Force-Sensing Laparoscopic Grasper

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Abstract

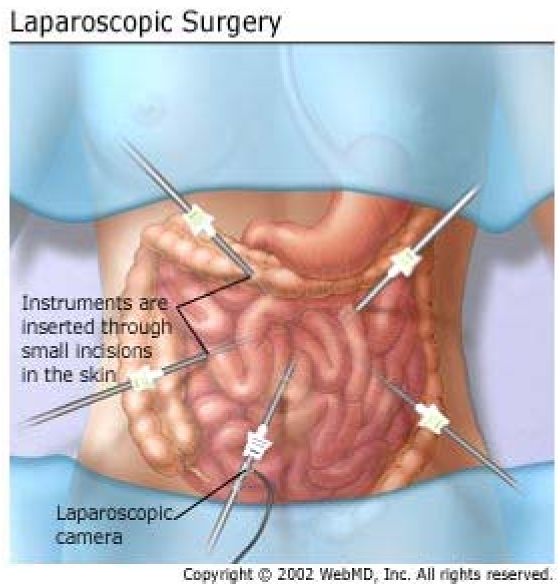
While teaching medical school students the skills necessary to utilize surgical tools, students are uninformed as to the limits of force and pressure allowed on the tissues they are working on. Two beneficial upgrades to the current tools would be a mechanism that provides feedback to the students and instructors when the limit has been exceeded and damaging force is being applied to the tissues and a jaw that reduces pinching of the tissue.

§1 Problem Statement

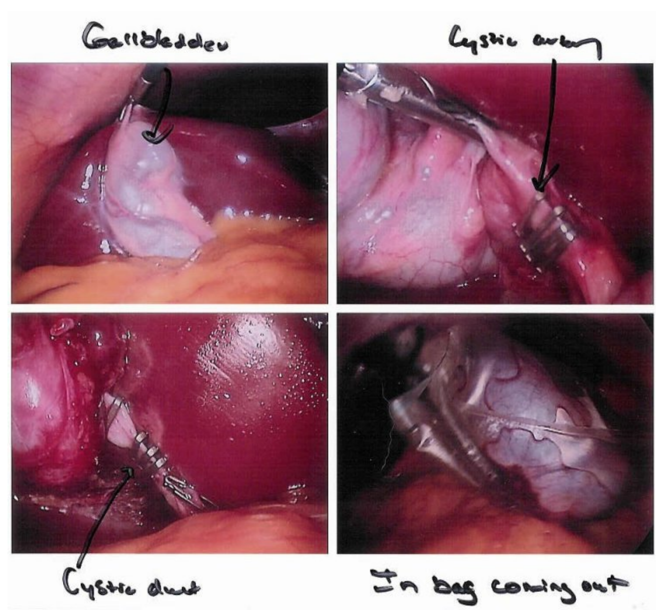
Laparoscopy is a method of surgery using very small incisions and a small video camera for monitoring. The instruments used must therefore be long and thin. The goal of this project is to design and build a laparoscopic grasping tool that provides feedback, auditory or otherwise. A feedback mechanism would be activated when the force applied to a piece of tissue is great enough to damage the tissue. Secondly, the jaw mechanism should be redesigned to reduce tissue damage by eliminating pinching at the pivot point of the jaws. This type of device would be an educational tool to benefit students and instructors by maintaining a defined standard force for grasping tissue and would also ensure less damage to the patient

§2 Background

Laparoscopic bowel surgery encompasses many diseases, including but not limited to colon cancer, colonic dysmotility (slow-transit constipation), Crohn's disease, Diverticulitis (diverticular disease), hereditary polyps, inflammatory bowel disease, rectal prolapse, and ulcerative colitis. It is a minimally invasive surgical technique that has slowly been replacing many traditional bowel surgical procedures in the past 15 years. It involves creating a pocket of gas (usually carbon dioxide) within the abdomen used to ease visibility of the site and removing or manipulating diseased states of the intestinal organs by means of 5 or 6 minute incisions in the abdominal cavity walls and viewing the procedure by the use of a laparoscope (a rod and lens system connected to a video camera) (Fig. 1). An example of the view provided to the surgeon is shown in Figure 2.



[1]**Figure 1. A cutaway view of laparoscopic surgery.**



[2]**Figure 2. A surgeon's view using a laparoscope.**

Traditional surgery to the abdomen involves a large incision down the length of the abdomen and requires a long recovery period. Numerous drawbacks to traditional surgery are minimized by laparoscopic techniques. New techniques and old surgical procedures are now being done laparoscopicly because of the many patient benefits. These benefits include reduced operative blood loss, reduced discomfort, shorter recovery periods, less pain and scarring, and less risk of infection.

