50% incidence, followed by the large intestine at 40%.[5]

Intestinal anastomosis procedures are regularly done on civilians as well as soldiers to correct for numerous problems, such as malignancies (i.e. cancers) and benign conditions (i.e. polyps, infections, inflammatory bowel disease, and Crohn's Disease).[6] However, regardless of the underlying cause that prompts the need of intestinal anastomosis, the same complications can ensue. Postoperative complications include anastomotic leaks, bleeding, wound infections, and anastomotic stricture.[6] Practice and familiarity with different anastomotic scenarios are crucial to protect the long term safety and longevity of the patient, with patients showing four times the risk of mortality should they experience an anastomotic leak.[7] In conclusion, practice and familiarity with the anastomosis procedure can ensure that complications such as leaks do not arise, decreasing the mortality rate of a procedure that is carried out on both soldiers and civilians alike.

Current products on the market that model the small bowel lack the proper shape or texture of human bowel tissue, some even being made with fabric.[8,9] In addition to the lack of accuracy, the synthetic models are expensive, costing up to $375 per model.[9]

The objective was to study the usefulness and efficacy of the synthetic small bowel tissue model to test residents' knowledge and skill of bowel repair, resection, and anastomosis.

Materials and Methods:

Small Bowel Fabrication

The synthetic small bowel was made from Dragon Skin® FX Pro, a silicone rubber developed by Smooth-On. It was internally lined with a cellulose fiber sheet from Uline to model the mucosa and reinforced with a one-ply woven organic cotton matrix to better match the stiffness of in vivo small bowel.[10,11] Silc Pig®, an additive coloring pigment from Smooth-On, was added to the silicone to aesthetically resemble the small bowel.[12]

The cellulose fiber sheet and organic cotton fiber matrix are wrapped sequentially around a straight polyvinyl chloride (PVC) pipe with a diameter of 1.27cm. The silicone is then applied externally to the cotton matrix and then enclosed by another straight PVC pipe with a diameter of 2.54 cm. The difference in the two PVC diameters determines the thickness of the silicone layer. After the silicone cures, the model is removed from the mold. A surgical lubricant is applied to the external silicone surface to reduce the coefficient of static friction and to represent the peritoneal fluid in the abdominal cavity. The fabrication process is laid out in a stepwise fashion in **Figure 1.**

MTS Testing

Mechanical testing of the synthetic small bowel was performed in the Biomedical Engineering Tissues Lab at UW-Madison. The silicone sample was placed in the MTS Criterion C43.104 equipped with a 2,248kg load cell, calibrated with a voltmeter (**Figure 2**). The raw data was collected by Test Suite software, and then analyzed with MATLAB R2015a.

Simulation Evaluation Questionnaire

All simulation exercises were scheduled and conducted from March to April 2017 at University of Wisconsin Hospital (UW Hospital) in Madison, WI through the residency surgical training program. The methodology was institutionally approved under the scope of the Simulation Lab at UW Hospital.

Physicians, physician assistants, surgical residents and medical students who are in the medical program or affiliated with the University of Wisconsin, School of Medicine and Public Health or UW Hospital were invited to participate in a simulation exercise that included repair, resection, and two-layer hand sewn anastomosis of the human small bowel. A demographic survey of the residents was initially administered. All participants indicated sex, current position, specialty, years in training, number of bowel repairs performed (0, 1-5, 6-10, 11-15, 16-20, >20), currently teaching anastomosis procedures (Y/N) and experience using synthetic models (Y/N). The participant was given a perforated bowel to resemble a gunshot wound (in basin with artificial blood) and tasked with completing a resection and anastomosis to repair the bowel. All necessary surgical instruments were provided including an open tray and sutures. The participants completed the procedure individually and were given 15 minutes to complete the simulation.[13] The synthetic model was then assessed by Dr. Jay Nathwani, a 5th year surgical resident in the Department of Surgery at UW-Health. A practiced surgeon's results should meet the following criteria: a) the diameter of the bowel will not be reduced by 50% or more, b) the sutures should not be caught on the back wall of the bowel and should not rip the synthetic tissue, and c) there should not be any air or fluid escaping from the incision line.

