Quantifying Forces at the Tool-Tissue Interface of a Surgical Laparoscopic Grasper

Astrini Sie

Timothy M. Kowalewski

Department of Mechanical Engineering,
University of Minnesota

1 Background

In laparoscopic minimally invasive surgeries (MIS) surgeons use laparoscopic tools to interface with tissue, performing tissue manipulation without haptic force feedback. Excessive force may cause tissue injury, leading to an increased rate of fatality from perforation, hemorrhage, or the less severe ileus, infection, and adhesion formation [1]. While the actual amount of force exerted at the tool-tissue interface during MIS is critical, current technologies and platforms such as FLS [2], ICSAD [3], and ADEPT [4] provide little or no information on the quantified force value.

Prior work by Brown et al. [5], Rosen et al. [6], De [1], and Roan [7] developed tools for measuring tool-tissue interactions on force and deformations with real time feedback on *in vivo* porcine models. However, the platforms presented force measurement exerted by the surgeons, obtained from sensors located at the proximal end of the tool. The actual amount of force delivered to the tissue was not measured directly but derived using kinematic relations of the tool linkage mechanism.

In this work, we develop a portable, general test bed for measuring the force at the proximal end (the force applied by surgeon's hand at the handle) and directly at the distal end (the force delivered to the tissue by the grasper jaws) of a laparoscopic grasper. We experimentally characterize the mappings between proximally measured and distally applied forces for two different laparoscopic tools: the motorized Mechanical Smart Endoscopic Grasper (MSEG) developed by Roan [7] and the Electronic Data Generation and Evaluation (EDGE) system (Simulab Corporation, Seattle, WA).

2 Methods

A calibration test bed was designed and machined. The CAD model was established based on a Babcock grasper (#33510 BL, Karl Storz GmBH & Co. KG, Tuttlingen Germany) used in the MSEG and a Maryland Grasper in the EDGE System. Hanging weights were favored over electromechanical sensors and actuators to lower costs.

We performed experiments on the MSEG. The MSEG was bolted into the test bed and erected on a tripod. The motor was disconnected from the partial pulley, and a 0.024 inch uncoated stainless steel cable (#2024, Sava Industries Inc, Riverdale NJ) was wrapped around the linkage, one end connected to the MSEG partial pulley and another end placed over a ball-bearing pulley, connected to incremental cylinder weights. The experimental setup is shown in Figure 1(top left).

A graphical user interface (GUI) and additional data acquisition channels were developed based on the original software of Roan et al. and the EDGE system. The experiment was performed by starting data logging then applying incremental cylinder weights to the proximal linkage (handle) of the MSEG. The cylinder weights were added incrementally from 100 g to a total of 1,000 g with a time delay of 5 s for each increment. While the experiment was running, the built-in strain gauges in the proximal end measured the force applied from the weights and the measurement data was recorded in log files as raw internal data.

Once calibrated, the experiment was repeated with applying the same sequence of weights at the distal end (grasper jaws) of the MSEG. Another calibration test bed was erected on a tripod, supporting the distal end of the MSEG. One jaw was fixed and the other jaw was connected to the weights. The proximal partial pulley position was held constant by a mechanical bolt attached to the calibration test bed. The experimental setup for this experiment is shown in Figure 1(top right).

In addition to the MSEG, we performed experiments on the EDGE grasper. The setup for this experiment was similar to the experiment at the distal end of the MSEG, except the EDGE grasper was positioned on the EDGE platform, shown in Figure 1(bottom), and the grasper handle was manually swept through its full range. Measured force and jaw angle data were recorded via the GUI from the EDGE platform.

3 Results

The plot of strain gauge measurement versus the applied weights for the MSEG handle is shown in Figure 2(top), while Figure 2(bottom) shows the plot of strain values versus applied weight for the experiment at the MSEG tool tip. Figure 3 shows the plot of measured force (F_{meas}) versus jaw angle for each applied weight at the jaw (F_{jaw}) for the EDGE experiment. Figure 4 shows the plot for 500 g extracted in 2D.

