Natural Orifice Transluminal Endoscopic Surgery (NOTES): An Opportunity for Augmented Reality Guidance

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Abstract. Laparoscopic techniques have gained wide acceptance because they offer a safe and less invasive alternative to open surgery. To further reduce the invasiveness of peritoneal access, the next logical step is to eliminate the incision through the abdominal wall using natural orifices as entry points. This Natural Orifice Transluminal Endoscopic Surgery (NOTES) approach has the potential to replace or augment current techniques. Several research groups have cut through the stomach or colon wall (per-oral transgastric or per-anal transcolonic) to perform organ resections in animal models, and some procedures in humans have been reported anecdotally. Widespread use of these techniques will depend on providing the physician with adequate visual feedback, clear indicators of instrument location and orientation, and support in the recognition of anatomic structures. Compared with laparoscopy, successful endoscopy must accommodate several additional complexities: (1) The flexibility of the endoscope tip complicates the understanding of its distal orientation. Successful navigation inside the stomach and in the abdominal cavity generally requires two years of sub-specialty training. (2) Several surgical targets lie in a retrograde position with respect to an incision in the stomach wall. Efficient and safe access to the pancreas, gall bladder, or the kidneys requires detailed knowledge of the tip placement relative to adjacent anatomic structures. (3) Since there is limited direct access to the abdomen, iatrogenic injuries, such as the accidental cutting of an artery, will be more dangerous and difficult to manage. We present here approaches to resolving these limitations though augmented reality techniques using pre-procedure CT or MRI imaging, real time tracking and reference image registration, and display to the operating physician. As an example, the utility of image registration techniques for orientation for the gastric access puncture is discussed in detail. It is anticipated that such augmentation will make intra-cavitary interventional techniques easier to master and use in practice, and thus more likely to be widely adopted.

Keywords: endoscopy, augmented reality, laparoscopy, image registration, NOTES

1. Introduction

Natural Orifice Transluminal Endoscopic Surgery (NOTES) is a new approach to surgical management of disease in the abdomen. Early stage animal model trials [1,2] and a small number of tests in human patients [3] have provided tantalizing prospects for the performance of surgical resections which leave no visible scars. While the impact of NOTES is being evaluated for many procedures, it may be especially beneficial to obese patients, for whom present techniques may be difficult in practice.

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More generally, it will reduce scarring and wound exposure, thereby permitting a faster recovery. However, NOTES presents significant challenges in surgical procedure; it will require new technical approaches through the use of novel instruments to address issues of efficacy, efficiency, and safety. Since the NOTES concept is directed at displacing elective procedures now performed using laparoscopy or laparotomy, the validation of NOTES will be challenging.

A multi-disciplinary, multi-institutional team has identified several barriers to the success of NOTES; here we concentrate on the subset of challenges which may be addressed through advanced navigation and visualization technology; that is, by Augmented Reality techniques.

2. Barriers to the widespread use of NOTES

A group of fourteen leaders in the fields of surgery and endoscopy met in mid-2005 to analyze the barriers to the widespread use of NOTES procedures in the abdomen. [4] They agreed that the significant barriers were:

- Effective access to the peritoneal cavity
- Near-perfect gastric (intestinal) closure
- Prevention of infection
- Development of suturing and anastomotic (non suturing) devices
- Support for spatial orientation
- Development of a multitasking platform to accomplish procedures
- Control of intra-peritoneal hemorrhage
- Management of iatrogenic events
- Identification and management of physiologic untoward events
- Compression syndromes
- Training providers

Of these factors, gastric (or other luminal wall) closure was judged the most important, with the related factor of infection control also being of significant concern. As many as three of these challenges, highlighted in bold type, may be approached through improvements in Augmented Reality (AR) technology.

