Sensorized Cannula for Measuring Body Wall Forces During Surgery

Paul M. Loschak[1*, 2]
Smita De[1*, 3]
Amy E. Kerdok[1]

[1] Intuitive Surgical Operations, Inc., Sunnyvale, CA, USA (* refers to interns)
[2] Harvard School of Engineering and Applied Sciences, Cambridge, MA, USA
[3] Department of Urology, Stanford Medical School, Stanford, CA, USA

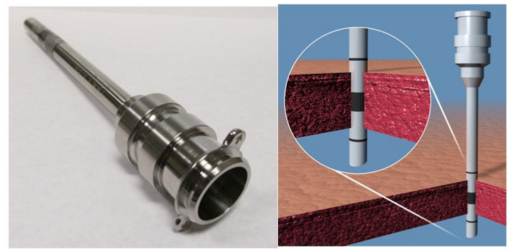

Fig. 1: (a) Robotic cannula, (b) in body wall

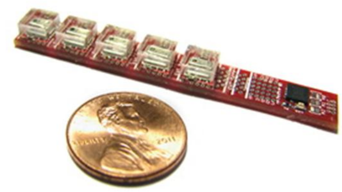

Fig. 2: Takktile strip [8]

1 Background

Minimally invasive surgical (MIS) techniques, including laparoscopy, are widely known to provide many benefits for patients [1]. More recently, teleoperated surgical devices have provided clinicians the ability to perform MIS procedures with the advantages of 3D vision and more dexterous instruments, which may provide additional benefits to the patient [2]. Laparoscopic and robotic procedures are done with instruments inserted through cannulas, which create ports from the outside to the inside of the patient (Fig. 1). Some MIS procedures have resulted in post-operative port site complications including wound infections and hernias [3]. There is minimal data regarding forces applied at the port sites and possible relation to such complications. This paper focuses on a surgical device that may be useful for assessing forces applied at the body wall that could relate to port site tissue injury.

A sensorized cannula was developed to monitor body wall forces during MIS procedures performed through the abdominal wall. Existing devices for measuring various forces during surgery have focused on measuring the forces exerted between instruments and tissue, or require a specially sensorized instrument in conjunction with a sensorized cannula [4-6]. It may also be possible to use an instrumented laparoscopic tool and analytically calculate the force at the body wall with well-defined boundary conditions (i.e., static forces). However, our goal was to have a force sensing tool in which any laparoscopic or robotic instrument can be inserted and used naturally.

2 Methods

A device for measuring forces at the interface between a cannula and a body wall must be small, robust to anatomic environments, and sensitive within the range of 0-50 N. This range was determined through preliminary porcine studies with a digital force gauge (Chatillon, FL, USA) and an 8 mm metal cannula. The final assembly must have a low profile such that the geometry of the sensorized cannula does not interfere with the surgical procedure or alter the way forces are applied to the body wall.

Many sensor options were considered in the design phase. Traditional force-torque sensors were not available in the proper form factor, miniature force sensors lacked the breadth of force range, and resistivity-based thin film sensors failed to provide reliable measurements when curved to the proper contour and introduced to an *in vivo* environment. Feasibility testing confirmed that all design specifications could be met by a set of tactile array sensors based on MEMS barometers on a printed circuit board (Fig. 2) [7].

Four off-the-shelf sensor strips with five barometers per strip [8] were arranged on four sides of an 8 mm diameter long-instrument cannula (Fig. 3) and modified with pliable materials to achieve the proper force range. Barometers measure the ambient air pressure through an air hole in the sensor housing, and therefore they are configured to measure forces on the same order of magnitude as those resulting from air pressure. Higher forces quickly cause the sensors to saturate. This force limit can be increased by using materials to trap air inside the sensor housing, thereby compressing air against the MEMS sensor when a force is applied to the material. Weather-resistant EPDM foam was found to tightly seal enough air inside the housing such that the MEMS sensor could measure more than 50 N without saturating. Hard plastic tubing (Teflon FEP, Shore D55) was wrapped around the assembly to distribute the load between sensors and sensor strips. The sensors were sealed with silicone to avoid damage

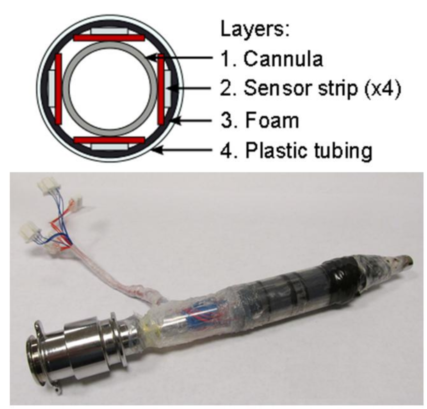

Fig. 3: (top) Cross-section of sensorized cannula, (bottom) final sensorized cannula assembly

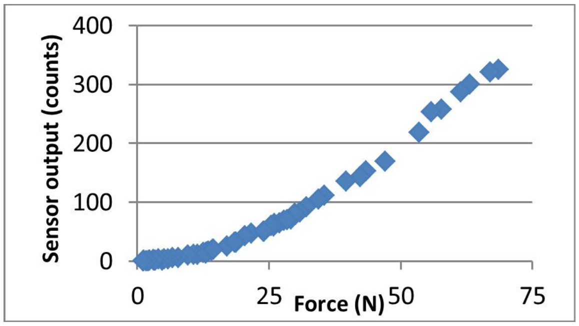

Fig. 4: Calibration curve for one sensor on a strip

from blood or moisture. Calibration was performed with a digital force gauge at the remote center, which is the location on the cannula that is aligned with the body wall. Fig. 4 shows the calibration curve of force vs. sensor output normalized to the sensor's max output value (in terms of counts). The nonlinear nature of the curve reflects the nonlinear behavior of the foam, the plastic tubing, and the silicone when forces are applied.

