Published in final edited form as:

Surg Endosc. 2008 December ; 22(12): 2659–2664. doi:10.1007/s00464-008-9792-4.

Evaluation of Real-Time Infrared Intraoperative Cholangiography in a Porcine Model

Jack J. Liu^{*,1}, Mehrdad Alemozaffar^{*,1}, Ben Mchone¹, Nadeem Dhanani¹, Fred Gage², Peter A. Pinto¹, Alexander M. Gorbach³, and Eric Elster^{2,4}

¹Urologic Oncology Branch, National Cancer Institute, Bethesda, MD

²Regenerative Medicine, Combat Casualty Care, Naval Medical Research Center, Silver Spring, MD

³Division of Bioengineering and Physical Science, National Institute of Biomedical Imaging and Bioengineering, Bethesda, MD

⁴Department of Surgery, Uniformed Services University of the Health Sciences, Bethesda, MD

Abstract

Introduction—Intraoperative cholangiograms (IOCs) may increase cost, surgical time, and radiation exposure to staff and patients. We introduce the application of passive infrared (IR) imaging to intraoperative cholangiography as a feasible alternative to traditional fluoroscopic IOCs.

Methods—A porcine model was used in which the gallbladder, cystic duct, CBD, and duodenum were exposed and an 18 gauge angiocatheter was inserted into the cystic duct. IR emission was detected using a digital IR camera (Lockheed Martin Inc., Goleta, CA) positioned at 30–60 cm above the abdomen. IR images were taken in real-time (~1/sec) during infusion of room temperature saline. A thermoplastic polymer stone was then inserted into the CBD. Once the artificial stone was placed, room temperature saline was again injected. A standard single shot renograffin IOC was obtained to confirm the obstruction. The experiment was concluded by a lateral 2mm CBD injury immediately proximal to the duodenum followed by infusion of room temperature saline.

Results—A total of 6 pigs were used. Baseline IR imaging was able to capture a visible temperature decrease, outlining the lumen of the CBD. With injection of room temperature saline, a decrease in temperature was visualized as a dark area representing flow from the CBD to the duodenum. After placement of the synthetic stone, real-time IR images displayed the injected bolus being slowed by the obstruction. The obstruction was correlated with fluoroscopic IOCs. Finally, after partial transection of the CBD, the IR camera visualized saline flowing from the site of injury and out into the peritoneal cavity.

Conclusions—CBD anatomy, obstruction, and injury can be clearly visualized with an IR camera. Intraoperative IR imaging is an emerging modality already being utilized in several surgical fields. Ultimately, the integration of IR and laparoscopic technology will be necessary to make IR technology important in laparoscopic cholecystectomy.

Keywords

Laparoscopic Cholecystectomy; Infrared Imaging; Intraoperative Cholangiogram

Corresponding/Reprints author: Eric Elster MD FACS, CDR MC USN, Regenerative Medicine, Combat Casualty Care, Naval Medical Research Center, 503 Robert Grant Ave Suite 2W123, Silver Spring, MD 20910, elstere@nmrc.navy.mil, Office: 301 319 8632, Fax: 301-295-1403.

*These authors contributed equally to this work.

Introduction

Laparoscopic cholecystectomy (LC) has revolutionized the way in which gallbladder disease is treated [1]. However, due to the limitations in visualization during laparoscopy, common bile duct (CBD) injuries have become significantly more common. The rate of CBD injuries is estimated to be 0.1–0.2% for open cholecystectomy (OC) and 0.2–1.6% for LC, roughly three times greater than its open counterpart [2–7]. These injuries are most often caused by misidentification or misinterpretation of biliary anatomy [8]. Ludwig et al showed that operation-relevant variations in the extrahepatic biliary system occurred in 12.8% of patients undergoing LC, while Moossa et al showed that variations in biliary anatomy play a role in 10–19% of CBD injuries [9].

Unrecognized CBD injuries can lead to severe morbidity secondary to biliary strictures and the need for reoperation [10]. Given such serious complications, routine intraoperative cholangiograms (RIOCs) have been proposed as a means to clarify biliary anatomy and detect injuries early. With RIOCs, up to 90% of CBD injuries can be detected whereas only 42% of injuries are detected with selective IOC's [11]. Despite their utility, RIOCs remain controversial since it increases cost, operative time, and exposure of patients and staff to radiation [12].

In order to address some of these disadvantages, alternative imaging modalities such as laparoscopic ultrasound (LUS) have been introduced [13]. Since LUS is less expensive, safe, and can be performed more quickly during surgery, its routine use may be more acceptable and selective IOC's can be performed only if LUS fails. Although LUS is as effective as IOC in detecting CBD stones, its ability to visualize biliary anatomy is inferior to IOC's [13]. LUS also carries with it several disadvantages such as a steep learning curve, need for special equipment, and is examiner dependent [13].