With the revolution of surgery quickly taking place, surgical techniques must be reformed and students educated more effectively. One such basic educational tool is practice; but while the instructing surgeon may know the requirements and basic feeling of proper performance, conveying this information to a student is difficult. Students feel detached from the patient and the amount of pressure applied to a tissue via a grasping instrument is unknown until the tissue shows signs of damage such as leaving marks or bleeding from the point of pressure application. Minimizing damage is crucial to providing adequate treatment to patients.

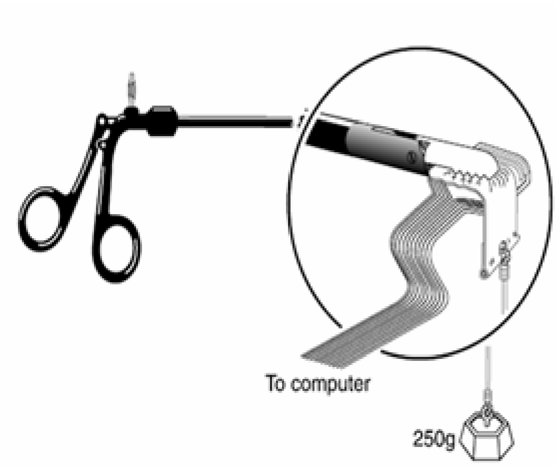
Current laparoscopic graspers are made by companies including Stryker (Fig. 3), Ethicon Endo-Surgery, Inc. (Fig. 4), DuoMed and many others. The devices, with small distinctions between, all have similar components: the long arm that extends into the body, the grasping claw used to grab tissue and hold it in place, and the handle used to manipulate the claw. They may be coated with high temperature-safe synthetic polymers to reduce weight and still remain autoclavable.

[3]**Figure 3. An example of the tools available by**

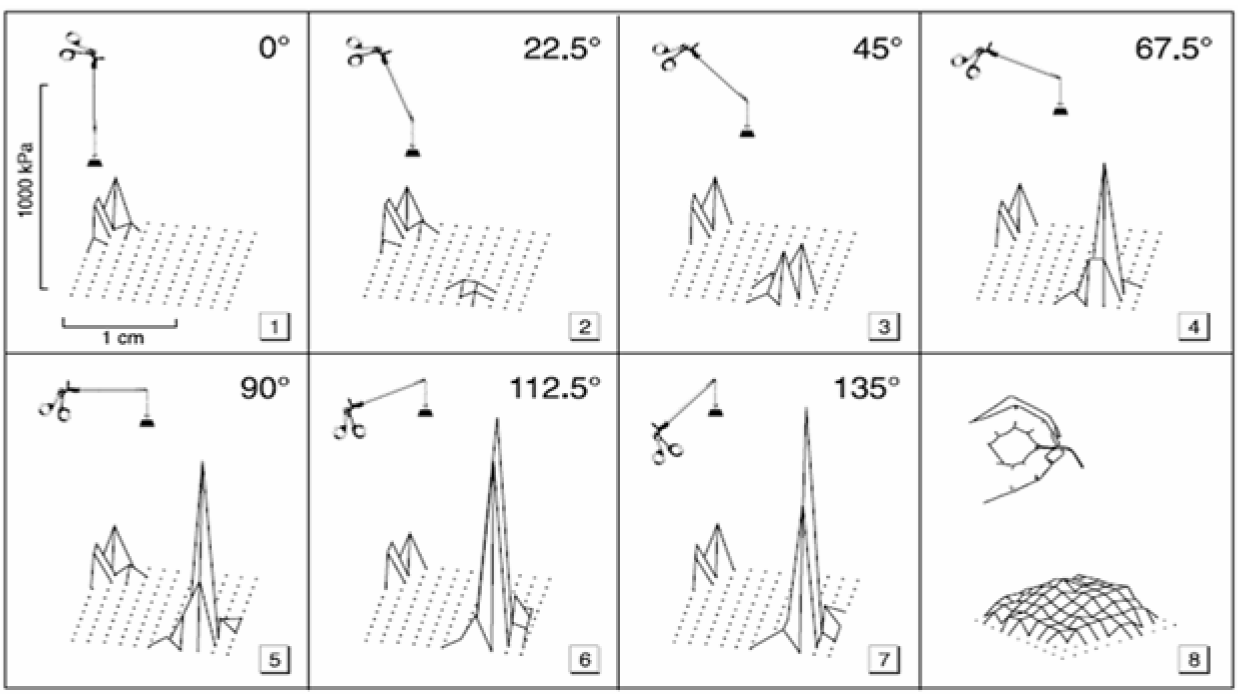
§3 Literature Search

Several studies were analyzed to determine the type of jaw shape that would suit the needs of the client. A study was done to see how the orientation of laparoscopic probes affects the pressure that is done on the tissue. A laparoscopic probe was used to grab a pressure sensor connected to a 250 g weight as shown in Figure 5. This sensor recorded the pressure distribution exerted by the graspers. This was done at varying angles. These are shown as results 1-7 in Figure

