Computer-Controlled Motorized Endoscopic Grasper for *In Vivo* Measurement of Soft Tissue Biomechanical Characteristics

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ABSTRACT

Accurate biomechanical characteristics of tissues are essential for developing realistic virtual reality surgical simulators utilizing haptic devices. Surgical simulation technology has progressed rapidly but without a large database of soft tissue mechanical properties with which to incorporate. The device described here is a computer-controlled, motorized endoscopic grasper capable of applying surgically relevant levels of force to tissue *in vivo* and measuring the tissue's force-deformation properties.

1. Introduction

Accurate biomechanical characteristics of tissues are essential for developing realistic virtual reality surgical simulators utilizing haptic devices. Surgical simulation technology has progressed rapidly but without a large database of soft tissue mechanical properties with which to incorporate. In addition, the majority of the research done on measuring mechanical properties of abdominal soft tissues has been performed *in vitro* on animals and cadavers. As simulation technologies continue to be capable of modelling more complex behavior, an (*in vivo*) tissue property database needs to be developed to fill this gap.

2. Background

The biomechanics of soft tissues that are load-bearing during physiological activities have been well studied (muscles, tendons, intervertebral discs, cartilage, blood vessels). Most of that work, however, has been done *in vitro* and/or on animal specimens. Much less testing has been done on the abdominal organs relevant to laparoscopic surgery.

A seminal work presenting tests of a wide variety of organs and tissues was done by Yamada.[1] Mechanical properties of a large number of tissues were compiled by Yamada. Some of the surgically relevant soft tissues were lung, esophagus, stomach, small and large intestines, liver, and gallbladder. Much of the work was done on animals *in vitro*, and a few were done on human cadavers. Viscoelastic behavior was not described. Other work has been done in testing and modelling the kidney.[2,3] Melvin *et al.* conducted *in vivo* experiments on rhesus monkey kidney and liver by placing the whole live organ onto a load cell and performing uniaxial unconfined compressions.[2] Farshad *et al.* tested pig kidney *in vitro* under various (multi-axial) loading conditions.[3] Both of those studies were done with the application of high impact injury modelling in mind, not the slow loads and displacements typically performed in surgery. Perhaps more directly relevant to surgery, some recent work was done by Carter *et al.*, in which they measured *in* *vitro* the force required to puncture pig liver and spleen with a scalpel and the displacement of the tissue at puncture.[4]

It has only recently become a major thrust of researchers to obtain *in vivo* measurements of tissue mechanical properties. Brouwer *et al.* developed several instruments for measuring porcine tissue response to extension and indentation *in vivo*.[5] Ottensmeyer *et al.* have been developing a set of instruments for obtaining *in vivo* multi-axial tissue response to quasi-static and dynamic loading.[6] Their group has designed a 1-D indenter for applying small, time-varying displacements, and a 3-D indenter for applying larger but slower displacements. Our previous instrument was capable of applying compressive force via voice-coil actuators.[7,8] This instrument was used to test several porcine abdominal tissues *in vivo* to measure their force-deformation response, similar to the work done by Brouwer *et al*.[5]

3. Methods & Tools

To study and characterize the abdominal tissues relevant to laparoscopic surgery, a few objectives must be met in the design of the testing device. First, most soft tissue structures within the body demonstrate aspects of nonlinear, viscoelastic behavior, so the ability to induce time-varying loads is critical in characterizing the tissue's true mechanical behavior. Second, the device should be capable of applying levels of force and deformation consistent with those seen in laparoscopic procedures. The device should also be hand-held, lightweight, have interchangeable tool tips, and be capable of entering the body through an endoscopic port.

To achieve these goals, we have adapted our previous design for the force-reflecting endoscopic grasper (FREG) [7,8] to a motorized endoscopic grasper (MEG) that uses a brushed DC motor instead of a voice-coil actuator. The motor is attached to a capstan that drives a cable and partial pulley. The pulley is attached to a ball joint that converts the rotational motion of the motor and pulley to a linear translation. (The linear movement occurs in a standard laparoscopic grasper shaft, which then drives the opening and closing of the jaws.) The motor is capable of producing 29 mNm of continuous torque, but it is coupled with a 19:1 planetary gearhead and partial pulley that increase the torque to 3.98 Nm. This torque is equivalent to 52 N of grasping force applied by a surgeon on an endoscopic grasper's finger loops, close to the maximum value applied by surgeons in our previous work.[9] Standard laparoscopic instruments can be attached to the base plate mount and inserted into the ball joint, allowing tool type to be changed with relative ease. Two strain gage force sensors are embedded in the partial pulley to provide accurate grasping force measurement for robust and precise control. A digital encoder, attached to the motor, measures position. Computer control is provided real-time via a PC using a PD (position) controller implemented in Simulink and dSPACE user interface and hardware. The MEG is a hand-held device that weighs about 0.7 kg (including grasper and protective covers) and can be inserted into the body through regular endoscopic ports to perform computer-controlled dynamic and static uniaxial compressive displacements of soft tissues *in vivo*. Compressive loadings can be static or dynamic, allowing for ramp-and-hold, creep, and stress relaxation tests.

