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NOVEL SINGLE INCISION, FREE MOTION LAPAROSCOPIC SURGICAL SYSTEM

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ABSTRACT

Laparoscopic surgery is a common minimally invasive procedure typically used in intestinal surgery. Several small incisions are made to allow specialized instruments to be inserted and operated in an inflated abdomen. There is limited mobility in these procedures and additional training must be completed for surgeons to become proficient. To increase the freedom of motion and reduce the required skill for the surgeon, the novel single incision, free motion (SIFM) laparoscopic surgical system is introduced. This device will allow for free motion of the tools with a single incision inside the body, using electromagnets, hydraulic, and motor actuation. Using a low friction material, an electromagnet on the outside of the skin translates the tool inside the body. Hydraulic and motor actuation allows for further control of the tool under the skin by tilting, extending and retraction. Experimentation was performed to measure the frictional forces of different materials gliding over porcine skin tissue. The results show that of the tested materials, teflon performed the best with high consistency and low coefficients of friction across a range of pressures. Future work will explore magnetic force and actuation to work with the low friction materials of SIFM.

Keywords: Laparoscopic Surgery, Minimally Invasive, Electromagnet, Instrument Friction

1. INTRODUCTION

Nearly 15 million Laparoscopic surgery procedures occur annually around the world and 4.8 million in the United States alone [1]. Since the first acknowledge laparoscopic procedure was performed in 1987, interest in this minimally invasive procedure has continued to increase [2]. The increased use of this surgical operation is likely due to its numerous and significant advantages over traditional open surgery. In laparoscopic surgery, typically three to five, 1~2 cm keyhole incisions are made around the abdomen, while the abdominal cavity is expanded with pressurized CO2 gas [3]. Whereas open surgery typically has a large 4-inch incision in the abdomen [4]. The laparoscopic approach offers faster recovery time, reduced surgical site infections, reduced scaring, and reduced patient pain due to its much smaller incision size [5,6]. Currently, laparoscopic surgery is the most used method for: bariatric surgery, antireflux surgery, appendectomy, cholecystectomy, colectomy, and occurs frequently in surgeries such as ventral hernia repair and rectal resection [7].

Although the small incision size used in laparoscopic surgery has many benefits for the patient, the procedure poses some challenges for the operating surgeon. Due to the fixed port location, the tools and instruments used must only pivot around the selected incisions. Therefore, there is a significant decrease in mobility and control for the surgeon, compared to open surgery. As a result, laparoscopic surgery can take more time and one study reports an average of 30 minutes more time was required for a laparoscopic colectomy compared to open surgery for the same operation [5]. Additionally, this lack of mobility can cause a surgeon to lengthen or add another port if necessary for the operation. Adding larger incisions or more ports will increase the recovery time and negate the positive impacts laparoscopic surgery had over open surgery. Adding additional ports can increase the risk of hernias which occur in 0.5% of procedures [8]. Another drawback to using laparoscopic surgery is the amount of training time required for a surgeon to acquire full proficiency. Due to the complexity and longer training time, surgeons require more patient cases to achieve the necessary experience. One study showed 200 to 250 patient cases are needed to gain full proficiency in laparoscopic prostatectomy [9, 10].

The use of magnetic materials in laparoscopic surgery has been introduced in recent years. Internal magnetic clips, made by Levita Magnetics, are used to retract tissue away from the working area and has been approved by the FDA [11]. This passive clip still requires multiple incisions for the tools.

To increase laparoscopic tool mobility and eliminate all but one port, the novel single incision, free motion (SIFM) laparoscopic surgical system concept was developed as shown in Figure 1. This system splits traditional laparoscopic tools into two halves. Both halves will be attached through a magnetic force through the skin. One half is the surgical tool inside the body, and the other half is controlled by the surgeon on the surface of the outside skin. The tools inside the body enter through a single port. The electromagnets allow free range of motion across the tissue surface with the ability to tilt and extend.

To successfully design SIFM, the appropriate materials must be chosen to slide across the tissue surface. A material with low coefficient of friction will allow for a strong magnetic force between the two plates while allowing for them to slide across the skin, increasing the range of motion available for the surgeon. This paper presents experimental methodology, results and conclusions measuring the friction force on ex vivo porcine tissue across varying frictional materials.