[4]**Figure 4. An example of the tools available by Ethicaon Endo-Surgery, Inc.**



[5]**Figure 5. Schematic representation of the experimental model showing the configuration of the pressure sensing transducer relative to the instrument jaw.**

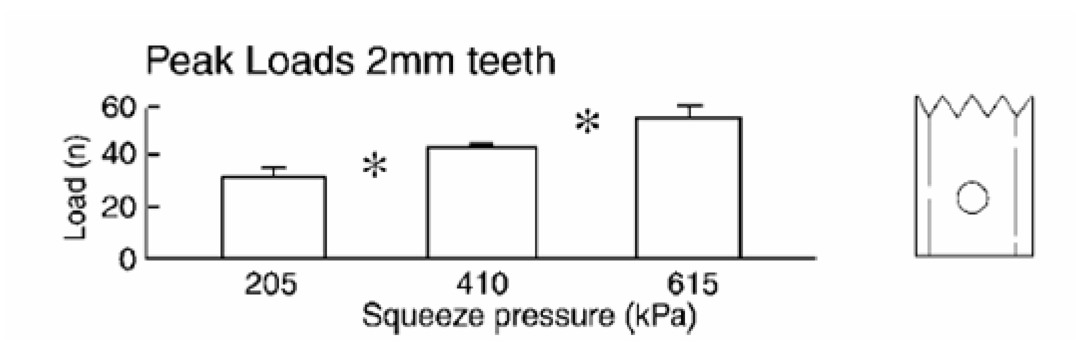


[5]**Figure 6. (1-7) Data showing spatial distribution and magnitude of pressure exerted by a laparoscopic grasper as the angle of retraction increases. (8)Pressure profile of the maximum pressure generated by the pincer grip of a surgeons finger and thumb.**

6. Result 8 is a comparison to the maximum pressure that can be produced between the index finger and thumb.

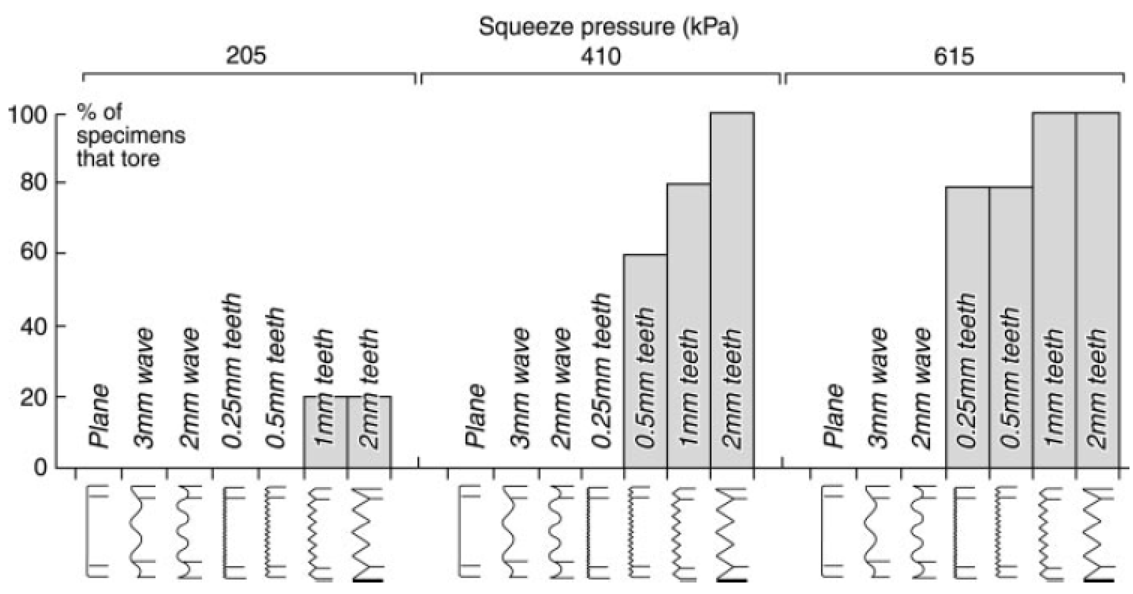
It can be seen from Figure 6 that there is always a pressure that is exerted by the jaws at the pivot point. This pressure can be reduced through an alternate design. The pressure at the tip of the jaws varies depending on the orientation in which it is used.