Multivariate Analysis

After completing the simulation procedure, the participants provided feedback by taking a post-assessment survey, which included whether or not the model accurately resembled a human small bowel, procedural accuracy and post-procedure confidence and satisfaction with the synthetic small bowel. The survey was ranked on a 5-point Likert scale (1=highly inaccurate, 5=highly accurate) and additional comments were submitted by the participants.

The data was analyzed using the one sample Wilcoxon signed-rank test, median rating for each item on the simulation evaluation questionnaire was compared against a hypothesized median of

3 (indicating an average or neutral response). Nonparametric analysis was chosen due to the survey results not meeting criterion for normality.

Results:

After the tensile test was performed by a MTS machine, the data was run through MATLAB R2015a to determine the elongation at break (Mean=66%) displayed in **Table 1** for both of the samples. There were not enough samples to perform statistical analysis yet.

Simulation Evaluation Questionnaire Results

Multivariate analysis

No data yet

Preliminary Resident Feedback

Dr. Nathwani was presented with an initial prototype of the small bowel. He only gave verbal comments and critiques, so we could not make the transition between the qualitative survey to a quantified "score" of realism, as was initially planned. His comments are listed below in **Table 2.** While Dr. Nathwani informed us that there is still room for improvement in the anatomical accuracy of the mucosa, he was very impressed in how our model accurately appeared and felt like actual human bowel. He ran some stitches through the silicone and cotton fiber matrix layer and noted that when pulled to tension, the string did not rip through the silicone, a feature that is necessary in performing bowel anastomosis (**Figure 3**). Overall, Dr. Nathwani said that, when paired with the proof-of-concept mesentery, he could easily look at the prototype and identify it as a human small bowel (**Figure 3**).

Discussion:

The elongation of failure or strain is the percentage that the bowel stretched from its original length at failure. The synthetic prototype lengthened to an average of 67.5% of its original length which is similar to the small bowel which lengthened about 62% of its original length at failure.[11] The one-ply organic cotton fiber matrix accurately provided the necessary resistance to stretch compared to that of small bowel. While this is just one mechanical attribute, it is the most relevant in its use as an assessment technique in learning how to correctly perform the anastomosis procedure. Following the two-layer hand sewn anastomosis, the teacher checks the sutures placement and tightness by pulling on both ends of the small bowel. The stitches tear if they are placed too close to the resected area or, in simulation purposes, if the underlying material is not strong enough. By ensuring that the mechanical property of the elongation of failure is comparable, the suture strength will behave comparatively to that of in vivo human small bowel tissue.

In regards to the preliminary survey results from Fall 2016, Dr. Nathwani gave strong qualitative satisfaction with the tensile strength, surgical performance, and structural integrity of our innovative synthetic small bowel design. Additionally, the materials to fabricate each synthetic bowel model cost $5.67. This final product is far less expensive than other models on the market while still maintaining its efficacy in providing residents and surgeons a realistic small bowel equivalent on which to practice life-saving procedures.

Conclusion:

Overall, the finished product offers more simulation advantages than the current products on the market with its high degree of anatomical and mechanical accuracy, ease of fabrication (and thus, real-time availability), and overall decrease in product cost.

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Tables:

Table 1:

MTS Result	**Sample 1**	**Sample 2**	**Average**
Elongation at Failure (%)	170.2	164.8	167.5

Table 2:

Question	Answer
Pigmentation?	Darker pink
Structural Integrity?	Pulls apart like mucosa
Tensile strength?	Feels just like bowel
Handling?	Needs to be more slippery
Surgery performance?	Feels a lot like tissue
Inner texture?	Needs improvement

List of Figure Legends:

Table 1: The elongation at failure was determined using the Data Cursor on the graph determined in MatLab R2015a from the MTS data collection. Two samples were analyzed from a single prototype.

Table 2: Dr. Nathwani's comments on the anatomical accuracy of this semester's final small bowel prototype.

