AN INTRA-OPERATIVE SYSTEM FOR RELATING ISCHEMIC DAMAGE TO RETRACTION FORCES

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Abstract - Clinical studies show that excessive retraction forces in general open and minimally-invasive laparoscopic surgery cause ischemic damage. We developed a system that can correlate ischemic tissue damage to retraction force and duration. Surgical retractors instrumented with force and tissue oxygenation sensors allow measurement of retraction force and local levels of ischemia. Real-time force and oxygenation data from the instruments are recorded and presented to the surgeon. Preliminary *in vivo* experiments on porcine liver indicate that (1) the rate of tissue ischemia onset is related to applied force and (2) retraction force thresholds exist, beyond which significant decreases in saturation are not observed.

INTRODUCTION

- In general open, laparoscopic and robotically assisted surgery, surgical retractors provide for visualization of the surgical site.
- Histological evidence shows that excessive retraction forces occlude the blood supply and lead to ischemic tissue damage.
- Few methods exist for quantifying retraction forces and resulting tissue damage to retracted tissue *in vivo*.
- Clinical studies show that the human liver has 15-20min normothermic ischemic tolerance, with major complications arising after 90min of ischemia[1].

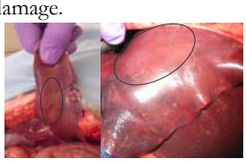


Figure 1. Discoloration at retraction site in porcine liver

PROBLEM ADDRESSED

- Develop a system for *in vivo* monitoring of oxygen saturation to warn of pending ischemic damage to the retracted tissue: design and manufacture specialized surgical retractors with integrated force and oxygenation sensors and monitor real-time force and tissue oxygenation data to surgeons.
- Determine the effects of retraction force magnitude and duration on the ischemic damage to living tissue and use this information to provide a threshold for the magnitude and duration of the maximum "safe" retraction force.

TECHNOLOGY

- Tissue oxygen saturation is monitored using oximetry-based techniques. Oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb) have different light absorption properties as shown in Fig. 2; therefore, as oxygen saturation increases (more HbO_2 and less Hb), light absorption for Red light decreases and for Infrared light increases. The relative changes in intensities of Red and IR light that are transmitted through tissue are used to determine the oxygen saturation of the blood. Wavelengths of 660nm (Red) and 880nm (IR) are used for these trials; the ratios of the light transmission of Red to IR are used to determine the change in tissue oxygen saturation[2].
- Retraction forces are measured using 6-DOF force/torque sensors mounted on the instrument shaft near the distal end.

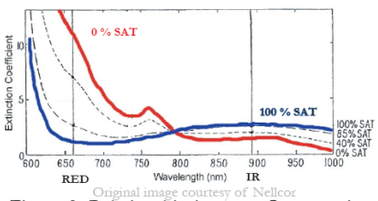


Figure 2. Relationship between O_2 saturation and optical impedance by wavelength of light.

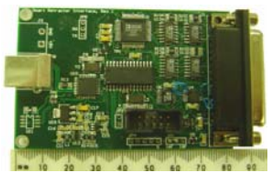


Figure 3. Retractor oxygenation sensor interface circuit board

MATERIALS & METHODS

- Standard retractors are instrumented with sensing elements for measuring local tissue oxygen saturation at the working surface. Fig. 4 shows sample sensing retractors; b & c show retractors used for correlating retraction forces and durations to oxygen saturation.
- Retractors are connected to a control PC through the programmable interface shown in Fig. 3. Calculations, monitoring, and forms of sensory substitution are the responsibility of the host PC. Fig. 5 shows the interconnection of the system's components.

Figure 4. Sample sensing retractors: a) laparoscopic Babcock grasper, b) Deaver retractor with force and oxygen sensing and c) customized Balfour retractor with force and oxygenation sensing

References:
[1] Harada, M., *et. al*, "Effect Of Intermittent Liver Ischemia On Outcome In Patients With Hepatocellular Carcinoma On Liver Cirrhosis", Journal of Medical Investigation, 46(3-4), Aug. 1999.
[2] Fischer, G., *et. al*, "Intra-operative Ischemia Sensing Surgical Instruments", Complex Medical Engineering, May 2005.
[3] Shibamoto, T., *et. al*, "Hepatic capillary pressure is estimated using triple vascular occlusion method in isolated canine liver", American Journal of Physiology, 271, Nov. 1996.

EXPERIMENTAL PROCEDURE

- Experiments were performed on *in vivo* porcine liver at the Minimally Invasive Surgical Training Center, Johns Hopkins Hospital using the system shown in Fig. 5.
- Constant retraction forces are applied to liver for two minutes, released for two minutes, and restored at constant force for two minutes as shown in Figure 6.
- The force levels were varied for each trial between 2.0, 3.5, 5.0, 6.5, and 8.0 N. (see Fig. 7)
- Tissue oxygen saturation are retraction forces are continuously logged

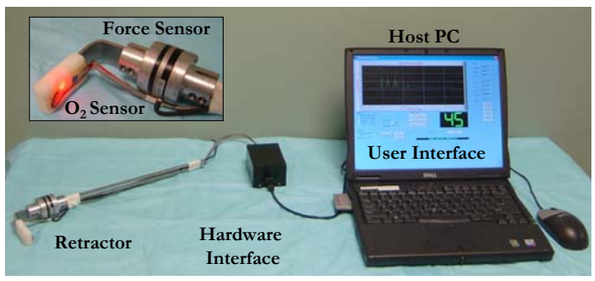
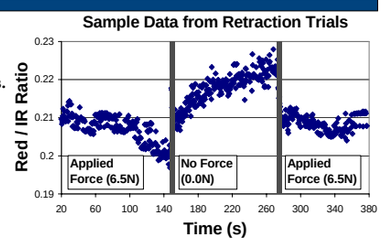


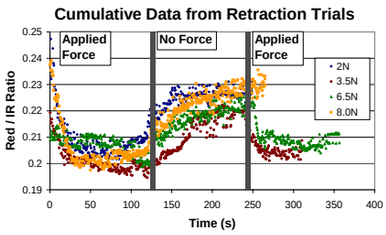
Figure 5. System components and interconnects for retraction trials

RESULTS

Figure 6 (above right). Representative data from trial with 6.5N, 0N, and 6.5N retraction forces. Figure 7 (below right). Preliminary results from trials with varying retraction forces.

Figure 8. Retraction experiment in progress





CONCLUSIONS

- Applying a minimal retraction force causes a significant drop in the local tissue oxygen saturation.
- Retraction forces tested exceeded both hepatic venous pressure (P_{hv} = 5.2 ± 0.2 mmHg ⇒ F = 0.78 ± 0.03 N) and hepatic arterial pressure (P_{ha} = 13.8 ± 1.1 mmHg ⇒ F = 2.08 ± 0.17 N).
- Once threshold is reached (0.8 - 2N), increased retraction force levels (3.5, 5.0, 6.5, 8.0 N) have little effect on tissue surface O_2 saturation

FUTURE WORK

- Continue porcine trials, including organs other than liver with larger variations in applied retraction pressure and for longer durations.
- Perform detailed porcine histological and survival studies to determine long-term effects of induced ischemic retraction damage.
- Quantify standard retraction forces applied during surgery by collecting data from human trials and determine safe levels.
- Apply system to training and surgical procedure quality assurance.

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