Development of a Gynecological Laparoscopic Trainer

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Abstract- **Laparoscopic surgery is a minimally invasive alternative to open surgery in that it only requires a few small incisions. However, the complexity of this type of surgery due to the inability to see directly into the patient's abdomen requires surgeons to master a variety of psychomotor skills. Laparoscopic trainers are devices that allow medical residents to safely practice these psychomotor skills, but the extent to which they enable proficiency of surgical skills is limited due to their lack of anatomical accuracy. The team worked with UMass medical to design a cost-effective and accurate gynecologic laparoscopic trainer for ObGyn residents and surgeons that mimicked the female human pelvis and allowed for the simulation of realistic gynecologic procedural steps. The resulting design incorporated silicone-molded vasculature and 3D printed structures to accurately simulate the pelvic region of a patient.**

I. INTRODUCTION

Laparoscopic surgery is a minimally invasive alternative to open surgery that has become significant in the gynecological field because it reduces postoperative complications such as minimized pain and bleeding [1]. Due to its reduced invasiveness and positioning of the patient, direct visualization of the abdomen without use of a monitor is concealed [2]. As a result, specialized skills are necessary to successfully practice laparoscopic procedures. Laparoscopic box trainers are often used during laparoscopic training, and while the utilization of these trainers proves to be an effective method for training medical residents, few box trainers bridge the gap between low cost and anatomical accuracy [3]. As a result, integrating sufficient and effective box trainers into residential programs is a challenge to many medical schools.

Residents at the University of Massachusetts Medical Center experience variability in their surgical training and are not able to accurately practice procedures using the trainers accessible to them. Virtual reality trainers are often expensive and do not offer effective haptic feedback, while reasonably priced box trainers do not accurately depict the gynecological anatomy and landmarks that appear during gynecologic procedures [3,4]. More specifically, the box trainers available at UMass Medical are geared towards general surgery, especially with regards to the positioning of the anatomical features. These trainers are focused on practicing skills rather than actual gynecological procedures. Therefore, there is a need for a cost-effective and accurate gynecologic laparoscopic trainer for ObGyn residents and surgeons that mimics the female human pelvis and allows for the simulation of realistic gynecologic procedural steps, resulting in more consistent and satisfactory training that can be incorporated into the residency curriculum. The goal of this project was to develop a low cost, high fidelity laparoscopic trainer for surgical residents that mimics the female pelvis, its surrounding organs, and necessary vasculature to allow for simulation of realistic gynecologic surgery case steps, primarily for hysterectomies and laparoscopic vaginal cuff closure.

II. METHODOLOGY

A. Design Process

To meet the design objectives for the laparoscopic trainer, it was split into three parts: the bony pelvis, the abdominal casing, and the vessels and organs. The bony pelvis was created by finding a pelvic model online, downloading it into Solidworks, and 3D printing it from PLA plastic. The model was printed in three parts and assembled together with superglue. The abdominal casing was designed and visualized in Solidworks, but the final design was laser-cutted using an Acrylic board. The casing was attached to an adjustable platform to provide different planes of view to mimic patient positioning in real life surgeries. The vessels and organs were created from a combination of 3D modeling and silicone molding. Parts modeled in Solidworks were printed from PLA and filled with silicone mixtures to create anatomical structures that resembled the elasticity of true vessels and organs. Solidworks models that were designed and used to create the silicone models and abdominal casing are seen below in Fig 1.

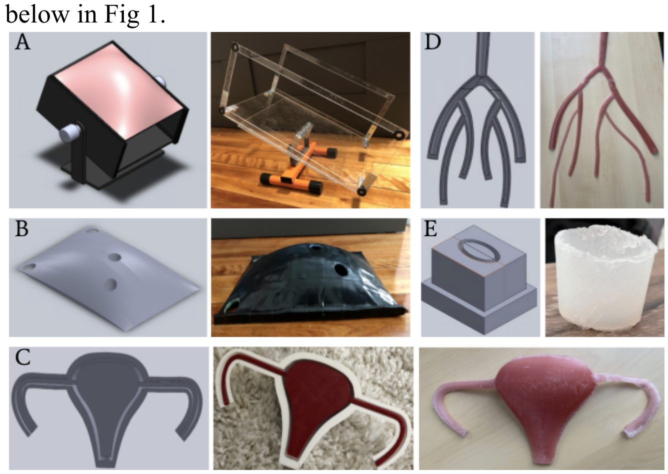

Fig 1. Solidworks models and final models of each part of the trainer. A) Abdominal casing box. B) Abdominal casing top curve. C) Uterus. D) Vessel network. E) Vaginal cuff.