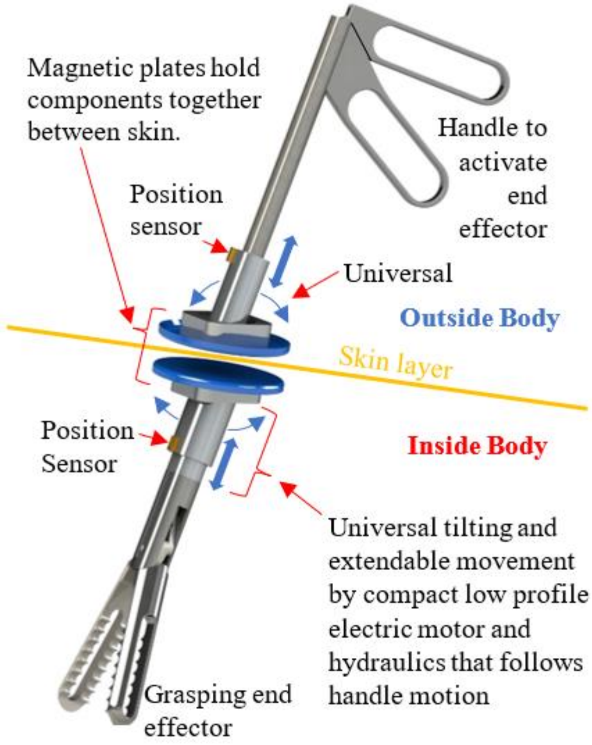

FIGURE 1: NOVEL SINGLE INCISION, FREE MOTION (SIFM) LAPAROSCOPIC SURGICAL SYSTEM

2. MATERIALS AND METHODS

The experimental setup includes a pneumatic cylinder mounted over a force sensor to apply a constant normal force to a porcine skin sample, as shown in Figure 2. As the normal force is applied, the porcine skin is pulled back and forth horizontally using a linear motor (Dunkermotoren, Bonndorf, Germany) at a max speed of 120 mm/s. The force sensor that records both frictional and normal forces is a Gamma IP65 (ATI, NC, United States). The pneumatic cylinder provided 6 constant forces during testing (10N, 20N, 40N, 50N, 60N, 80N).

The static and kinetic coefficients of friction for 4 different materials were assessed. The materials used were Acetol, Nylon, Teflon, and fine (220 grit) Sandpaper.

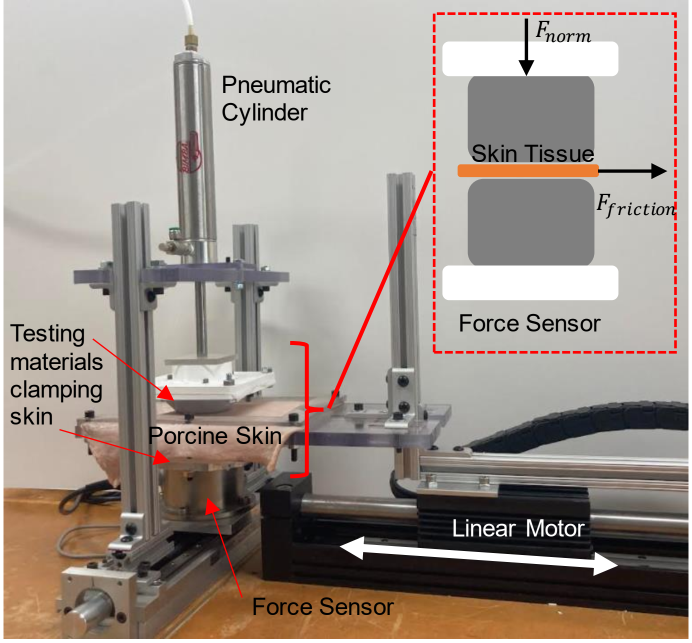

FIGURE 2: FIXTURE TO TEST FRICTION COEFFICIENTS FOR LOW FRICTION MATERIALS SLIDING OVER PORCINE SKIN

3. RESULTS AND DISCUSSION

The average static and kinetic coefficient of friction for each material tested is shown in Table 1. The force sensor, as shown in Figure 2, recorded the normal force (F_{norm}) and the frictional force ($F_{friction}$) simultaneously. The coefficient of friction is calculated from those values recorded by the force sensor. By analyzing the data, an average static and kinetic coefficient of friction is calculated. The difference between the static and kinetic is also shown in Table 1.