Another study shown used fresh sheep stomach to analyze the effect of apposing pressure on grip security. It was determined that increasing the apposing pressure increased the peak load for all types. The results for 2-mm teeth pattern is shown below in Figure 7 measured as peak load. This same trend was also shown to be true for all jaw patterns.



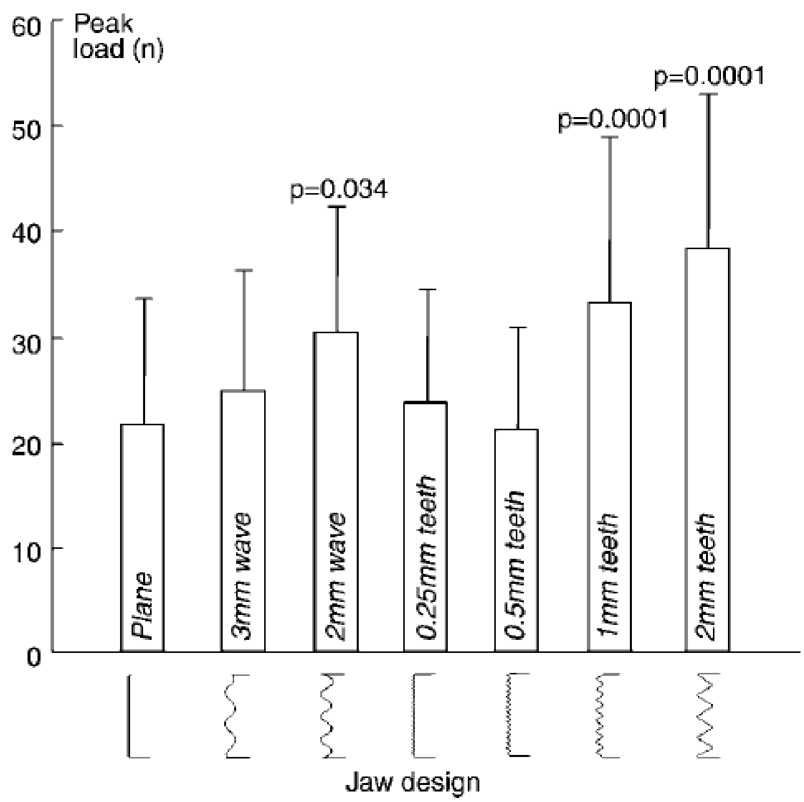
[6]**Figure 7. Graph showing the results for 2-mm teeth measured as peak load.**

A study was also done on the damaging effects of different jaw patterns.



[6]**Figure 8. Perforation of samples using different jaws and different pressures. Grey=% of sample that tore.**

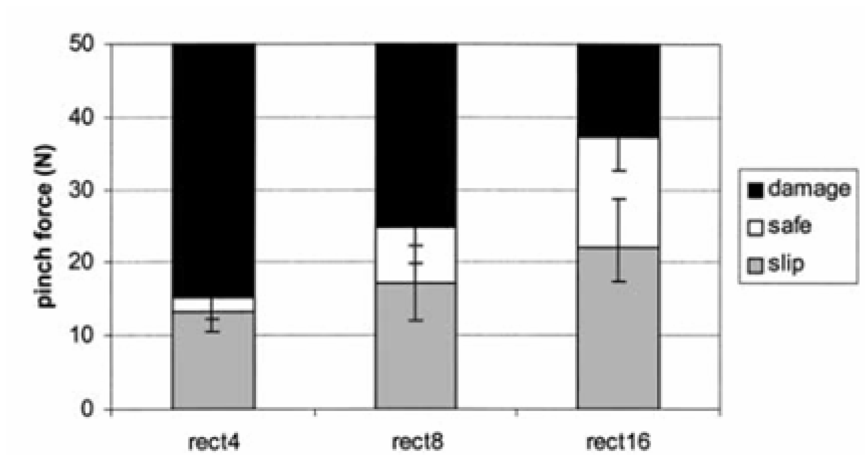
Different jaw patterns were used to grasp fresh sheep stomach at different pressures. The percentage of sheep stomachs that were perforated by each jaw pattern at each pressure is shown above in Figure 8. From this figure, it can be seen that the only jaw patterns that did not perforate the sheep stomach at all pressures were the flat and the 2 and 3 mm wave patterns. To determine which of these patterns was better, another experiment was conducted by the research group. This study demonstrated how the peak grasping load varied by the pattern of the jaw. This was conducted independent of squeeze pressure. The results of this experiment are shown below in Figure 9.



