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LAPAROSCOPIC TROCAR INSERTION FORCE SIMULATION

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ABSTRACT

Laparoscopic surgery is a common minimally invasive procedure that is performed through small ports in the abdominal wall. The ports are created with tools called trocars that are used to inflate the abdominal cavity and are used as gateways for surgical tools. There is limited training on trocar insertion for novice surgeons and it is a crucial step in the laparoscopic procedure. There are several challenges associated with placing and inserting trocars in the abdominal area. In this paper, experimental data is used to create a mathematical model for the expected trocar force, which had an average error of 3.67%. A novel trocar training system is proposed to effectively simulate the haptic feeling of inserting a trocar into the abdomen.

Keywords: Laparoscopic Surgery, Minimally Invasive, Trocar, Instrument Force, Stretchable Natural Rubber

1. INTRODUCTION

Laparoscopic surgery is a minimally invasive surgical procedure used to access the inside of the abdomen without large incisions like in open surgery. Laparoscopic surgery is typically performed with three to five, 1~2 cm keyhole incisions [1]. Due to the smaller incision size, laparoscopic surgery has reduced recovery time and provides several health benefits for the patient compared to open surgery [2,3]. Laparoscopic surgery is performed by inserting the tools through gateways called trocars. A trocar is inserted into the incision and pushed through the underlying subcutaneous tissue and muscle. The trocar is then used to inflate the abdominal cavity with CO_2 gas and laparoscopic tools can be easily inserted through the trocar [4].

When performing laparoscopic surgery, instruments must be easily inserted into the body and removed as needed. The trocar is used to seal the surgical openings and create a tunnel-like entry for easy access to the abdomen [5]. While this process of trocar insertion may be routine for many skilled surgeons, developing appropriate training for novice surgeons is critical because the risk of complications associated with poor procedural performance can be life-threatening to the patient [5]. Additionally, incorrect placement of trocar locations will require additional ports, increasing the chance of hernias and slowing the recovery time [7].

Extensive training is required for a surgeon to become proficient in laparoscopic surgery [6], and constant advancements increase the demand for an effective training system [8]. Laparoscopic surgery is especially challenging in pediatric patients where space to maneuver tools is very limited. There is currently no training system that focuses on the initial insertion of trocars into the ports. Current training tools often have predetermined port locations for tool insertion into the body, which do not require the trainee to practice the force required to insert the device into the abdomen. It has been reported that decisions surrounding the force and location required to cut through the abdomen are made “on the spot” [8] in real surgical scenarios. For a novice surgeon, it can be risky and overwhelming to make decisions on the amount of force applied and the location of the port, with little to no prior experience and no effective tool available to practice.

When inserting a trocar, it can be particularly challenging to know the force required to break through the multiple layers of the abdomen. Specifically, the abdomen has seven layers in which the size and thickness vary from person to person [9]. On average, the rectus abdominus and transverse abdominal muscle are approximately 14.9 mm thick for men, and 12.2 mm thick for women [9]. Furthermore, the average transverse abdominis and external and internal oblique thickness are approximately

19.1 mm and 14.4 mm respectively [9]. The skin and subcutaneous tissue thickness can range from 2.2 to 28.1 mm in men and 5.2 to 27.4 mm in women [10]. When it comes to the layer of fat, the thickness can range drastically based on the patient. This can make it difficult to prepare novice surgeons for the force required when perforating through the abdomen [11].

Inserting a trocar requires the surgeon to insert the instrument through the muscle and avoid applying excessive force. The device must be inserted at the correct angle and depth depending on the patient's size and anatomy, as shown in Figure 1 [13]. Although pressure may vary, one study found that the average pressure to insert a trocar was 3.42 PSI [13]. Measuring force at different points of a laparoscopic procedure can be used to better understand anatomy differences that can be applied to more effective training systems.

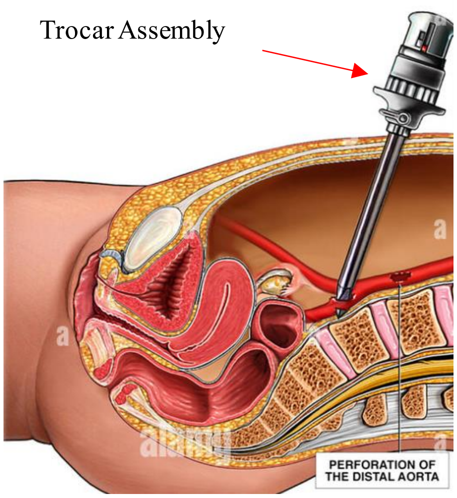


FIGURE 1: TROCAR ASSEMBLY INSERTION INTO THE ABDOMINAL CAVITY [13]

