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Comparison of Monoscopic Insertable, Remotely Controlled Imaging Device With a Standard Laparoscope in a Porcine Model

Nancy J. Hogle, MS, Tie Hu, PhD, Peter K. Allen, PhD, and Dennis L. Fowler, MD

Laparoscopic imaging has remained relatively unchanged since the introduction of the rod–lens system. The intent here is to improve imaging by designing and building sensors and effectors placed directly into the body and controlled remotely. An 11-mm monoscopic insertable pan/tilt endoscopic imaging device with an integrated light source was studied. In vivo testing included simulated appendectomy, nephrectomy, suturing, and running the bowel in a porcine model (n = 6). Subjective impression and time for each procedure were compared using each imaging modality. The insertable imaging device seemed easier and more intuitive to use than a standard laparoscope. Time to perform procedures was better than or equivalent to a standard laparoscope. The insertable camera was subjectively preferred, and times for completion of complex tasks were shorter using the insertable camera. The insertable imaging device has the potential to be an integral part of surgical system platforms.

Keywords: laparoscopy; laparoscopic surgery; robots; robotic surgery; minimally invasive surgery; optical imaging

The design of the laparoscope has not fundamentally changed since the invention of the rod-lens by Hopkins and the cold light source of fiber optics by Karl Storz in the 1950s.[1] Traditional endoscopes use fiber optics to deliver light into the abdomen and a rod-lens to transmit the image back to the charge-coupled device (CCD) camera sensor. By viewing the image from the endoscopic camera, surgeons operate laparoscopic tools to perform surgery. Laparoscopic surgery has several well-known, well-documented advantages:

- Easier recovery: less pain,[2] shorter length of hospital stay,[3] shorter time until return to normal activities[4,5]
- Reduced cost: reduced cost for hospital care,[6,7] reduced societal cost attributable to quicker return to work[4,5]
- Reduced physiologic derangement: less pulmonary embarrassment,[2,8] less stress response,[9,10] less suppression of the immune system[11]
- Fewer acute postoperative complications[12]
- Fewer late events: fewer small bowel obstructions attributable to adhesions,[13] fewer incisional hernias[13]

However, this new technique drastically increases the complexity of a surgeon's operation because of the rigid, sticklike instruments, limited range of motion, impaired depth perception, loss of sense of touch, and the difficulty in varying the perspective view of the operative field.[14] In the laparoscopic surgery paradigm, putting long sticks into small openings is still the state of the art. The fulcrum point created by the abdominal wall restricts the motion of the scope to 4 degrees of freedom (DOFs), so that the only translation possible is along the camera axis. Our goal is to

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overcome these limitations imposed by the use of the traditional endoscope.

We envision surgery in the future as radically different from today. New thrusts in computer and robotic technologies make automated surgery, if not feasible, an approachable goal. It is not difficult to foresee teams of insertable robots performing surgical tasks inside the body under both surgeon and computer control. Our intent is to build and design sensors and effectors that can be placed directly into the body cavity where they can be controlled remotely and can perform surgical and imaging tasks unfettered by traditional endoscopic instrument design. We have initially focused on developing an inexpensive, insertable, remotely controllable camera with multiple DOFs.[15,16]

Figure 1. Prototype monoscopic insertable imaging device used in this experiment.

Materials and Methods

Prototype

In earlier work we designed a robotically actuated, multicamera, 5-DOF system that can be inserted entirely into the abdominal cavity and is remotely controlled.[15,17] Our experience with this prototype led us to a new design for an insertable imaging device containing a CCD camera, integrated light-emitting diode (LED) light source, and motion platform.[16] The prototype device used in this study consists of an outer shell and has 1 camera, a CCD chip with 450 lines of resolution. This device is 11 mm in diameter and contains 3 motors that move the camera. The device can pan over a range of 120° and tilt over a range of 90°. It is controlled by a simple joystick interface that is intuitively easy to control. The integrated light source consists of a ring of LEDs that are attached to the end of the camera–lens assembly. Figure 1 demonstrates the prototype camera used in this study.