B. Testing

To ensure the team's device met the client's main requests, verification methods and data analysis were used to validate the device features. The first test consisted of qualitative, mechanical testing in which the anatomical accuracy of the silicone was evaluated through mechanical compression testing. Three silicone vaginal cuff models were created using a silicone molding kit that contained two different parts (Part A: Part B) to be mixed to fabricate the material. The first cuff had equal parts of the two components, while the second cuff had a 4:3 ratio and the third a 3:4 ratio of part A to B. Compression testing of each cuff using three different weights was conducted to find the strain caused by the applied loading on the cuff models in order to calculate the elastic modulus of each cuff using Equations 1 and 2.

$$\varepsilon_{long} = \frac{d_{short,f} - d_{short,i}}{d_{short,i}} \quad (1)$$

$$E = \frac{\sigma}{\varepsilon_{long}} \quad (2)$$

Where ε_{long} is the longitudinal strain, $d_{short,f}$ is the final diameter of the short end of the vaginal cuff, $d_{short,i}$ is the initial diameter of the short end of the cuff, E is the elastic modulus, and σ is the stress applied from the weight. Comparisons between each of the vaginal cuff models were made as well as comparisons between the silicone models and actual vaginal tissue values. The second group of tests consisted of resident testing. Utilizing initial surveying, laparoscopic skills testing, and post-surveying, this testing provided qualitative validation of the final design from residents who would be most likely to use the device. Overall, both types of testing allowed the team to verify specific design choices used in the process of creating the device in addition to validating the device as a whole in regards to the specified design objectives and client requests.

III. RESULTS

A. Final Design

The flexibility of the silicone vessels, vaginal cuff, and uterus phantom mimics the elasticity of the true anatomic structures. The curved top of the final assembly, shown in Fig 2, mimics the inflated stomach of a patient undergoing laparoscopic surgery, and the removable port inserts act as platforms for surgical tools. The adjustability of the device provides a minimum of a 45° angle in either direction to mimic the angling of a patient during surgery.

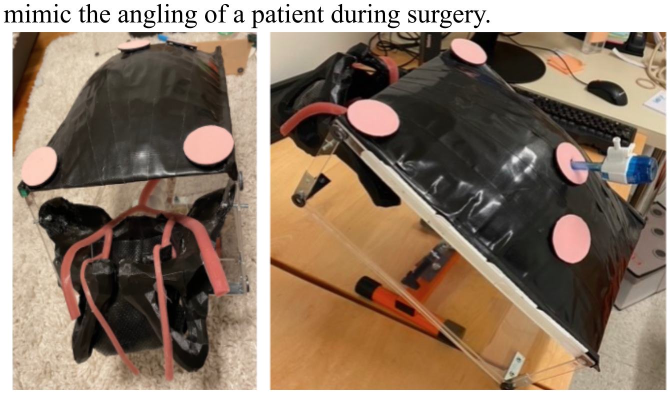

Fig 2. Final assembly of gynecological laparoscopic trainer.

B. Mechanical Testing Results

Mechanical testing was conducted to verify anatomical accuracy of the anatomical models. This verification step was crucial in determining if ample haptic feedback would be given to the users when undergoing surgical tasks like vaginal cuff closure. The resulting elastic modulus, E, of each cuff are seen in Fig 3. The 1:1 ratio cuff resulted in the highest elastic modulus (1338 Pa) compared to the elastic modulus of cuff 2 and cuff 3 with values of 904 Pa and 761 Pa, respectively.

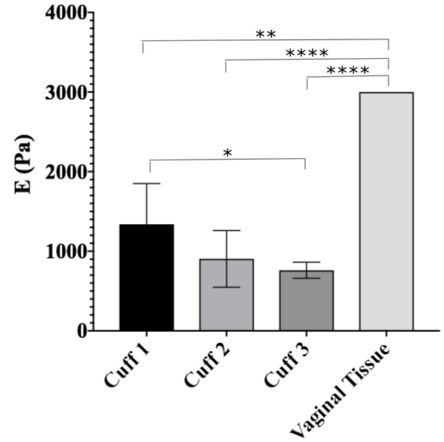

Fig 3. Comparison of cuff elastic moduli.

The differences in composition between the three cuff models were not drastic due to caution of the silicone not curing well or remaining in a liquid state, which would thus not allow for proper compression testing to take place. The first cuff model, however, demonstrated a higher elastic modulus value that is closer to that of inner vaginal wall tissue (~3.0 kPa).

IV. CONCLUSION

The main focus was on creating anatomical structures that simulated properties of the true features to create a new design of a laparoscopic trainer that provides residents at UMass Medical a more realistic alternative to practicing laparoscopic skills. In terms of anatomical accuracy, this device expands beyond the realistic vaginal cuff model used with the trainers at UMass by incorporating a curved top, pelvic model, and adjustability component. Together, these features provide residents with a more realistic operating site to practice laparoscopic skills. Additionally, the device is much less expensive than those currently used at UMass. While the current trainers at UMass do well to enable basic skills training through use of its training platforms, the team's device allows specific procedural skills to be practiced through use of its anatomical structures and detachable components.

V. References

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