An emerging modality is the application of infrared (IR) imaging in the assessment of organ perfusion and anatomy. IR imaging can provide anatomic detail and information about tubular flow by detecting minute differences in heat between tissues. Recent advances in IR imaging has allowed for accurate detection up to one hundredth of a degree Celsius. Instead of radioactive contrast, cold or warm saline can be used to depict anatomy and flow through tubular structures. Thermal coronary angiography (TCA) which uses IR technology to assess coronary artery bypass patency is a similar technology being investigated for use in cardiothoracic surgery [14,15]. Given the concerns associated with RIOCs and the need for effective intraoperative biliary imaging, IR technology may be a useful addition to LC. In this study, we evaluate the ability of IR imaging to provide useful and accurate visualization of the biliary system in a porcine model.

Methods

IR Camera

An advanced IR camera (Lockheed Martin IR Imaging Systems, Inc., Goleta, CA) with an internally-cooled IR focal plane array detector (320×256 pixels) was utilized to capture temperature gradients across exposed tissue by passive detection of IR emission. IR emission at the measured wavelength (3–5 μ) is directly proportional to temperature and the camera has a sensitivity of up to 0.02° C. It was mounted on a Zeiss operating microscope stand to provide stable positioning and mobility directly over the operative field.

An electric cooling device is activated 20 minutes prior to imaging to maintain the camera's detector at an optimal operating temperature. The camera is then positioned at 30–60 cm above

the biliary system. The typical field of view included the gallbladder, cystic duct, CBD, and duodenum, producing a spatial resolution for individual pixels of approximately 1 mm per pixel. Sequential IR images are obtained at 1 frame per second for 250–600 seconds and digitized at 14 bits per pixel. Images were stored on a laptop computer mounted on the microscope stand and projected in real-time on the OR wall in pseudo-color.

Animal Experiments

All animal procedures were approved by the Institutional Animal Care and Use Committee (UOB-006) at the National Cancer Institute. The animals were maintained in accordance to guidelines issued by the Institute of Laboratory Animal Resources, National Research Council.

A total of 6 male Yucatan pigs between 7 to 8 months of age and weighing between 23 to 28 kg were used for this pilot study. The pigs were maintained under general anesthesia using 1% isoflurane. Once adequate anesthesia was established, a midline laparotomy was performed followed by isolation of the gallbladder, cystic duct, and cystic artery. A cholecystotomy was created, from which bile was evacuated and an 18 gauge angiocatheter was inserted into the gallbladder and secured in position.

Baseline images of the gallbladder, cystic duct, CBD, and duodenum were obtained. Room temperature saline (22°C) was then injected into the gallbladder via an 18 gauge angiocatheter, and IR images were acquired during infusion. A cholecystectomy was then performed and the cystic duct was cannulated with an 18 gauge angiocatheter (Figure 1). Room temperature saline was infused again, but via the cystic duct while IR images were captured.

An obstruction was then introduced by using a 1cm synthetic thermoplastic polymer stone. The synthetic stone was passed retrograde through the ampulla and into the CBD via a duodenostomy. Room temperature saline was infused into the angiocatheter while IR images were captured. The obstruction was confirmed by performing a single shot renograffin IOC.

An injury was then created by a 2mm transverse laceration to the CBD at 2cm above the duodenum. Room temperature saline was again infused into the cystic duct and IR images were captured.

Results

IR imaging was successfully performed on all 6 animals. The baseline IR images were capable of visualizing biliary structures even prior to the injection saline contrast. The lumens of the CBD and duodenum can be visualized as areas of lower IR intensity which is surrounded by areas of higher IR intensity, representing surrounding tissue (Figure 2A). After injection of room temperature saline into the CBD, an area of low IR intensity can be seen extending unimpeded through the biliary system highlighting the anatomy of the CBD and duodenum (Figure 2B). The area may appear larger than the actual luminal size due to cooling of the areas immediately outside the CBD and duodenum.

Both the IR camera and renograffin IOC's were able to demonstrate an obstruction in the CBD. Unlike the previous images, there is no evidence of flow into the duodenum after injection of room temperature saline (Figure 3A). Instead, we can see an area low IR intensity just distal to the angiocatheter which stops abruptly in the CBD. The renograffin IOC confirmed the obstruction. It is illustrated by a radio-opaque area that stops abruptly at the site of obstruction (Figure 3B).

A 2mm injury was successfully made in all 6 animals. IR imaging was able to demonstrate the injury by visualizing an extravasation of infused room temperature saline into the operative

field. This leakage was represented by a general area of low IR intensity around the CBD (Figure 4).