Table 1: VALUES OF THE STATIC AND KINETIC COEFFICIENTS, AND THEIR CORRESPONDING DIFFERENCE FOR THE 4 DIFFERENT MATERIALS TESTED

		Normal Force (N)					
Materials		10	20	40	50	60	80
Acetol	Static	0.81	0.45	0.25	0.19	0.16	0.12
	Kinetic	0.63	0.38	0.21	0.17	0.15	0.11
	Diff.	0.176	0.070	0.038	0.017	0.011	0.009
Nylon	Static	0.64	0.41	0.22	0.18	0.18	0.15
	Kinetic	0.58	0.30	0.18	0.16	0.15	0.10
	Diff.	0.059	0.109	0.038	0.019	0.026	0.052
Teflon	Static	0.62	0.36	0.17	0.14	0.12	0.09
	Kinetic	0.54	0.32	0.15	0.12	0.10	0.08
	Diff.	0.088	0.034	0.015	0.014	0.017	0.011
Sand-paper	Static	1.45	0.87	0.57	0.53	0.42	0.29
	Kinetic	1.23	0.73	0.47	0.43	0.31	0.23
	Diff.	0.213	0.137	0.103	0.094	0.114	0.060

The linear motor slid the skin back and forth several times between the tested material mounted to the force sensor, and an identical part fixed to the pneumatic cylinder. The coefficient values were calculated with the equation:

$$\mu = \frac{F_{friction}}{F_{norm}} \qquad (1)$$

where μ is the coefficient of friction. The static coefficient is the average of the peak values that occur during the back and forth sliding motion. The kinetic coefficient values are the average of the small section of plateaued values that occur during the sliding motion. The linear motor slid the skin back and forth eight times, as shown by the eight peaks per test, in Figure 3.

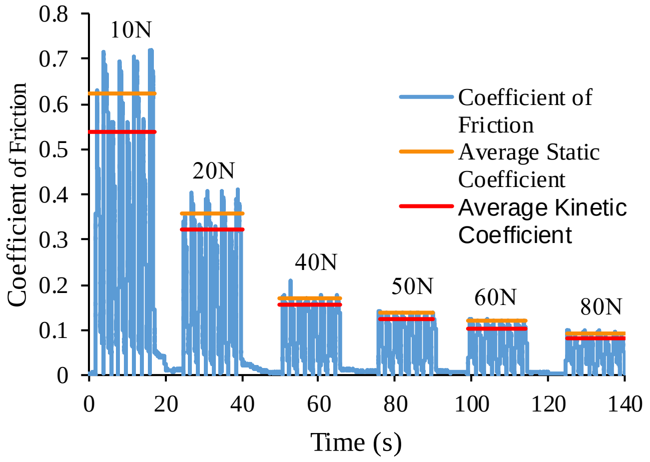

FIGURE 3: CALCULATED COEFFICIENT OF FRICTION FOR TEFLON WITH APPLIED NORMAL FORCES OF 10N, 20N, 40N, 50N, 60N, AND 80N

Of all the measured materials, Teflon generally had the lowest static and kinetic coefficient of friction with porcine skin. Over the six forces tested, Teflon had an average static coefficient of 0.25, whereas Nylon and Acetol had 0.3 and 0.33 respectively. By contrast, sandpaper had a static coefficient of 0.69 over the six tests. Teflon also had the lowest average kinetic coefficient of 0.22. Nylon and Acetol had kinetic coefficients of 0.25 and 0.27 respectively. Sandpaper had a higher kinetic coefficient of 0.57. Little bunching of the skin occurred in Teflon as well. Materials with higher friction coefficients caused the skin to stretch elastically and bunch up. Sandpaper, with the largest coefficient of friction, caused the porcine skin to bunch the most, which resulted in inconsistent data, large peaks of coefficient of friction data, and a large error. Furthermore, the issue of elastic build-up and bunching does not occur as frequently in higher normal force data sets. With a higher normal force, the testing material kept the skin tight and ironed out the wrinkles that form on the other side as it slides through. This relationship is shown in Figure 3, as smaller and more consistent peaks occur after a 40N normal force.

A higher normal force results in smaller coefficient of friction because a consistent flat surface is pressing on the skin. Whereas with a lighter normal force, the skin caused the disk to shift and dig into the skin slightly. Additionally, at higher normal forces, the skin tissue starts to lubricate the material as it slides, further decreasing the coefficient of friction, as shown in Figure 4 and Figure 5.

