Surgeon workload and motion efficiency with robot and human laparoscopic camera control

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Abstract

Background: Surgeons are now being assisted by robotic systems in a wide range of laparoscopic procedures. Some reports have suggested that robot-assisted camera control (RACC) may be superior to a human driver in terms of quality of view and directional precision, as well as long-term cost savings. Therefore, we set out to investigate the impact of RACC of surgeon motion efficiency.

Methods: Twenty pigs were randomized to undergo a standardized laparoscopic Nissen fundoplication with either a human or RACC system, the AESOP 2000. All procedures were performed by the same surgical fellow. Time was recorded for dissection and suture phases. Inertial motion sensors were used to monitor both the surgeon’s hands and the camera. Digitized data were analyzed to produce summary measures related to overall motion.

Results: The operative times were slightly longer with RACC (mean 80.2 ± 20.6 vs 73.1 ± 15.4 min, not significant). With regard to operative times and surgeon motion measures, the only statistically significant differences were for setup and breakdown times, which contributed <15% to the total time for the procedure.

Conclusion: In terms of impact on surgeon motion efficiency and operative time under normal surgical conditions, RACC is essentially the same as an expert human driver. However, careful planning and structuring of the surgical suite may yield some small gains in operative time.

Key words: Robot — Laparoscopy — Motion — Efficiency — Performance — Camera control

Robotic systems are now being used to assist in a wide range of laparoscopic procedures [2–4, 7, 9, 10, 12, 14]. Some reports have suggested that robot-assisted camera control (RACC) may be superior to human driver in terms of quality of view and directional precision, as well as long-term cost savings. The objective of this study were (a) to compare robotic and human camera control during laparoscopic surgery, with a specific focus on surgeon motion efficiency; (b) to investigate the use of inertial sensors for continuous, objective measurement of surgeon motion; and (c) to make progress toward the development of a comprehensive, quantitative performance-based model for surgeon motion efficiency. “Motion efficiency” is a measure defined by the motion of the surgeon’s hands.

Different types of robots representing a range of complexity and modes have been developed for use in minimally invasive surgery. For example, with the Zeus (Computer Motion Inc., Goleta, CA, USA) [7] and da Vinci systems (Intuitive Surgical Inc., Sunnyvale, California, USA) [2], the seated surgeon controls manipulators from a workstation. The robotic manipulators produce the desired functional motions in the actual surgical field. The da Vinci system provides 3-D visualization of the operative site. These systems can scale motions of the hand to allow greater control in high-dexterity applications that would otherwise be limited by the manual performance capacities of the surgeon. Although not investigated in the present study, issues regarding the objective documentation of surgeon motion efficiency are applicable to any such system.

In conventional laparoscopic surgery, a human assistant controls the laparoscopic image by directing the laparoscope on the operative field, following the instructions of the surgeon. This task requires ongoing active communication between the surgeon and the assistant, and confusion or physical space conflicts may arise. Because the surgeon must focus on directing the assistant, he or she is distracted from the actual operation. Human camera control may result in a suboptimal
image due to tremor, off-center drift, or the loss of horizontal orientation; therefore, frequent correction is required. In addition, inadvertent collisions with tissue may result in the need to clean the lens frequently. These problems tend to diminish the concentration of the surgeon and impede the flow of the operation.

In an effort to alleviate the problems associated with a human camera assistant, robotic camera systems such as AESOP (Computer Motion, Inc.) have been developed [11, 14]. Few studies have been done to examine the differences in human vs robotic control of the laparoscope. The ones that are available [5, 8] do not involve the voice-controlled (vs foot pedal–controlled) robots, and none of them includes an objective measurement of surgeon movements that would permit the evaluation of ergonomic aspects of these configurations. As noted by Berguer et al. [1], ergonomic considerations play an important role in the cumulative trauma problems experienced by laparoscopic surgeons. Although there are limited data to suggest that, in this context, robotic systems are superior to human ones (i.e., in global terms, such as reduced total procedure time), results vary from study to study.

Materials and methods

We conducted a prospective randomized trial in a porcine model to compare a human camera-controlled condition to a robotic camera-controlled one. Twenty-four adult pigs underwent laparoscopic Nissen fundoplication [2, 9], alternating between human and robot camera control. The first four operations were used to refine the experimental procedure and to allow the surgeon to become familiar with the setup and the operation. The next 20 operations provided the basis for the data set analyzed.

Equipment

An AESOP Model 2000 voice-controlled robot (Computer Motion, Inc.), designed for use in surgery [14], was chosen for the robot camera-controlled condition. Specially developed inertial sensors (Human Performance Institute, Arlington, TX, USA) were employed to record motion data. In the configuration that we used, the system includes three identical sensor units, each of which consists of a small, lightweight cube (~4 x 4 x 4 cm) containing an array of inertial sensors. Two sensor units were mounted to the back of each of the surgeon’s hands to monitor surgeon motions. Flexible cables led from each sensor unit up the surgeon's arms and down his back to a waist-mounted junction box; the cables were clipped to the surgical gown along their paths to provide strain relief. A third sensor unit was mounted to the laparoscope to monitor camera motion.

Each sensor unit contains four inertial sensors. Three sensors are orthogonally mounted angular velocity sensors. The fourth sensor measures linear acceleration along two axes. When properly oriented on the surgeon’s hand, a sensor unit provides signals representing the pitch, roll, and yaw motions of the hand segment, which are approximately equivalent to wrist flexor–extensor, forearm pronator–supinator, and wrist radial–ulnar deviator motions with the arms in typical laparoscopic surgery positions. The linear acceleration sensors measure accelerations in a plane coincident with the dorsal surface of the hand (one axis oriented along a proximal to distal line, or generally along the long axis of the trocars, and one axis oriented along a med- dial–lateral line) (Fig. 1).

The sensor unit analog outputs (5 channels each × 3 sensor units = 15 channels) were low-pass filtered (~5 Hz) and interfaced to a 16-channel Data Acquisition System with 14-bit resolution (Dataq Model 720I, Dataq Instruments, Akron, OH, USA), which in turn was interfaced to a notebook computer for data logging via its parallel interface (printer) port. Data acquisition software (WinDaq Lite; Dataq Instruments) was employed to log event notes and to stream digitized data (16 samples/sec per channel) to hard disk. For each 10-min surgical epoch, this resulted in the collection of 288 Kbytes of data (15 channels × 16 samples/sec × 2 bytes/sample × 60 sec/min × 10 min).

Procedures

The surgical procedure consisted of a laparoscopic Nissen fundoplication. To minimize variations due to experience, all operations were performed by a single surgical fellow (E.H.). When a human camera driver was used, the same surgical nurse (S.T.) performed in this capacity for all of the operations. A surgical assistant and research coordinator were also present during each surgery. Pigs were euthanized immediately postoperatively.

During each operation, the hand motions and laparoscope motions were continuously digitized. The research coordinator was assigned exclusively to monitor this process and to log event notes. All surgeries were videotaped (laparoscope camera), along with a surgeon voice channel, for selective use in later investigation of specific segments of interest and for use in other ergonomic studies. Experimental personnel were instructed to limit vocal outputs to communication essential for the execution of the surgical procedures.