4 Interpretation

For the MSEG, the strong ($R = 0.9999$) linear correlation obtained verified the accuracy of the strain gauge on the proximal end. A good correlation for the distal end ($R = 0.9843$) suggested a linear fit may be acceptable for the specific, fixed handle position. Equations 1 and 2 show the linear relationship.

$$\mathrm{Strain}_{d,\mathrm{fixed}} = 0.44382\, F_{\mathrm{handle}} \qquad (1)$$

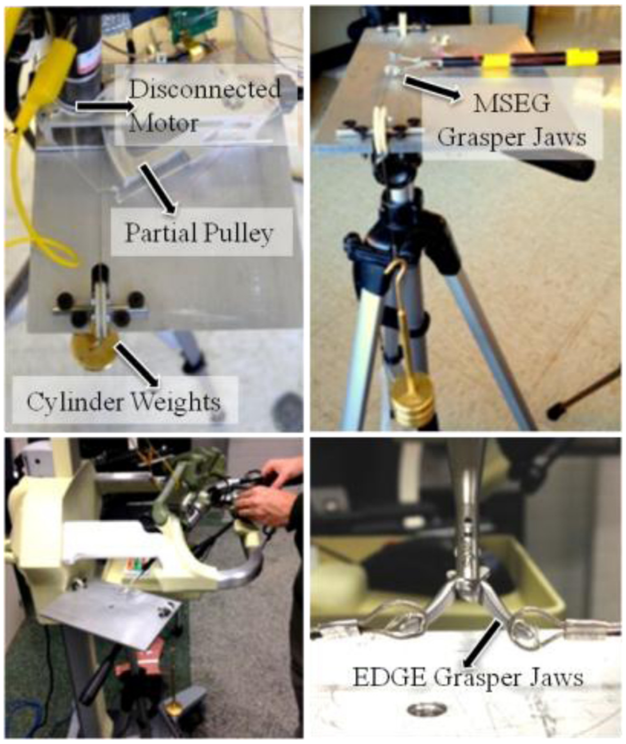

Fig. 1 Setup for MSEG proximal (top left) and distal (top right) end experiments, and EDGE grasper (bottom) experiment

---

Manuscript received March 15, 2013; final manuscript received April 26, 2013; published online July 3, 2013. Assoc. Editor: Arthur G. Erdman.

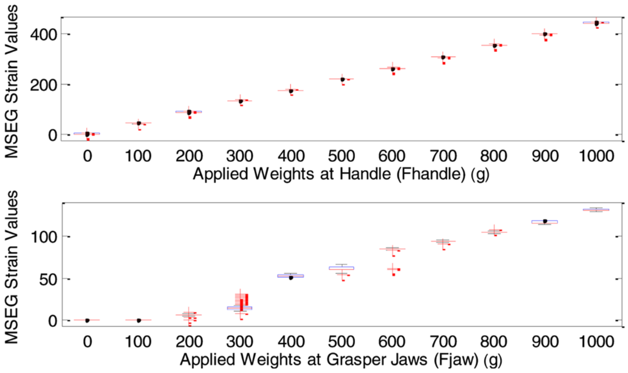

Fig. 2 MSEG box plots of applied weights vs. measured strain values at the proximal end (top) and the distal end with fixed handle position (bottom)

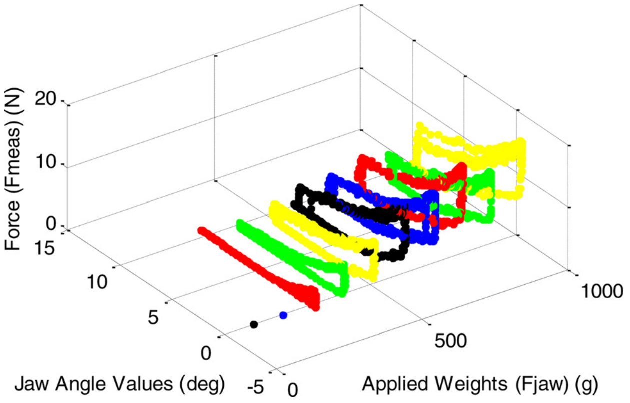

Fig. 3 EDGE grasper measured force values versus jaw angle at different applied weight intervals over full handle position

$$\mathrm{Strain}_{p,\mathrm{fixed}} = 0.14655F_{\mathrm{jaw}} - 12.545 \qquad (2)$$

However, we observed inconsistencies on the values reported by the strain gauges for separate experiments. This finding implies that the strain gauge force-measuring mechanism of the MSEG is unreliable and requires a better design for measuring force.