A novel trocar training system is proposed to effectively simulate the haptic feeling of inserting a trocar into the abdomen. This system will simulate the forces by deflecting and breaking through multiple thin rubber sheet layers. Rubber sheets break at specific positions using a heated coil trocar, as illustrated in Figure 2. This system provides novice surgeons with a cost-effective and safe method to practice. In addition, this system will effectively measure trocar position to provide the user with an accurate assessment of their performance. This paper focuses on measuring rubber material deflection to determine how layered rubber sheets can be arranged to create a prescribed haptic force.

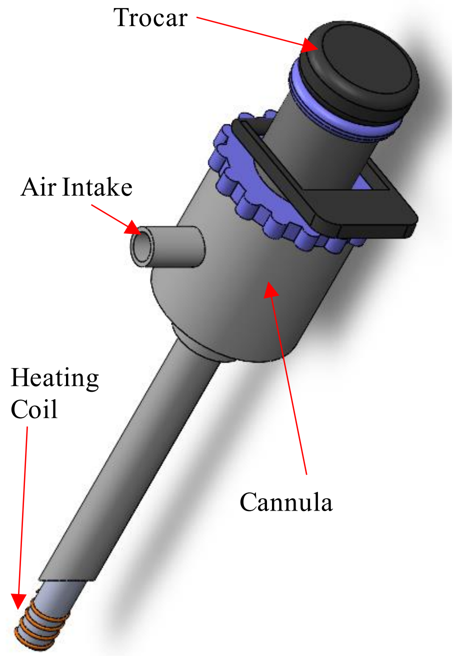
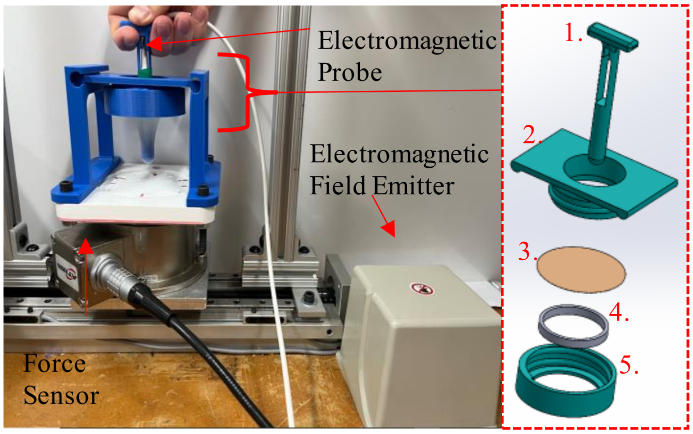


FIGURE 2: TROCAR ASSEMBLY CONTAINING THE CANNULA AND TROCAR WITH HEATING COIL

2. MATERIALS AND METHODS

The goal of this experiment is to test how varying rubber thickness along with varying diameters of mounted rubber can impact the simulated haptic force. With this knowledge, the force prescribed in the trocar training system can be specifically tuned to match desired simulated force profiles.

To evaluate the haptic force that can be created by layered rubber sheets an experiment was performed as shown in Figure 3. The experimental setup includes a polylactic acid or PLA fixture that was mounted to a Gamma IP65 force sensor (ATI, NC, United States). A natural rubber strip was placed between two separate PLA disks and a modeled trocar was pushed into the natural rubber as shown in Figure 3. To accurately measure the position of the trocar during insertion an internal electromagnetic tracker (NDI, VT, United States) was used. As the rubber strip stretched, the force was recorded on the IP65 force sensor. The rubber was easily replaced by separating the disks and loading them in a new piece. MATLAB and LabVIEW were used to measure and record all forces and distances during testing. The remaining details and outline of the research study are presented in this section.



1. Model Trocar
2. PLA Disk Top
3. Rubber Material
4. Varying Disk Diameter
5. PLA Disk Bottom

FIGURE 3: EXPERIMENTAL DESIGN SETUP FIXTURE TO TEST TROCAR FORCE

The experiment included testing varying port diameters of mounted rubber (44, 38, 32, 25, 19 mm) and varying rubber material thickness (0.15, 0.2, 0.25, 0.3 mm). The position of the trocar, with the attached electromagnetic tracker, is recorded as it is pushed into the rubber sheets, and the force is simultaneously recorded. The trocar had a diameter of 12 mm. With four different rubber thicknesses, and five different diameters, in total there were 20 tests performed that recorded the force and displacement of the rubber.