Operative Technique

The experimental protocol underwent review and approval by the Institutional Animal Care and Use Committee (IACUC). Female Yorkshire swine weighing approximately 30 to 50 kg were obtained from Animal Biotech Industries, Inc. (Danboro, Pa) and allowed to acclimate in our animal husbandry unit for 3 to 5 days. Animals were cared for in accordance with US Department of Agriculture and IACUC regulations. After acclimation, the animals (n = 6) received general anesthesia, and a standard laparoscope was inserted for the purpose of comparison and for recording the monoscopic insertable imaging device inside the abdomen. The surgeon inserted the monoscopic insertable imaging device with integrated light source into the abdomen through a small incision fitted with a 15-mm trocar or a GelPort® (Applied Medical, Rancho Santa Margarita, Calif). The monoscopic insertable imaging device was introduced caudally and held in place with 2 sutures (Figure 2). The insertion trocar contained only the power and imaging wires, which do not fully occupy the trocar diameter, allowing additional tooling to be used through the same port.

Using additional laparoscopic trocars and instruments, a surgeon (DLF) performed the following tasks: running the bowel for 150 cm, simulated appendectomy, nephrectomy, and intracorporeal suturing. Each procedure was completed twice, once using a standard laparoscope and video camera and once using the insertable camera. Although the intent was to perform each procedure with each image source in each animal, not every procedure was completed in each animal because of technical failures with the insertable camera. A surgical novice (postdoctoral engineering fellow or engineering graduate student) controlled the image source for each procedure. Each animal was euthanized according to strict protocol at the conclusion of the procedures.

Data Collection and Analysis

The surgeon, the surgical assistant, and the camera operator subjectively evaluated the image quality and control for each set of procedures. In every case, the other people in the room (research graduate students, surgical residents, and a research associate) provided subjective evaluation. The camera operator subjectively evaluated ease of use of each camera type for each set of procedures. The time for each

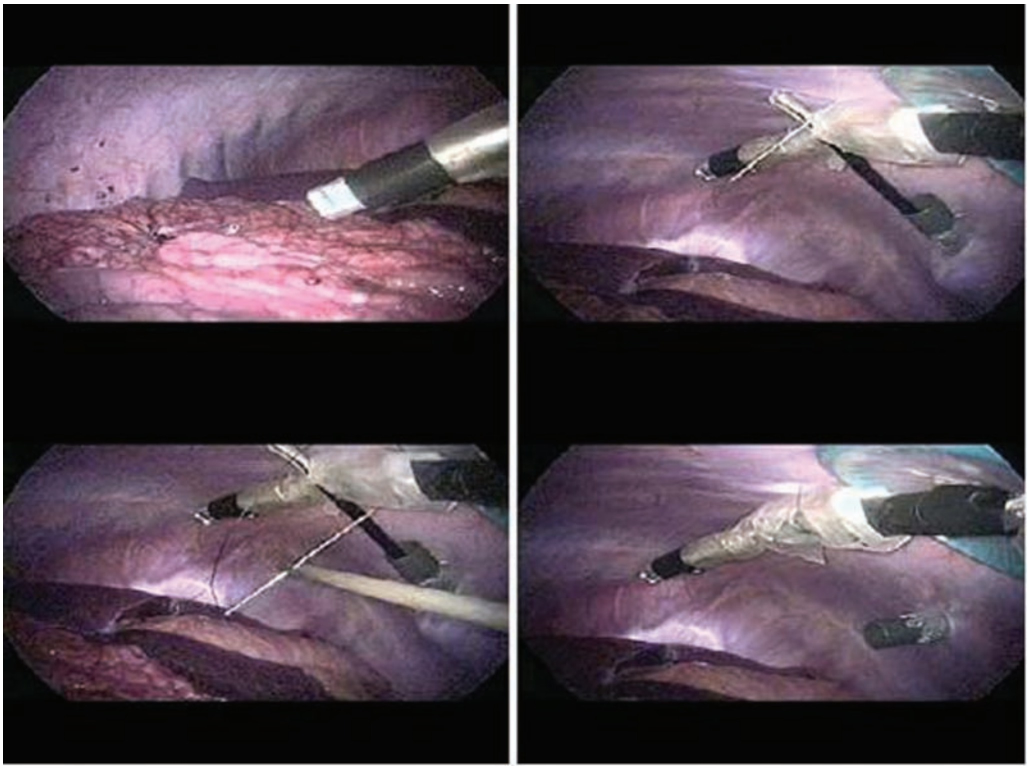

Figure 2. Upper left: Image of camera being inserted into the abdominal cavity. Upper right: Insertion of needle used to attach monoscopic insertable imaging device to abdomen. Lower left: Needle looping around device for attachment. Lower right: Device firmly attached to abdominal wall.

procedure was documented and then tabulated for comparison.