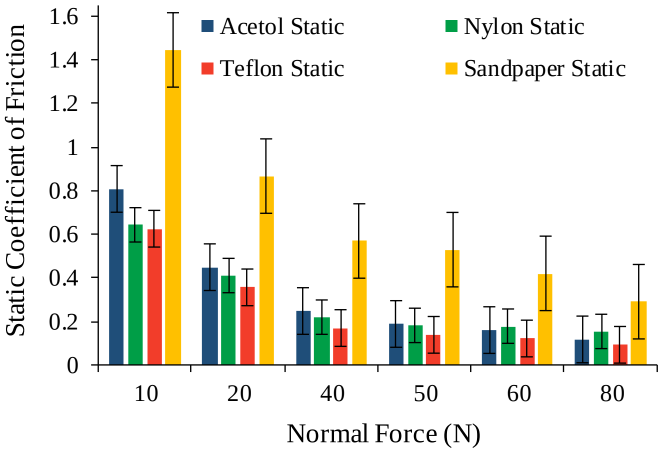

FIGURE 4: STATIC COEFFICIENT OF FRICTION OF ACETOL, TEFLON, NYLON, AND SANDPAPER OVER SIX DIFFERENT NORMAL FORCES

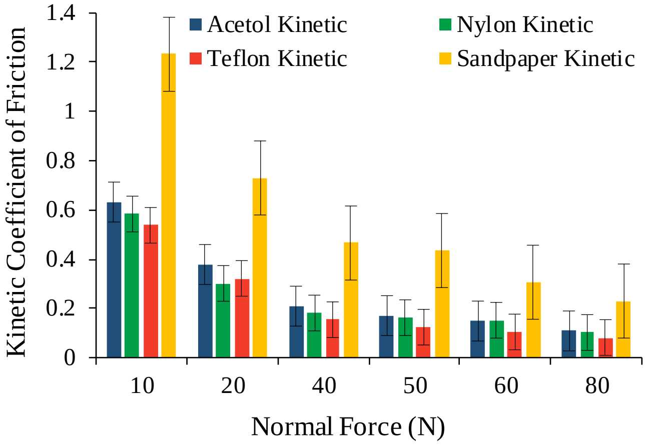

FIGURE 5: KINETIC COEFFICIENT OF FRICTION OF ACETOL, TEFLON, NYLON, AND SANDPAPER OVER SIX DIFFERENT NORMAL FORCES

The desired material to use for future applications will be Teflon, due to its relatively consistent data, low static and kinetic coefficient of friction, and finally, its smaller difference in static and kinetic coefficient. A small difference is important when sliding along an elastic material such as skin tissue because similar friction coefficients prevent the skin from being pulled and abruptly released. Teflon had a difference in coefficients of 0.03, whereas both Nylon and Acetol had values of 0.05. In comparison, sandpaper had a difference value of 0.12. The small difference in Teflon is another reason why bunching did not occur as frequently as it did in the other materials. Sandpaper had the largest difference in coefficient data as shown in Figure 6 and would pull on the skin and release it briefly which caused more bunching.

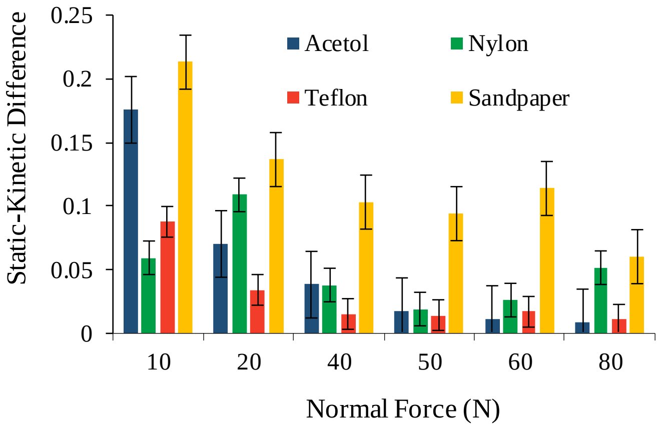

FIGURE 6: DIFFERENCE IN STATIC AND KINETIC COEFFICIENT OF FRICITON FOR ACETOL, NYLON, TEFLON, AND SANDPAPER

4. CONCLUSION

The SIFM design was introduced and frictional data for the materials was experimentally tested. Teflon was found to be the most promising material due to its small error, low coefficient of friction, and small difference between static and kinetic friction. Results from this experiment will be applied to material design decisions to improve user control in the SIFM system.

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