3. RESULTS AND DISCUSSION

The results from the experimental testing show that decreased mounted diameter size and an increase in rubber thickness create greater resistance, as shown in Figure 4. The decreased mounted rubber diameter means a shorter length of material is being stretched and therefore greater resistance is felt. The greater thickness of rubber material the larger volume of material that must be stretched and therefore greater resistance is felt.

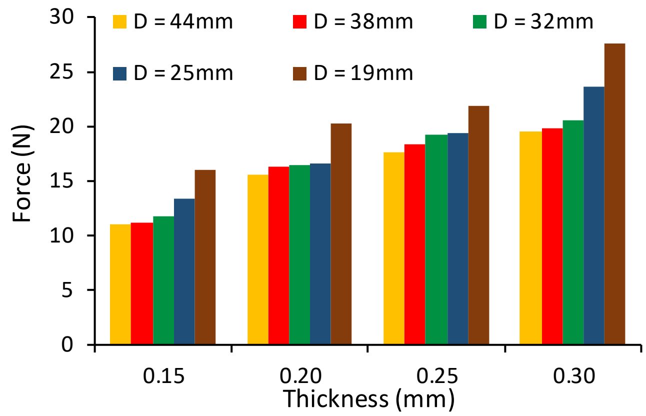


FIGURE 4: FORCES AT A TROCAR DISPLACEMENT OF 42 MM FOR ALL THICKNESSES AND DIAMETERS

On average, the change in diameter resulted in an exponential change in force. Furthermore, changes in thickness resulted in linear changes in force. These trends in the force plot were made into a single equation with the use of supervised machine learning. This equation was found by assigning coefficients to the parameters: port diameter, rubber thickness, and trocar position. The coefficient matrix was calculated by using the gradient descent equation and a cost function:

$$J = \frac{1}{2*m} * \sum_{i=1}^{m}(A * x_i - y_i)^2 \qquad (1)$$

Where J is the cost function, A is the coefficient matrix, m is the number of data sets, x_i and y_i are the parameter matrix and corresponding force values, respectively. The coefficients matrix was calculated by using the gradient descent equation:

$$A_{new} = A_{old} - \alpha * \frac{dJ}{dA} \qquad (2)$$

Where A_{new} is found iteratively by subtracting the coefficient matrix by the cost function, and α is a chosen learning rate variable. The coefficients from gradient descent are multiplied by their corresponding parameter to find the calculated force values as shown in equation 3:

$$y_{calc} = A_1 * x_1 + A_2 * x_2 + A_3 * x_3 + A_4 * x_1 * x_2 + A_5 * x_1 * x_3 + A_6 * x_2 * x_3 \qquad (3)$$

Where y_{calc} is the calculated force value, x_1,x_2, and x_3 are displacement, diameter, and thickness, respectively. And the A values are from the coefficient matrix. This equation predicted force values with an average error of 3.67%. The calculated force results from gradient descent are shown in Figure 5 and compared to the measured force. The calculated relationship between force, position, thickness, and port diameter can be used in future designs to simulate necessary force plots.

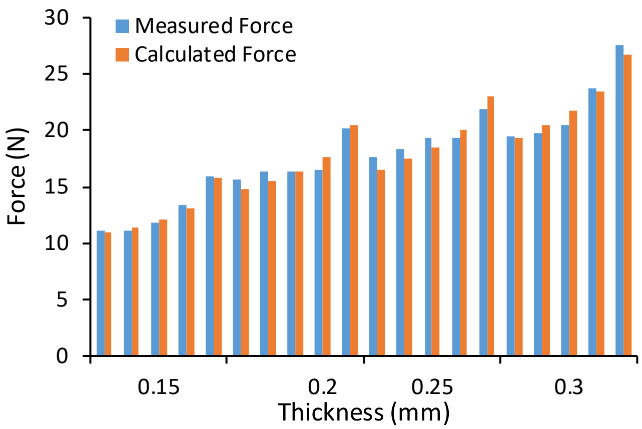


FIGURE 5: FORCE COMPARISON OF VALUES FOUND WITH GRADIENT DESCENT AND REAL VALUES MEASURED AT 42 MM

4. CONCLUSION

This paper presented experimental results for a novel trocar training system that simulates haptic force using material deflection. The experimental results showed the relationship between insertion force, position, material thickness, and material mounted diameter. Supervised machine learning methods developed a predictive equation with a 3.67% average error. In future use, several rubber layers with varying combinations of thickness and diameter will be overlayed to simulate expected force data while inserting a trocar into the abdomen.

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