3 Results

The performance of the sensorized cannula was validated through live porcine model MIS experiments. A sensorized laparoscopic tool was outfitted with a force-torque sensor (ATI Nano25, NC, USA) to measure the surgeon's force input to the tool. A simple static analysis of the tool was then used to calculate the resultant body wall forces. During testing, body wall forces were measured by the cannula sensor and the ATI-sensorized laparoscopic tool simultaneously. Typical surgical tasks that require static interaction with tissue in an upper GI setup were performed. Two independent examples of static gallbladder retraction tests are shown in Fig. 5. Both tasks demonstrate the agreement between the cannula sensor (blue line) and the ATI sensor (green line). Across multiple tasks, the sensorized cannula measurements showed agreement with the ATI sensor to within 98% accuracy on average. Although validation tests were performed quasi-statically due to the limitations of the laparoscopic tool's static analysis, it is important to note that the sensorized cannula measurements are valid for dynamic forces as well.

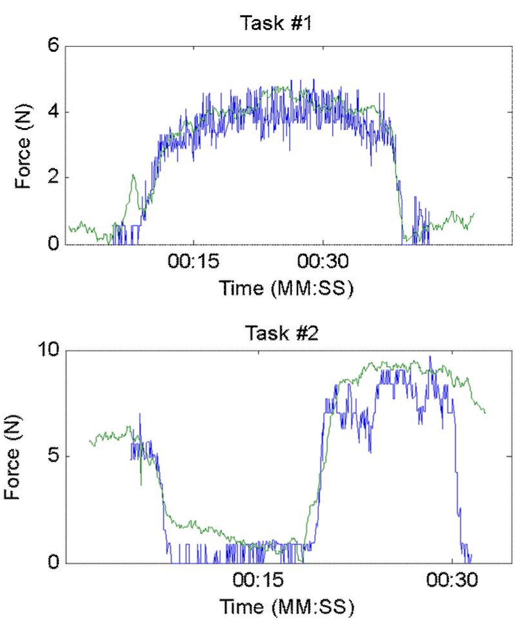

Fig. 5: Agreement between sensorized cannula (blue) and ATI (green) measurements during static retraction tasks

4 Interpretation

Currently, one proof of concept for measuring body wall forces has been developed and tested during MIS techniques. Experiments (to be published separately) were designed to measure the changes in body wall forces for MIS tasks ranging in motion speed, size, and forcefulness in tissue interaction. Work is currently being done to reduce the outer diameter of the sensorized cannula assembly and to improve the assembly process for repeatability, calibration, and reliability for *in vivo* environments. Other methods of modifying the force range, such as casting the assembly in rubber, are also being explored.

The success of this device, a proof of concept for a sensorized cannula, shows that it is possible to directly measure body wall forces at port sites during MIS. It should be noted that tissue damage is a function of pressure, and the larger diameter of the sensorized cannula does affect the pressure distribution of typical forces. Nonetheless, this device may enable clinicians to better understand and potentially reduce port site tissue injury.

References

[1] Venkat R., et al., 2012, "Laparoscopic Distal Pancreatectomy Is Associated With Significantly Less Overall Morbidity Compared to the Open Technique: A Systematic Review and Meta-Analysis," Annals of Surgery, 255(6), pp. 1048-1059.

[2] Khan M.S., et al., 2012, "A dual-centre, cohort comparison of open, laparoscopic and robotic-assisted radical cystectomy," Int. J. Clin. Pract., 66(7), pp. 656-62.

[3] Karthik S., et al., 2013, "Analysis of laparoscopic port site complications: A descriptive study," J Minim Access Surg, 9(2), pp. 59–64.

[4] Richards C., et al., 2000, "Skills evaluation in minimally invasive surgery using force/torque signatures," Surgical Endoscopy, Vol. 14, pp. 791-798.

[5] Tholey G., et al., 2004, "Design, Development, and Testing of an Automated Laparoscopic Grasper with 3-D Force Measurement Capability," Medical Simulation, Vol. 3078, pp. 38-48.

[6] Hanna G.B., et al., 2008, "Development of force measurement system for clinical use in minimal access surgery," Surg Endosc, Vol. 22, pp. 467-471.

[7] Tenzer Y., et al., 2012, "Inexpensive and Easily Customized Tactile Array Sensors using MEMS Barometers Chips," (Under Review) Accessed Oct. 21, 2013, http://biorobotics.harvard.edu/ publications.html.

[8] Takktile, LLC, Accessed Oct. 21, 2013, http://www.takktile.com/.