3. The potential advantages of Image Registered NOTES

Over the past two decades, many investigators have sought to show image and instrument position in 3D models; with several collaborators we have explored the use of real time systems which track instruments and display relevant data in the context of registered 3D models of the patient. This work is based on the recent development of tiny, but very accurate position sensors [5] and very fast interface and software systems [6] which permit complex visualization with no discernible lag. A series of experiments have shown that the presentation of probe position in sparse 3D models and the display of a spatially matched reformatted reference image (Fig. 1) provide valuable support to the operator in positioning intra-corporeal probes and understanding the content of
ultrasound images they can provide. These “Image Registration” (IR) techniques have been used to improve task performance in laparoscopy [7] and endoscopy, [8] (Fig 2) and have been explored for guiding transgastric access [9] as a first step in developing image registered NOTES techniques. In these studies, both timed task performance (Fig 3) and analysis of the kinematics data on probe motion were used to quantify the benefits of IR technology. Our overall conclusion (see the works referenced) is that such augmented reality techniques as Image Registration significantly improve the utility of intra-corporeal ultrasound, this is supported by structured survey analyses of the users, in which they reported much less frustration and need to concentrate when using the IR-augmented systems, while scoring much higher on the task metrics. From a technical perspective, we determined that real time performance was far more
important than ultra precise registration; an error or a few millimeters was accepted by the physician operators.

Techniques such as Image Registration appear to have many opportunities to support NOTES. These include probe guidance, positioning the probe on a surface in the desired orientation (Fig. 4), showing the anatomic structures distal to the probe (which will be important for puncture sites), and showing the relationship to other instruments.

As an example, consider the challenge of per-oral transgastric access to the abdomen. The operator of the endoscope is above the mouth of the patient, more than 0.5m from the puncture site. Figure 2 shows this relationship in a porcine model test. The operator positions the endoscope probe tip on the stomach wall. Clearly, the probe should not puncture the arteries on the posterior surface or those adjacent to the stomach. Figure 5 shows the arterial structure outside the stomach wall in a surface rendering of a contrast enhanced CT of a porcine model in supine position. The endoscopic view shown in Figure 5 (left image) mimics the view that an endoscopist will face; that is, looking down the esophagus toward the anterior stomach wall. While the details of the vascular structure are somewhat different in humans (and among individuals), the principle is that the major vessels distal to the puncture site must not be injured. However, the solution of this is not as simple as just make a pre-procedure CT and then tracking instruments, because the endoscopist will generally inflate the stomach to gain a better working space. This, in turn will press the stomach wall against other vascular structures, and certainly distorts the position of the vessels attached to the stomach.
outer stomach wall. Further evaluation, preferably in human subjects, will be necessary to determine the limitations of the Image Registration technique in this context.

4. Other Augmented Reality Techniques

Path planning in 3D has recently been highly developed by various groups, initially for virtual colonography and then bronchoscopy, notably at Penn State [10] and in the SuperDimension broncoscopic biopsy system. [11] It may also be valuable to compare the expected structure seen thorough the endoscope with that created from a model of the visual field using the CT data, incorporating the visual distortions of the endoscope optics. [12]

Many investigators, notably Aylward and collaborators, [13] have highlighted the details of the vascular structure, which are visible in pre-procedure CT, and intra-procedure optics and ultrasound to provide both orientation and localization of, for example, resection targets. This is particularly appealing in real time, since the blood vessels “move” with the target, which may be displaced from the pro-operative position, subject to respiratory effects, etc.

5. Discussion

From these preliminary results, it is reasonable to expect that Augmented Reality approaches including (but certainly not limited to) Image Registration and similar comparison techniques will be implemented in the clinical practice in NOTES procedures. The methods developed for the evaluation of existing laparoscopic and endoscopic techniques may also be used to evaluate new NOTES procedures and to compare among various approaches. However, changes in patient posture, as well as respiratory and peristaltic motion will continue to challenge techniques, such as Image Registration, which depend on a reasonable correspondence with pre-procedure images. An eventual solution may be the ability to do real time registration using the details of vascular structure, perhaps acquired by 3D ultrasound.

6. Summary

Augmented Reality approaches may provide the missing links between general surgery, conventional endoscopy, and NOTES by providing contextual information in an intuitive and easily implemented display. The Image Registration technique, which appears (in early tests) to be beneficial for conventional endoscopy and laparoscopic imaging, may be one of many successful approaches to ensuring the practicality and widespread used of NOTES interventions.
7. Acknowledgements

This work was supported by CIMIT® under US Army MRMC Cooperative Agreement DAMD 17-02-2-0006. The information does not necessarily reflect the position of the government, and no official endorsement should be inferred. The authors thank N. Stylopoulos and D. Rattner for helpful comments, and Ascension Technologies and Olympus for equipment donations.

8. References