[6] Figure 9. Effect of jaw design on grip security, measured as peak load. Conducted independent of squeeze pressure.

Looking at figure 9 it can be determine that the 2 mm wave pattern is the best option for our grasping device. It does not damage the tissue compared to other patterns, and out of the patterns that do not damage the tissue it can hold the largest amount of load.

To determine the effect of the size of a grasper on safety and efficiency a study was done that compared the grasping effects of different jaw sizes on safety and efficiency. Three flat jaw sizes were used: 8x4 mm, 8x8 mm, and 8x16 mm. The slip and damage force ranges were recorded for each pattern. These results are shown in Figure 10.



[7]**Figure 10. Damage, slip and safe ranges for jaws of varying size.**

It can be seen from Figure 10 that the safe range increase as the size of the jaw increase. However, our device needs to fit inside of a 5 mm port so the width of the jaw will have to remain at a constant 5mm.

§4 Design Constraints

The client, Dr. Charles H. Heise, has expressed his wishes for the project to include several features. The first feature, and the most important, is the redesign of the jaw mechanism. Surgeons today, not just students, have witnessed the extra damage incurred to tissue by a pinching of the tissue as the closing point of the grasping claw comes together. This harmful effect needs to be minimized or eliminated completely. A second requirement is a means to provide feedback to the surgeon or student, via an auditory or tactile response to tissue-damaging force. Further requirements include the dimensions of the device: the claw and arm must be less than 5 mm in diameter to accommodate the 5 mm diameter port; the length of the device should be similar to those currently on the market, which corresponds to a length of about 30 cm. The device should provide a means to maintain varying partial closure of the claw. And lastly, the device should be disposable or sterilizable by means of an autoclave at about 121ºC. Additional design constraints are provided in the Product Design Specifications (Appendix B).

§5 Design Options

Three design possibilities will be discussed and contrasted. A design matrix (Appendix A) will be used to analyze the possibilities according to cost, maintenance, sterilization ability, strength, cumbersomeness, connectivity, and accuracy. A final design will be chosen and pursued based on the outcome of the design matrix and group discretion and consensus.

Since a major factor in the re-design of the laparoscopic instrument is on reducing the jaw pressure, much focus was on creating the floating-point jaw mechanism. One jaw design was determined and maintained throughout all three design possibilities. The force- measurement and feedback options are what make each design unique.

Jaw Mechanism

In order to minimize tissue trauma and maximize grasping security, the following jaw mechanical structure is adopted. The information found during the research phase indicates that the most desirable

results stem from the wavy-patterned

grip type. Four pivot points, located inside the shaft as shown, are connected to the grippers with four bars. The two parallel wave-patterned grippers are formed to ensure that the grippers always open and close in parallel positions relative to each other (Figure 11). When closing, the jaws will close in an outward fashion, projecting forward while closing.

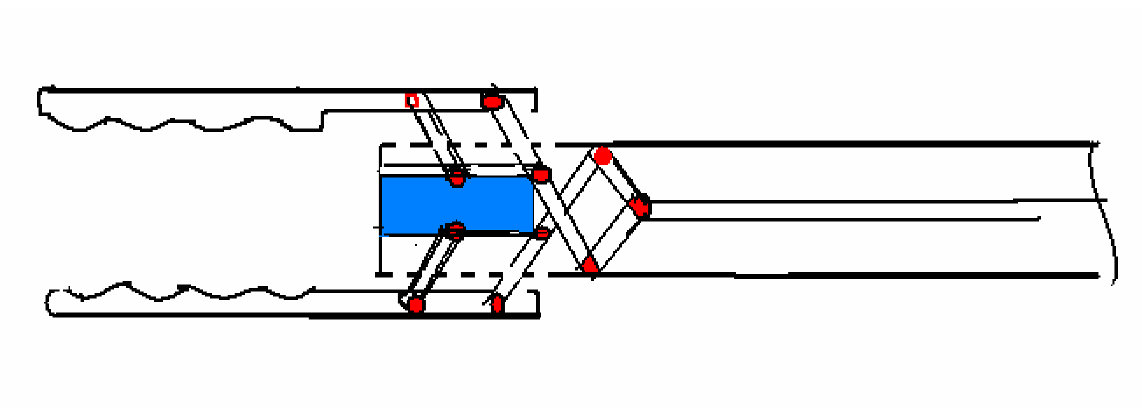


Figure 11. Figure jaw mechanical structure (cross section view) Connections highlighted in red are pivot points.