Discussion

Since the introduction LC, many efforts have been taken to reduce the rate of CBD injury. Standard principles and IOC's have been introduced to prevent such injuries [16]. The benefits of RIOC's have been studied extensively and have shown promising results in the reduction of CBD injuries. Despite these potential benefits, there is still no consensus regarding the routine use of IOC's for reasons of cost, increased surgical time, and radiation exposure. Alternative imaging modalities such as LUS have also been considered to address some of the drawbacks of radio-contrast IOC's, however, its accuracy and feasibility are controversial [13]. IR imaging technology may be a feasible alternative to address many of the drawbacks of traditional RIOC's. Using real-time IR assessment, we were able to clearly demonstrate biliary anatomy, obstruction, and injury.

Due to the drawbacks of RIOC's, the majority of surgeons only use them selectively. IOC's are typically used only when the suspicion for injury is high or clinical or radiographic signs suggest the presence of a CBD stone. Besides the problems with increased operative time, cost, and radiation exposure, there are several additional concerns about IOC's that prevent its routine use. Opponents to RIOC's are also concerned about iatrogenic injury due to mistaken cannulation of the CBD [17]. There is also concern about unnecessary exploration of the biliary system since the sensitivity of IOC's for CBD stones is not well-established [18].

Our results demonstrate that IR imaging is both a feasible and useful application to intraoperative imaging and may have several advantages over traditional IOC's. As our images illustrate, IR imaging has the sensitivity to distinguish luminal and solid structures even without contrast. When saline contrast is used, the course of the CBD is clearly demonstrated. We successfully demonstrated the presence of a CBD obstruction which was confirmed by a single-shot renograffin IOC. Biliary injury was also easily visualized as an extravasation of saline contrast. IR imaging has the potential to address many of the drawbacks of fluoroscopic IOC's. By using saline as contrast, there is no concern about excess radiation exposure. The room temperature saline also quickly equilibrates to surrounding temperature which allows for convenient repeat imaging of the biliary system. Additionally, we were able to image the CBD by injecting saline contrast via a cholecystomy. This is important since CBD injuries are another concern with IOC's.

To address the problems of surgical time and cost associated with RIOC's, we are currently developing a laparoscopic camera that will have the capability of alternating between visible and IR spectra. This camera would allow for rapid acquisition of IOC's without the need for additional staff or equipment. We are also collaborating to develop an algorithm to fuse IR and visible images to provide an integrated display [19]. Another important advantage of IR imaging is that images are acquired in real-time. This can provide surgeons with constant anatomic information that can adapt to the changing operative field and may even help decrease operative time.

Although there may be many disadvantages to RIOC's, their benefits in LC have been well documented and studied. We have shown that IR imaging may have the potential to address the issues regarding surgical time, cost, and radiation exposure associated with RIOCs. Coupled with the development of a laparoscopic IR camera and an algorithm for image fusion, this technology may play a significant role in the future implementation of RIOC's. Clearly, this technology will need to be studied in a clinical model which contrasts standard fluoroscopic IOC with IR IOC to further develop these promising results.

Acknowledgments

Supported by the intramural research funds of National Institute of Health and Department of Defense (work unit number: 602227D.0483.01.A0518, Medical Free Electron Laser program). The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. I am a military service member (or employee of the US Government). This work was prepared as part of my official duties. Title 17 U.S.C. 105 provides that 'Copyright protection under this title is not available for any work of the United States Government.' Title 17 U.S.C. 101 defines a U.S. Government work as a work prepared by a military service member or employee of the US Government as part of that person's official duties.

Abbreviations used in this paper

IR, infrared; IOC, intraoperative cholangiogram; RIOC, routine intraoperative cholangiogram.