Figure 1: A schematic showing the steps of how the final prototype was fabricated. Labels A-F are noted in fabrication description. First, the outer PVC pipe was cut in half lengthwise (**1A)** to be used as the outer mold later. Second, the organic woven cotton fiber matrix acted as the silicone's scaffolding matrix and was painted a red to model the meaty red color of the mucosa (**1B).** Third, Smooth-On Dragon Skin® FX Pro was mixed and dyed the correct color of the muscularis (**1C**). The inner PVC pipe was covered in the cotton matrix (**1D** wrapped in **1B**). Then the muscularis-modelling silicone mixture was spread on the cotton-fiber matrix uniformly and such that no cotton fiber matrix was visible (**1E**). Finally, the PVC encased in the cotton fiber matrix/silicone was placed in one half of the cut PVC from 1A, covered with the second half of PVC, and secured to cure in a tightened clamp (**1F**).

Figure 2: MTS testing performed on a small bowel synthetic model. The raw data was collected from Test Suite software and further analyzed with MATLAB R2015a.

Figure 3: On the left, Dr. Nathwani running a stitch through the synthetic small bowel prototype. On the right, the final synthetic small bowel with the proof-of-concept mesentery.

Figures:

Figure 1:

Figure 2:

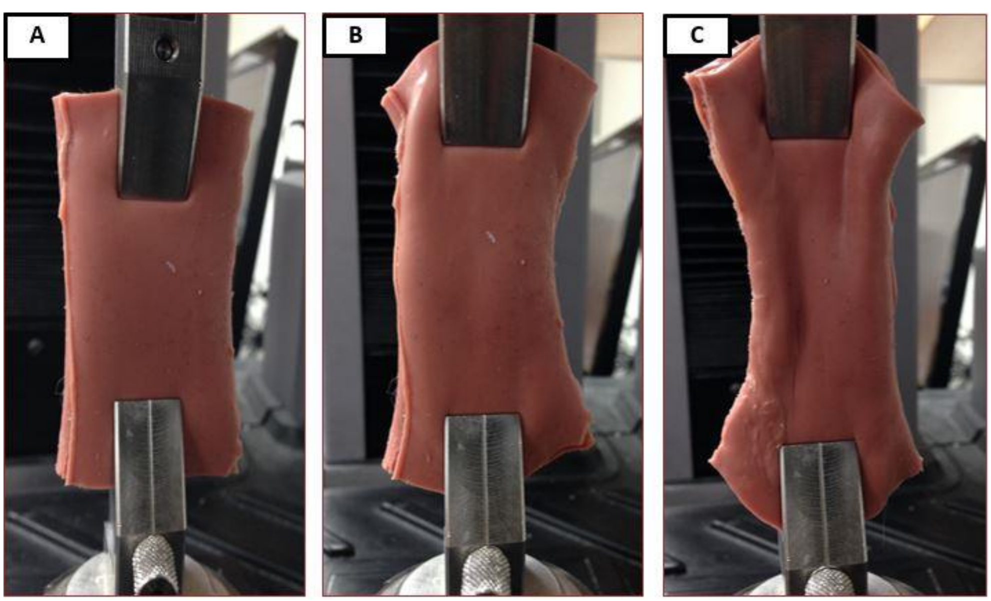
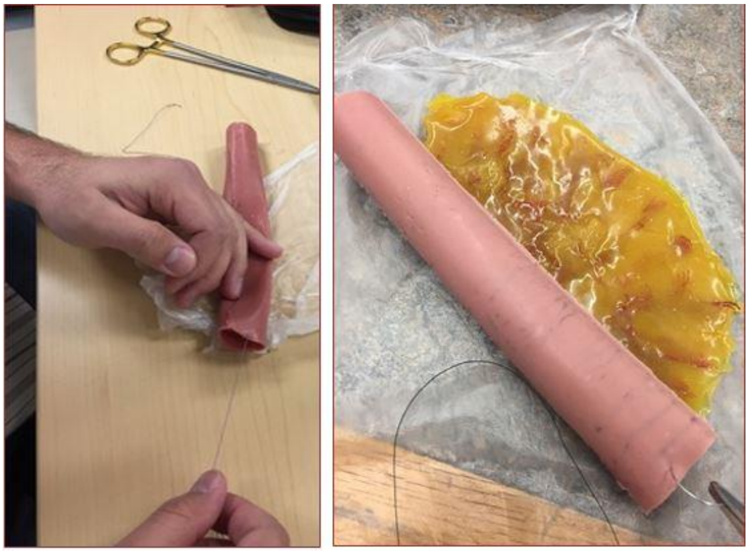


Figure 3:



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