The F_{meas} and F_{jaw} at the EDGE grasper in Figure 3 demonstrate a nonlinear relationship that is highly dependent on the jaw angle. Figure 4 indicates considerable hysteresis within each cycle of grasper jaw angles: for the same jaw angle measured force differs between "grasping" and "releasing". While a multidimensional surface regression can be used to approximate the mapping $F_{\mathrm{jaw}} = f(F_{\mathrm{meas}}, \theta_{\mathrm{jaw}})$ the hysteresis suggests this would be inaccurate unless it accounts for direction of grasp: $F_{\mathrm{jaw}} = f(F_{\mathrm{meas}}, \theta_{\mathrm{jaw},t})$.

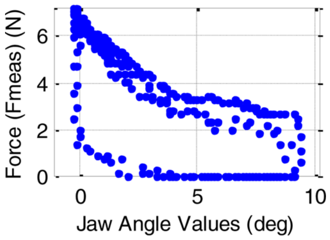

Fig. 4 EDGE grasper measured force versus jaw angle for 500 g applied at grasper jaws

We conclude that measurement of applied force at the tool-tissue interface is confounded by grasper position, direction-dependent friction, and mechanism parameters. Unless these influences can be reliably accounted for, this work motivates direct measurement of forces at the distal end (jaws) directly at the tool-tissue boundary. Further studies should take into account differences in angle of force acting on the grasper within each grasping motion.

References

[1] De, S., 2008, "The Grasper-Tissue Interface in Minimally Invasive Surgery: Stress and Acute Indicators of Injury," Department of Bioengineering, University of Washington.

[2] Peters, J., Fried, G. M., Swanstrom, L. L., Soper, N. J., Sillin, L. F., Schirmer, B., Hoffman, K., and Sages FLS Committee, 2004, "Development and Validation of a Comprehensive Program of Education and Assessment of the Basic Fundamentals of Laparoscopic Surgery," Surgery, **135**(1), pp. 21–27.

[3] Hayter, M., Friedman, Z., Bould, M., Hanlon, J., Katznelson, R., Borges, B., and Naik, V., 2009, "Validation of the Imperial College Surgical Assessment Device (ICSAD) for Labour Epidural Placement," Canadian Journal of Anesthesia/Journal Canadien d'anesthesie, Springer, **56**, pp. 419–426.

[4] Macmillan, A., and Cuschieri, A., 1999, "Assessment of Innate Ability and Skills for Endoscopic Manipulations by the Advanced Dundee Endoscopic Psychomotor Tester: Predictive and Concurrent Validity," Am. J. Surgery, Elsevier, **177**, pp. 274–277.

[5] Brown, J., Rosen, J., Moreyra, M., Sinanan, M., and Hannaford, B., 2002, "Computer-Controlled Motorized Endoscopic Grasper for In Vivo Measurement of Soft Tissue Biomechanical Characteristics," Studies in Health Technology and Informatics, IOS Press, 1999, pp. 71–73.

[6] Rosen, J., Brown, J., Barreca, M., Chang, L., Hannaford, B., and Sinanan, M., 2002, "The Blue Dragon-A System for Monitoring the Kinematics and the Dynamics of Endoscopic Tools in Minimally Invasive Surgery for Objective Laparoscopic Skill Assessment," Studies in Health Technology and Informatics, IOS Press, 1999, pp. 412–418.

[7] Roan, P. R., 2011, "An Instrumented Surgical Tool for Local Ischemia Detection," ProQuest Dissertations and Theses, University of Washington.