§5.1 Strain Gauge on the Shaft

The principle of using strain gauges as stress sensors is based on the property of the Wheatstone bridge. In this four-element Wheatstone bridge, two gauges undergo compression and two undergo tension. For example, if the resistors are labeled clockwise starting at the top left, and if R1 and R3 are in tension (positive) and R2 and R4 are in compression (negative), then the output will be proportional to the sum of all the strains measured separately. Whether bending strain, axial strain, shear strain, or torsional strain is being measured, the strain gage arrangement will determine the relationship between the output and the type of strain being measured. The pressure sensor is connected to a conditioner in which voltage is applied onto the Wheatstone bridge. Change in resistance can be monitored as change in output voltage.

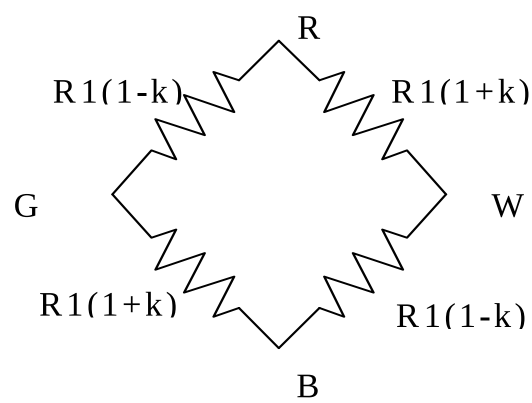


Figure 12. A Wheatstone Bridge. Output voltage changes with resistance changes due to various strains.

Pressure on the grasper will be tested and calibrated to the output voltage. A threshold can be set experimentally using animal tissue. Once the threshold is reached or exceeded, an alarm piezoelectric buzzer system will be activated.

The first design possibility is called the Strain Gauge on the Shaft (Figure 13), and implies directly as the name states. In this design the strain gauges can be fixed on the shaft of the grasper. In this way it will measure the compression and tension stresses along the shaft, which corresponds to the pressure applied by the user at the jaw.

Although putting the strain gauges on the shaft is an intuitive solution, this design faces one major problem: In order to firmly fix a strain gauge onto the equipment, the surface must be flat and large enough to accommodate the gauge. The reasoning behind this came from an installation expert stating that custom molds would need to be made for each gauge for fixation purposes. This presents a problem in that curvature of the shaft surface is not able to provide enough fixing area. The solution, designing the fixating platform for the gauge to be rectangular, creates a manufacturing difficulty.

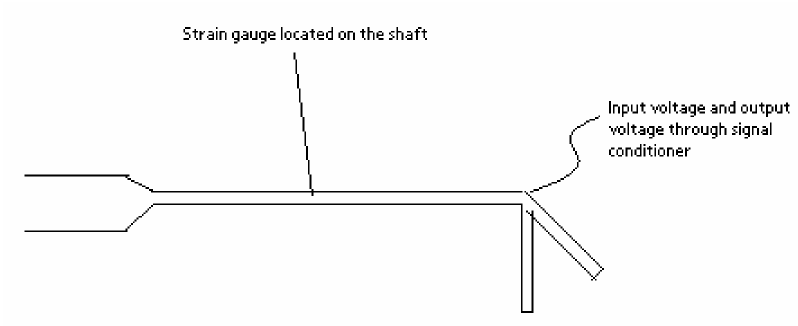


Figure 13. Strain Gauge on the Shaft

Advantages and Disadvantages

The main advantage of placing a strain gauge in the shaft is that there is less clutter on the instrument, which will create a minimal nuisance to the user. The disadvantages are four-fold. One disadvantage is the manufacturing difficulty and practicality of putting the strain gauges in the 5mm diameter of the shaft. A second disadvantage is the reduced accuracy of measurement, as compression and tension forces will be small in relation to the forces in the jaw. A third disadvantage is the increased cost due to using high-temperature resistant materials necessary because of routine autoclaving procedures with temperatures in the range of 130˚C. The components (strain gauges, bonding agents, connecting wires, Teflon wire insulation) must remain permanently fixed to the surface, which means that they cannot be removed for other sterilization methods or when the measurement is not needed. If the gauges were detached and reattached, re-calibration would be necessary. The fourth disadvantage is that a heavy and expensive signal conditioner is required to supply voltage to and monitor output from the sensor. This increases the clutter and inconveniences surgeons during operation with more wires and equipment.

§5.2 Strain Gauge on the Handle

An alternative to placing the gage on the shaft is to put it on the handle to measure the bending moment produced by the user while grasping objects (Figure 14). The same principles of the Wheatstone bridge are applied in this case, but the strain gauges are oriented differently to measure the bending moment as compared to the compression or tension forces.

