Dynamic Calibration Method for Instrumented Laparoscopic Surgical Graspers[1]

Michael Winek
Department of Mechanical Engineering,
University of Minnesota,
111 Church Street SE,
Minneapolis, MN 55455

Robert Sweet
Department of Mechanical Engineering,
University of Minnesota,
111 Church Street SE,
Minneapolis, MN 55455

Timothy M. Kowalewski
Department of Mechanical Engineering,
University of Minnesota,
111 Church Street SE,
Minneapolis, MN 55455

1 Background

The prevalence of minimally invasive surgical (MIS) procedures is on the rise due to the promise of fewer complications; however, these surgeries are more technically difficult and require greater training than their traditional counterparts. To counteract this, surgeons undergo more training and utilize surgical simulators to gain experience without risking patients' health. To increase the accuracy and, therefore, effectiveness of the surgical simulators, tissue property databases have been created, such as the Human Tissue Property Database created by the Center for Research in Education and Simulation Technologies, which test excised tissues postmortem for their mechanical properties [1]. Databases such as this have potential beyond their utilization in simulation and may serve as a platform for automated diagnostic systems capable of characterizing the health of tissues during surgical procedures [2]. Because of the importance to surgical simulation now and in the future of automated diagnostics, tissue property databases must better their accuracy to reflect the complex mechanical behavior of biological samples in vivo [2,3]. This upgrade requires the development of instrumentation capable of collecting data nondestructively in vivo, as well as nonintrusively to a surgical environment.

A promising approach to collecting data nondestructively and nonintrusively during surgical procedures is the modification of current MIS tools to contain sensors, and occasionally actuators separate from the operating area [3–6]. Due to the small size of the operating component and the slender connection to the handle, it is not practical to include these additions to the tool anywhere except the handle. Tools, such as the motorized smart endoscopic grasper (MSEG) tool, created by the BioRobotics Lab at the University of Washington, utilize a strain gauge and encoder equipped motor in place of the handle to provide actuation to the jaw and record the stress and strain experienced by the tissue being grasped [6]. Previous efforts to calibrate the MSEG system by the Medical Robotics and Devices Lab at the University of Minnesota have focused on static loading at discrete locations rather than quasi-static loading recorded continuously over a range of the tool's motion [7]. This paper describes the latter method of calibration in order to provide more accurate interpretation of the friction and momentum within the system.

With a calibrated instrument capable of recording data in vivo as well as for benchtop testing, it is possible to create a model of tissue property decay with respect to time postmortem. Successfully doing this with a standardized excision and storage procedure can allow accurate in vivo properties to be derived from the abundance of previously collected ex vivo data currently in databases. This ability to back-compute more meaningful information from already available sources promises to have significant impacts on healthcare through higher quality surgical simulations as well as by providing a reference platform for diagnostic equipment to evolve from. Beyond healthcare, the successful modeling of tissue degradation can impact the field of biomechanics by allowing the compilation and utilization of collected data between studies encouraging greater collaboration to occur.

2 Methods

To calibrate the instruments, a method was necessary to record dynamic distal grasping force and jaw position and compare it with the recorded force and handle position. To accomplish this, a benchtop platform was created to record data while analysis was done using MATLAB (MathWorks, Natick, MA). The instrument used in this testing was the instrumented Babcock grasper as used by Sie [7].

2.1 Distal Sensor Platform Construction. The distal sensor platform seen in Fig. 1 consisted of a digital caliper (Neiko Tools, China) with a shear load cell rated to 780 g (Phidgets, Calgary, Alberta) attached to each outside jaw via aluminum mounts. Attached to each load cell is an aluminum extension defining the location surgical graspers can squeeze.

2.2 Data Recording. This system connects to a circuit built around an AD623 Instrumentation Amplifier (Analog Devices, Inc, Norwood, MA) that is connected to a host computer through an Arduino Uno (Smart Projects, Italy) that time stamps the samples and sends them to a serial com capture utility via a USB 2.0 connection.

2.3 Distal Sensor Platform Calibration. The sensor platform was calibrated with dead weights to a linear fit (Fig. 2).

2.4 Calibration Data Collection. Repeated trapezoidal loading was applied to the instrument, while load and position information were recorded for both the jaw and handle portion of the tool. Multiple separations were set in the calibration caliper to create an effective map of the force mapping. Data sets were time-aligned by finding the scale and offset constants TS and $T0$ to minimize total error $= \sum_t \left| \text{Force}_{\text{Handle},i} - \text{Force}_{\text{Jaw},i} \right|$. Figure 3 shows the accuracy of the predicted jaw displacement and force to the measured jaw displacement and force, respectively. Figure 4 shows the F_{Jaw} and d_{Jaw} response to F_{Handle} and θ_{Handle}.