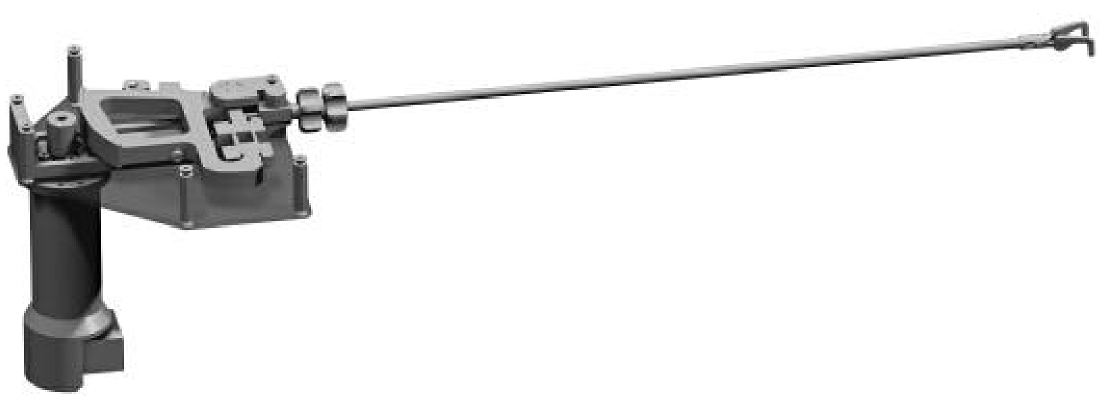

Figure 1. Motorized Endopscopic Grasper (MEG) (top cover not shown).

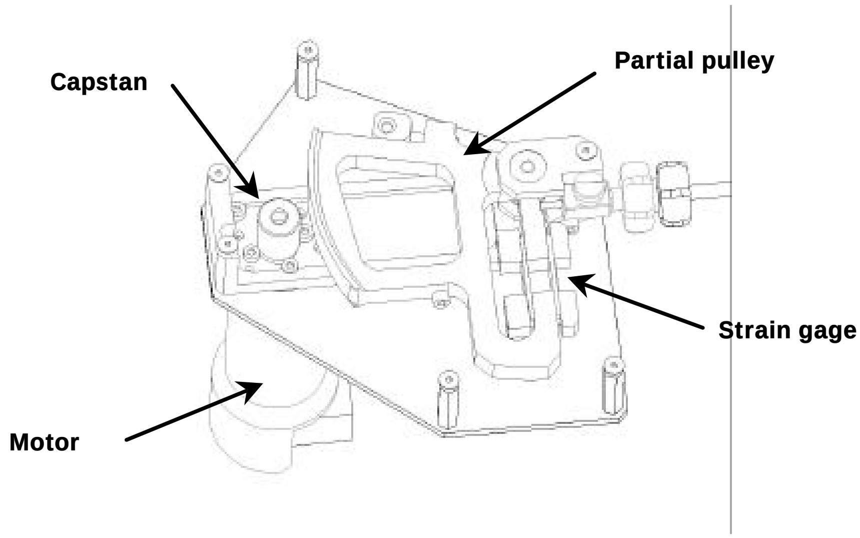

Figure 2. Close-up of the MEG drive system components.

4. Conclusion

The device reported here is a newly developed tool for taking measurements of soft tissues *in vivo* using a minimally invasive or open setup. The new device can control and measure grasping force and deformation of tissues, accept a wide variety of tool types, and can apply physiological and surgically realistic levels of force and deformation to the tissues. The MEG will help provide realistic data for surgical simulation and corroborate the results of other researchers.

The MEG is currently being used on latex rubber samples (tissue physical models) and porcine soft tissues. These tissues will have their stress-strain properties characterized under various loading types, including static and dynamic. Time-dependent properties such as creep and stress relaxation will also be studied. Other work will compare *in vivo* MEG data with *in vitro* MEG and universal testing machine data to observe changes in tissue mechanical properties postmortem. Determination of tissue response (damage) to various loadings and tool tips will also likely be performed.

5. References

[1] H. Yamada, *Strength of Biological Materials*, ed: F.G. Evans, Robert E. Krieger Publishing Co., Inc.: Huntington, N.Y., 1973.

[2] J.W. Melvin, R.L. Stalnaker, V.L. Roberts, M.L. Trollope, "Impact injury mechanisms in abdominal organs," *Proceedings of the 17th Stapp Car Crash Conference*: 115-126, 1973.

[3] M. Farshad, M. Barbezat, P. Flueler, F. Schmidlin, P. Graber, P. Niedere, “Material characterization of the pig kidney in relation with the biomechanical analysis of renal trauma.” *J Biomechanics*, 32(4): 417-25, 1999.

[4] F.J. Carter, T.G. Frank, P.J. Davies, A. Cuschieri, "Puncture forces of solid organ surfaces," *Surg. Endosc.*, 14(9): 783-6, 2000.

[5] I. Brouwer, J. Ustin, L. Bentley, A. Sherman, N. Dhruv, F. Tendick, "Measuring in vivo animal soft tissue properties for haptic modeling in surgical simulation," Proceedings, MMVR-2001:69-74, 2001.

[6] M.P. Ottensmeyer, J.K. Salisbury, "In vivo mechanical tissue property measurement for improved simulations," Proceedings of the SPIE, 4037: 286-93, 2000.

[7] B. Hannaford, J. Trujillo, M. Sinanan, M. Moreyra, J. Rosen, J. Brown, R. Lueschke, M. MacFarlane, "Computerized Endoscopic Surgical Grasper," Proceedings, MMVR-98, 1998.

[8] J. Rosen, B. Hannaford, M. MacFarlane, M. Sinanan, "Force Controlled and Teleoperated Endoscopic Grasper for Minimally Invasive Surgery - Experimental Performance Evaluation," *IEEE Transactions on Biomedical Engineering*, 46(10): 1212-1221, 1999.

[9] J. Rosen, M. Solazzo, B. Hannaford, M. Sinanan, "Objective Laparoscopic Skills Assessments of Surgical Residents Using Hidden Markov Models Based on Haptic Information and Tool/Tissue Interactions," Proceedings, MMVR-2001:417-23, 2001.