Results

The subjective assessment of the surgeon, surgical assistant, and camera operator was that the image provided by the device was equivalent to the image provided by the laparoscope with attached video camera, despite greater familiarity with the laparoscope. Other participants in the room confirmed this finding. The monoscopic insertable imaging device was able to pan and tilt easily to accommodate the surgeon's need for new views of the surgical site, and the camera operator felt subjectively that it was easier to use the joystick than the laparoscope. The prototype device used in this study consists of an outer shell and has one camera, a CCD chip with 450 lines of resolution. The laparoscopic system used for comparison in this study was a 10-mm, 0°, standard laparoscope and a video camera with 450 lines of resolution.

Figures 3 through 6 show representative views from the insertable camera during the various procedures performed during the surgical procedures. The nephrectomy demonstrated in Figure 6 was a more complicated procedure that required more camera movement. The pan/tilt feature worked well to provide a range of views during different portions of the procedure.

Table 1 shows the times for each procedure using either a standard laparoscope or the monoscopic insertable imaging device. In all types of procedures, use of the monoscopic insertable imaging device did not adversely affect the surgeon's ability to perform the procedure efficiently. The surgeon was faster with the insertable camera for the more technically difficult procedures of suturing and nephrectomy.

Discussion

The experiments suggest that the monoscopic insertable imaging device is easier to use than a normal

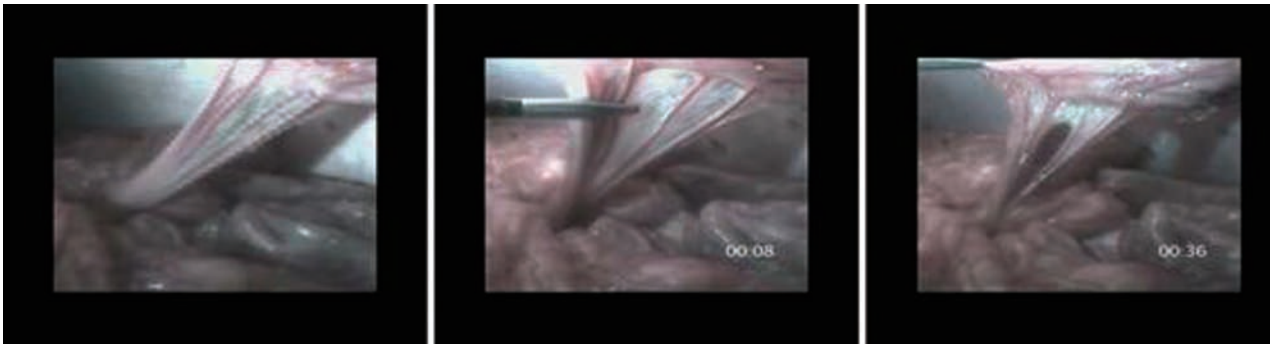

Figure 3. Images of appendectomy from monoscopic insertable imaging device.

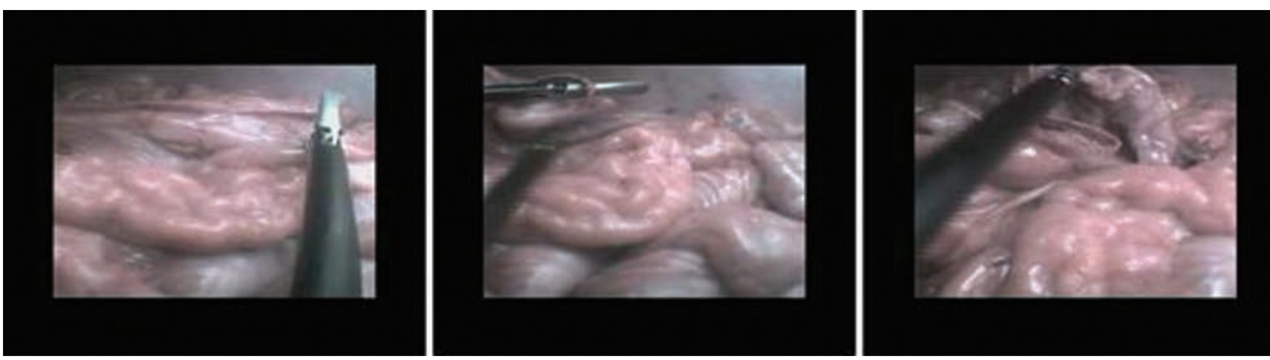

Figure 4. Images of running the bowel from monoscopic insertable imaging device.