Reference List

1. Gallstones and laparoscopic cholecystectomy. NIH Consensus Development Panel on Gallstones and Laparoscopic Cholecystectomy. *Surg Endosc* 1993;7(3):271–279. [PubMed: 8503085]
2. Adamsen S, Hansen OH, Funch-Jensen P, Schulze S, Stage JG, Wara P. Bile duct injury during laparoscopic cholecystectomy: a prospective nationwide series. *J Am Coll Surg* 1997;184(6):571–578. [PubMed: 9179112]
3. Berci G. Complications of laparoscopic cholecystectomy. *Surg Endosc* 1998;12(4):291–293. [PubMed: 9543515]
4. Davidoff AM, Pappas TN, Murray EA, Hilleren DJ, Johnson RD, Baker ME, Newman GE, Cotton PB, Meyers WC. Mechanisms of major biliary injury during laparoscopic cholecystectomy. *Ann Surg* 1992 Mar;215(3):196–199. [PubMed: 1319620]
5. Deziel DJ, Millikan KW, Staren ED, Doolas A, Economou SG. The impact of laparoscopic cholecystectomy on the operative experience of surgical residents. *Surg Endosc* 1993;7(1):17–21. [PubMed: 8424225]
6. Gigot J, Etienne J, Aerts R, Wibin E, Dallemagne B, Deweer F, Fortunati D, Legrand M, Vereecken L, Doumont J, et al. The dramatic reality of biliary tract injury during laparoscopic cholecystectomy. An anonymous multicenter Belgian survey of 65 patients. *Surg Endosc* 1997;11(12):1171–1178. [PubMed: 9373288]
7. Regoly-Merei J, Ihasz M, Szeberin Z, Sandor J, Mate M. Biliary tract complications in laparoscopic cholecystectomy. A multicenter study of 148 biliary tract injuries in 26,440 operations. *Surg Endosc* 1998;12(4):294–300. [PubMed: 9543516]
8. Olsen D. Bile duct injuries during laparoscopic cholecystectomy. *Surg Endosc* 1997;11(2):133–138. [PubMed: 9069144]
9. Moossa AR, Easter DW, Van SE, Casola G, D'Agostino H. Laparoscopic injuries to the bile duct. A cause for concern. *Ann Surg* 1992 Mar;215(3):203–208. [PubMed: 1531914]
10. Ostroff, J.; LaBerge, JM. Endoscopic and Radiologic Treatment of Biliary Disease. In: Feldman, M.; Friedman, LS.; Brandt, LJ., et al., editors. *Feldman: Sleisenger & Fordtran's Gastrointestinal and Liver Disease*. Vol. 8th ed.. Philadelphia, PA: Saunders Elsevier; 2006. p. 1503-1535.
11. Ludwig K, Bernhardt J, Lorenz D. Value and consequences of routine intraoperative cholangiography during cholecystectomy. *Surg Laparosc Endosc Percutan Tech* 2002;12(3):154–159. [PubMed: 12080254]
12. Piacentini F, Perri S, Pietrangeli F, Nardi M Jr, Dalla TA, Nicita A, Lotti R, Castaldo P, Gabbrielli F, Castiglia D, et al. [Intraoperative cholangiography during laparoscopic cholecystectomy: selective or routine?]. *G Chir* 2003;24(4):123–128. [PubMed: 12886750]
13. Machi J, Oishi AJ, Tajiri T, Murayama KM, Furumoto NL, Oishi RH. Routine laparoscopic ultrasound can significantly reduce the need for selective intraoperative cholangiography during cholecystectomy. *Surg Endosc* 2007;21(2):270–274. [PubMed: 17122981]
14. Garbade J, Ullmann C, Hollenstein M, Barten MJ, Jacobs S, Dhein S, Walther T, Gummert JF, Falk V, Mohr FW. Modeling of temperature mapping for quantitative dynamic infrared coronary

- angiography for intraoperative graft patency control. *J Thorac Cardiovasc Surg* 2006;131(6):1344–1351. [PubMed: 16733168]
15. Sonmez B, Arbatli H, Tansal S, Yagan N, Unal M, Demirsoy E, Tukenmez F, Yilmaz O. Real-time patency control with thermal coronary angiography in 1401 coronary artery bypass grafting patients. *Eur J Cardiothorac Surg* 2003;24(6):961–966. [PubMed: 14643815]
 16. Stewart L, Way LW. Bile duct injuries during laparoscopic cholecystectomy. Factors that influence the results of treatment. *Arch Surg* 1995;130(10):1123–1128. [PubMed: 7575127]
 17. Strasberg SM, Eagon CJ, Drebin JA. The "hidden cystic duct" syndrome and the infundibular technique of laparoscopic cholecystectomy--the danger of the false infundibulum. *J Am Coll Surg* 2000;191(6):661–667. [PubMed: 11129816]
 18. Nickkholgh A, Soltaniyekta S, Kalbasi H. Routine versus selective intraoperative cholangiography during laparoscopic cholecystectomy: a survey of 2,130 patients undergoing laparoscopic cholecystectomy. *Surg Endosc* 2006;20(6):868–874. [PubMed: 16738972]
 19. Hanna B, Gorbach A, Gage F, Pinto P, Silva J, Gilfillan L, Kirk A, Elster E. Intraoperative assessment of critical biliary structures with visible range/infrared image fusion. *American Transplant Congress*. 2007

Figure 1.
Visible light image of the general surgical field after cholecystectomy and placement of a catheter through the cystic duct.

Figure 2.

Corresponding IR imaging of the CBD and duodenum after cholecystectomy. (A) View of the biliary system prior to room temperature saline infusion. (B) View after injection of room temperature saline into the CBD. Saline can be seen flowing unimpeded from the CBD into the duodenum.

(A)

(B)

Figure 3.

IR and single shot Renograffin IOC of a CBD obstruction created by a synthetic stone. (A) IR image with black and white color scheme demonstrating an impedance to contrast flow (B) A Renograffin IOC confirms the successful obstruction.

Figure 4.
IR image of the biliary system after a 2mm injury to the CBD. Extravasation of room temperature saline is demonstrated by the low intensity area surrounding the CBD.