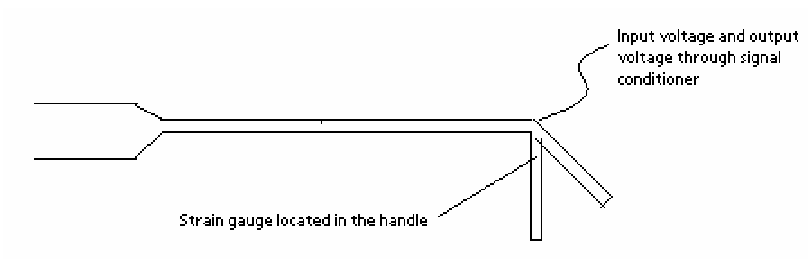


Figure 14. Strain Gauge on the handle

Advantages and Disadvantages

This has a few advantages over the first design. First of all, it avoids the fixation area problem, as the handle has enough flat area for fixation of the strain gauge. Secondly, the strain gage in this configuration is four times more sensitive to changes in bending moments. However, this design also has several drawbacks associated with the natural properties of strain gauges. In an ideal strain gauge situation, the change in resistances would be due only to the deformations of the surface to which the sensor is attached. The first disadvantage is that in a real application, temperature, material properties, the adhesive that bonds the gauge to the surface, and the stability of the metal all affect the detected resistance. This disadvantage, in addition to the last three mentioned for the previous design, all contribute to complications with the second design.

§5.3 Microchip Force Sensor on the Handle

The third design will use a force sensor that changes resistance dependent on the magnitude of the force that is applied. Placement of the sensor will be on the inside of the handle where the surgeon places his index finger. The compressive force between the grasper that will be exerted on the intestine will be directly proportional to the amount of force that the surgeon uses to squeeze the handle of the laparoscopic instrument. From this we can measure the force that the surgeon uses and determine how much force is on the bowel. Placement of the sensor in the handle is ideal over other places such as at the hinge of the handle or where the handle pulls the shaft due to its simplicity. Designing a simple interchangeable part that can fit inside the handle will be easier to design and make than fabricating an entire laparoscopic instrument. This also allows flexibility of use with other instruments. Since it will also be removable, the instrument may still be autoclaved while the sensor package itself could be rubbed down with alcohol.

The force sensor will rest against the handle on the inside of the index finger hole with a metal covering over it to focus the area that the surgeon might touch to the point of contact on the sensor. The sensor will be a 2 mm square sensor from CUI Inc. and can measure from 0 to 1500 grams with a maximum load of 3.0 kg. There will be two wires going from the sensor to a small box containing the rest of the circuit. This box may be made to attach to the handle of the laparoscopic instrument, worn on a wristband by the surgeon, or simply set aside. The changing resistance from the sensor will be used to vary the voltage on the input of a comparator. The reference voltage input will simply be a voltage divider circuit with a potentiometer for calibration. The output of the comparator will connect to an oscillator to drive a magnetic buzzer. The circuit will run off of a 6.0 V battery with a voltage regulator to bring it down to 3.3 V. Because of this, and the fact that the components will consume minimal power, the circuit will last a long time.

Advantages and Disadvantages

The main advantage of this design is its simplicity and ease in design. Currently used laparoscopic instruments do not need to be redesigned to accommodate a force sensing mechanism allowing easier integration of the device into the market. Mounting strain gauges and/or redesigning the handle of the instrument are costly, thus making our third design a viable solution. The next most important aspect of this design is that it will be detachable, making it possible for the instrument to still be autoclaved. This way, the preparation time for surgery will not be drastically increased. Another advantage is that the surgeon will have the option to either wear or set aside the circuit box, making as little inconvenience as possible. With the circuit running off of a battery, there will be no long wires draping across the operating room that could potentially get in the way. The circuit used for this design will not only last a long time but can be easily calibrated to buzz at whatever threshold force the surgeon thinks is appropriate.

A disadvantage of this design is the assumption that the surgeon will always squeeze the handle in the same spot. One surgeon may be different from another and may hold the instrument differently is such a way that the measured force on the sensor is not the actual force being applied. Since this device will be used for educational purposes, preciseness is not as important, yet this only serves as a guide to the students.

§6 Proposed Design

After discussing the advantages and disadvantages of our three designs, it is the most reasonable to go with our third design. The third design offers an easier solution that can be integrated into the existing market. It does not have the high cost of manufacturing as the other two designs do. It offers easier maintenance as there is only a battery that needs occasional replacement. This design makes autoclaving still possible which is a key factor in surgical equipment. It’s less cumbersome as there will be few wires to deal with and the overall strength of the design is the greatest. The only concern is that the surgeons apply all the force they used to the sensor. However, this problem can be eliminated by placing the sensor in the proper place.