Figure 5. Images of suturing from monoscopic insertable imaging device.

laparoscope and that there is no need for special training of the operator to use the device in clinical procedures. Standard laparoscopes create the need for counterintuitive movement by the operator attributable to pivoting about the insertion point (eg, to move the laparoscope to the right, the external part of the unit is moved to the left, pivoting on the insertion point). This can cause confusion for untrained operators. The insertable camera is moved by a simple joystick interface that is intuitively easy to learn.

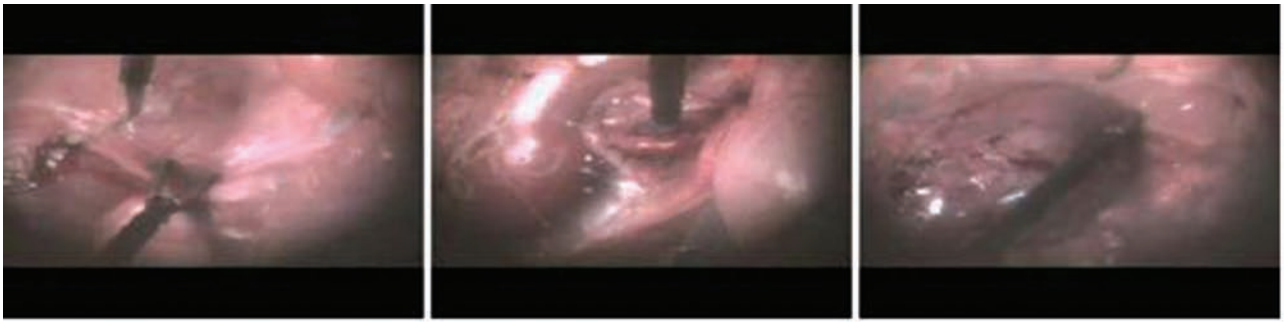

Figure 6. Images of nephrectomy from monoscopic insertable imaging device.

Table 1. Procedure Times

Procedure	Device	Mean time, s
Running bowel	Laparoscope	179.50
Running bowel	Monoscopic insertable imaging device	202.67
Appendectomy	Laparoscope	158.57
Appendectomy	Monoscopic insertable imaging device	195
Suturing	Laparoscope	300
Suturing	Monoscopic insertable imaging device	240
Nephrectomy	Laparoscope	1260
Nephrectomy	Monoscopic insertable imaging device	1185

By using the pan/tilt axes, the device can provide a broader and larger field of view than a traditional laparoscope. The device requires a single access port through which other instruments may be placed, if desired. It also provides more fiexibility than a standard laparoscope and camera, because it is placed entirely inside the body cavity and may obtain images from a number of controllable directions.

In this small, single-site, single-surgeon, 4-procedure evaluation of this prototype, we demonstrated equivalency in imaging and time to complete these procedures. On this basis, we believe that our work should be continued and advanced. A few additional enhancements will be necessary before beginning clinical trials. Although there was sufficient light to perform the procedures from our integrated lighting, we plan to use more powerful LEDs in future prototypes. Additionally, we will implement a simpler method for fixation to the abdominal wall. Future prototypes will include both mechanical and digital zoom capabilities and 3-dimensional imaging. In the longer term, additional sensors and tools may also be added to this platform to truly realize computer-guided surgery.

Our study has several limitations. The video images of the procedure were viewed by only 1 surgeon. However, we engaged in this study with a proof-of-concept design. The plan was to learn the limitation of the monoscopic device and use the lessons learned in this device to plan the development of a stereoscopic or otherwise more advanced device.

Another limitation is that the visualization technique used first in each exercise was not randomized. The reason for this was efficient use of lab time. We did randomize use of the visualization technique by lab session, and no more than 1 animal was used per session (ie, in the first session, the standard laparoscope was used first in all 4 procedures and then the monoscopic device was used to complete all 4 procedures; in the second session, the monoscopic device was used first to complete all 4 procedures and then the standard laparoscope was used in all 4 procedures).

Conclusions

We developed an insertable monoscopic pan/tilt insertable imaging device with integrated LED light source and demonstrated proof of concept by performing 4 surgical procedures in an animal trial. We believe that this insertable imaging device can be an integral part of future surgical system platforms.

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