2.5 Tissue Measurements. The instrumented Babcock grasper was taken to the visible heart lab (VHL) at the University of Minnesota where in vivo compressions could be recorded. The same tissues were then excised and tested at frequent intervals using the same Babcock grasper. Collected data are seen in Fig. 5.
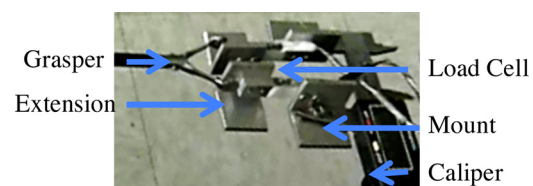

Fig. 1 Distal sensor platform equipped with digital caliper for simple adjustment of jaw separation and mirrored load cells to measure load applied by each jaw undergoing compressions from an instrumented Babcock grasper
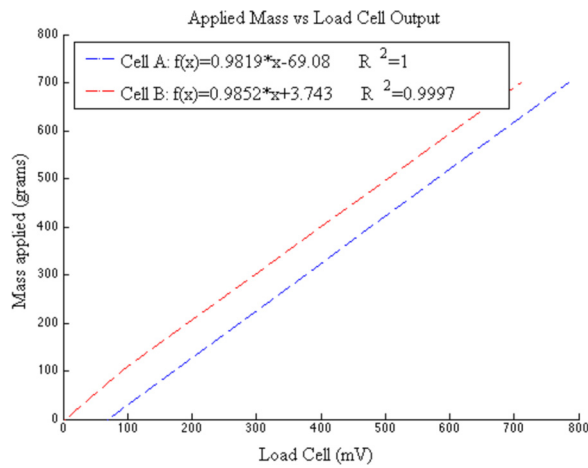
3 Results

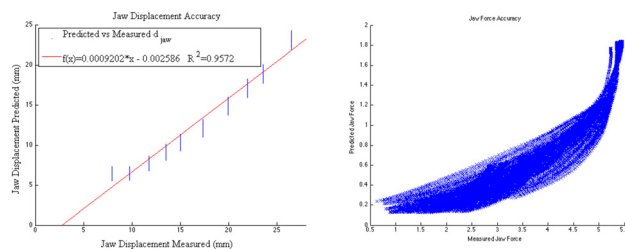Fig. 2 Calibration curve for load cells

Fig. 3 Jaw displacement accuracy (left) and jaw force accuracy (right) from dynamic calibration

4 Interpretation

Representative preliminary data in Fig. 5 show that there is substantial change in the tissue properties following sacrifice of the animal and excision. We see the in vivo data collection experienced greater resistance to compression. This is shown by larger forces experienced than ex vivo samples for given compressions. Additionally, there is a trend in diminishing mechanical response in the liver present in these recordings. This behavior was representative of changes recorded for multiple tissue types excised from sacrificed porcine specimens made available by collaborators at the VHL. The causes of tissue property decay are widespread, including changes in temperature, environment, and fluid loss [2]. To minimize these changes, common practices include utilization of stabilizing solutions to retard decay and controlling environmental factors to match in vivo conditions as closely as possible; however, time is not a factor that can be controlled so researchers must rush to test samples as soon as possible after sacrifice while attempting to maintain consistent times for each specimen, a task that can be difficult if not impossible due to logistical problems and unforeseen technical obstacles faced when performing experiments on biological samples.

The success of the instrumented Babcock grasper in collecting the decay of mechanical properties in porcine tissues is promising; however, further work must be done to develop a robust model capable of accurately predicting change.
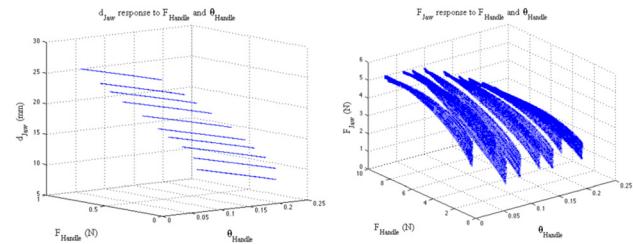

Fig. 4 Calibration curves for the instrumented Babcock grasper. (Left) is the d_{Jaw} response to F_{Handle} and θ_{Handle} (right) is the F_{Jaw} response to F_{Handle} and θ_{Handle}.
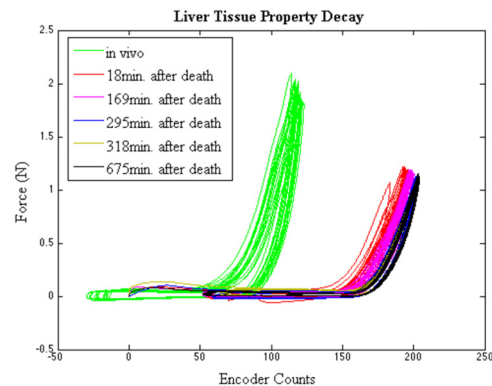

Fig. 5 Handle force versus encoder count representing the recorded data in vivo (leftmost) and ex vivo data collected from a porcine model over multiple consecutive trapezoidal compressions

Future work will address the remaining inaccuracy in the dynamic calibration of the instrumented Babcock grasper as seen in Figs. 2 and 3 to extract more accurate data for tissue property decay model development.

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