§6 Potential Problems

Problems that could arise in the design are limited to the building of a prototype. The grasper design is sound but needs manufacturing and building. The biggest problems will be getting parts made precisely enough that it can function normally and be assembled easily. The circuit also still needs to be assembled and tested. It is also important to insure that noise does not affect it or that it does not affect other operating room equipment.

§7 Future Works and Goals

The major objective is to build a laparoscopic probe that is atraumatic to abdominal tissues. We plan to do this by introducing a new grasping device on the end of the probe. This device will use a clamping mechanism where the two ends of the grasper close parallel to each other, where as existing instruments have a pivot point in the grasper which can exert damaging pressure to abdominal tissue.

A secondary objective is to incorporate a pressure sensor to the device that will alert the surgical staff if too much pressure is being exerted on the bowel tissue. The signal should be some type of auditory device. We will accomplish this by using a force sensor in the handle of the laparoscopic instrument.

During the rest of the semester, we plan to complete our solid works drawing of the grasper. Once this has been completed, we will look into 3D printing or rapid prototyping to come up with a plastic prototype. Meanwhile the circuit components are still being ordered and it must be assembled and tested. This circuit then needs a box to house it and a way to fasten it. After final assembly the entire device must be tested for functionality and recalibrated. Any problems that arise must also be solved.

§8 References

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Appendix A

Design Matrix

Design	Maintenance (5)	Sterilization (5)	Strength (5)	Cumbersomeness (5)	Connectivity (5)	Accuracy (5)	Feasibility (5)	**Total (35)**
Strain Gage on the Handle	1	4	2	5	1	3	2	**18**
Strain Gage on the Actuator	2	4	2	2	1	2	1	**14**
Force Sensor	3	3	5	4	3	2	4	**24**

*Scale: 1-5

1: Poor

3: Satisfactory

5: Outstanding

Appendix B (PDS)

March 3, 2006

Atraumatic grasping instrument –Product Design Specifications

Team:

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Darshan Patel (Communicator)
Clara Zhang (BSAC)
Andrew Eley (BWIG)

Function: Current minimally invasive laparoscopic surgical tools are insufficient in their ability to grasp and hold a large amount of the bowel without causing injury to the patient when performing surgery. A new tool suited to this task by providing feedback (auditory or tactile) to the surgeon is necessary. The goal is to reduce injury due to excessive pressure to the bowel organs during laparoscopic surgery.

Client requirements:

. • "floatable" jaw to reduce pinching of bowel
. • Provide feedback of pinching pressure
. • must fit through 5mm port
• must be about 30 cm long
. • optional ratcheting for locking
. • autoclavable or disposable

Design requirements:

1. Physical and operational characteristics

a. *Performance requirements*: The design must be able to grasp a large portion of bowel without causing damage, and provide feedback of the pinching pressure. The option to lock or not lock the grasper in place would also be preferable

b. *Safety*: The design must not be hazardous to surgeons or the patient. The design must be sterilized, decontaminated, and disinfected so the risk to patient safety is minimized. The grasping end must not have separate or loose parts that could possibly get lost in the patient.

c. *Accuracy and reliability*: Accuracy is an important aspect of this design, but precision is not a major concern. It must be precise enough to ensure that no damage is done to the tissue. The grasping mechanism must be solid with little slack.

d. *Life in service*: The final design will be used repeatedly during surgery. It must be made of durable material such as stainless steel. The circuit should need little maintenance.

e. *Shelf life*: This device should last several years in a hospital environment.

f. *Operating environment*: The design must be autoclavable, and easy to use in an operating room.
g. *Ergonomics*: The handle should be easy to use and grasp by a surgeon.
h. *Size*: This device must fit through a 5mm port and measure about 30 cm. long.
i. *Weight*: The design should not be heavier then a pound.
j. *Materials*: Autoclavable parts must be used for the grasper, such as stainless steel. Other materials may be used, for parts that could be detached, as long as it can be sterilized and not compromise patient safety.
k. *Aesthetics, appearance, and finish*: The device will look like a regular laparoscopic instrument.

2. Product characteristics:

a. *Quantity*: One model will be prototyped; if successful, it can be manufactured and used for future use.
b. *Target product cost*: The cost of building the prototype should be under a few hundred dollars.

3. Miscellaneous:

a. *Standards and specifications*: FDA approval is not required.
b. *Customer*: The client would prefer the model to be inexpensive, and reusable.
c. *Patient-related concerns*: Sterile equipment must be used to ensure patient safety, thus the device must be autoclabable.