Robotic surgery, telerobotic surgery, telepresence, and telementoring

Review of early clinical results

G. H. Ballantyne

Minimally Invasive and Telerobotic Surgery Institute, Hackensack University Medical Center, 20 Prospect Avenue, Hackensack, NJ 07601, USA

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Abstract
Although laparoscopic cholecystectomy rapidly became the standard of care for the surgical treatment of cholelithiasis, very few other abdominal or cardiac operations are currently performed using minimally invasive surgical techniques. The inherent limitations of traditional laparoscopic surgery make it difficult to perform these operations. We, and others, have attempted to use robotic technology to (a) provide a stable camera platform, (b) replace two-dimensional with three-dimensional (3-D) imaging, (c) simulate the fluid motions of a surgeon’s wrist to overcome the motion limitations of straight laparoscopic instruments, and (d) offer the surgeon a comfortable, ergonomically optimal operating position. In this article, we review the early published clinical experience with surgical robotic and telerobotic systems and assess their current limitations. The voice-controlled AESOP robot replaces the cameraperson and facilitates the performance of solo-surgeon laparoscopic operations. AESOP provides a stable camera platform and avoids motion sickness in the operative team. The telerobotic Zeus and da Vinci surgical systems permit solo surgery by a surgeon from a remote sight. These telerobots hold the camera, replace the surgeon’s two hands with robotic instruments, and serve in a master–slave relationship for the surgeon. Their robotic instruments simulate the motions of the surgeon’s wrist, facilitating dissection. Both telerobots use 3-D imaging to immerse the surgeon in a three-dimensional video operating field. These robots also provide operating positions for the surgeon console that are ergonomically superior to those required by traditional laparoscopy. The technological advances of these telerobots now permit telepresence surgery from remote locations, even locations thousands of miles away. In addition, telepresence permits the telementoring of novice surgeons who are performing new procedures by expert surgeons in remote locations. The studies reviewed here indicate that robotics and telerobotics offer potential solutions to the inherent problems of traditional laparoscopic surgery, as well as new possibilities for telesurgery and telementoring. Nonetheless, these technologies are still in an early stage of development, and each device entails its own set of challenges and limitations for actual use in clinical settings.

Key words: Robots — Robotic surgery — Telerobotic surgery — Telesurgery — Telepresence — Telementoring — Telemmedicine — Laparoscopy — Laparoscopic surgery — AESOP — da Vinci — Zeus

With the advent of video laparoscopy, the staid surgical suite of the 19th century entered the computer age [1]. The magnified and computer-enhanced video image provided surgeons with superior exposure and visualization of the abdomen. Yet even a decade after the introduction of video laparoscopic colectomy, most gastrointestinal operations are still performed using 19th century instruments and techniques. Indeed, in the year 2000, < 3% of colon resections in the United States were done laparoscopically [2]. Why have surgeons failed to embrace minimally invasive gastrointestinal, urological, and cardiothoracic surgery despite the obvious advantages to their patients?

Most laparoscopic gastrointestinal operations are difficult operations to learn, master, and perform routinely. Surgeons face a long learning curve. Moreover, a number of inherent pitfalls of laparoscopy hinder the performance of advanced laparoscopic procedures. These pitfalls include:

1. An unstable camera platform
2. The limited motion (degrees of freedom) of straight laparoscopic instruments
3. Two-dimensional imaging
4. Poor ergonomics for the surgeon
Since the introduction of video laparoscopic cholecystectomy, surgeons have speculated that computers, 3-D imaging, and robotics could overcome these pitfalls of laparoscopy [3, 4, 5].

In this article, we review the early published clinical experience with surgical robotic and telerobotic systems and assess their current limitations. We also briefly review the early experience with telepresence surgery and telementoring. Despite the paucity of documentation in the current literature, we will also address on the specific limitations of the currently available robotic and telerobotic surgical systems. Our aim here is to provide a perspective on the state of this emerging field and to chart the directions in which it should evolve.

Definitions

Robotic surgery

The first robots introduced into clinical practice served as camera holders. In 1994, the FDA approved AESOP for clinical use as a robotic camera holder; more recently, it also approved a second robotic camera holder, the Endoassist (Armstrong Healthcare Ltd., United Kingdom). Surgical robots are controlled directly by the surgeon, who stands at the side of the operating table.

Telerobotic surgery

More recently, surgical robots have evolved into telerobotic surgical platforms that permit surgeons to operate on patients from remote locations using robotic instruments. The surgeon and telerobot work in a master–slave relationship. Telerobots have been specifically designed to overcome all four of the pitfalls of laparoscopy. They maintain a stable camera platform, use instruments that articulate at the end to simulate the movements of the surgeon’s hand, use three-dimensional (3-D) imaging systems, and permit the surgeon to perform complex, advanced laparoscopic operations while comfortably seated in an ergonomically correct position. Telerobotic surgical systems have only recently achieved limited approval for clinical use in the United States. At the present time, telerobotic surgical systems offer a limited selection of instruments and bulky configurations that impede many specific surgical procedures. Moreover, clinical experience, with the systems is limited. Thus, telerobotics must be regarded as an emerging technology that is still in its infancy and in an early phase of feasibility testing. The current generation of telerobots is not sophisticated enough to displace prevailing standard surgical practice.

Telepresence

The development of satisfactory telerobotic platforms has kindled interest in telepresence surgery and telementoring. Telepresence projects a virtual image of the operative field to a remote site [6, 7]. Using the telerobot to telescop their hand motions to the remote operating room, surgeons perform operations without actually seeing their patients. Telepresence enables a surgeon on an aircraft carrier, for example, to operate on a wounded soldier on the battlefield [8].

Telementoring

Telementoring uses similar technology to create a virtual classroom, or even a “virtual university” [9]. Telementoring permits an expert surgeon, who remains in his/her own hospital, to instruct a novice in a remote location on how to perform a new operation or use a new surgical technology. Telepresence thus provides a new strategy for the training of surgical residents [10, 11] as well as a new means of disseminating novel surgical approaches around the world [12].

Robotic replacement of the camera holder

The first clinically successful robot, the Robodoc, was introduced for use in total hip replacement [13, 14]. The initial goal was to replace the camera holder with a surgeon-controlled robot. In 1993 at the University of California at Davis, Moran was the first to employ a passive electronically-regulated, pneumatically controlled camera holder [15]. Working in Tübingen, Germany, Buess et al. developed a prototype of a robotic camera holder, the FIPS Endoarm [16]. This robotic arm was remotely controlled with a finger ring that was clipped to one of the surgeon’s instruments. It moved with four degrees of freedom while maintaining an invariant point of constraint motion.

A British company, Armstrong Healthcare Ltd., markets a robotic camera holder known as the “Endoassist” [17, 18] that has recently received FDA approval for use in the United States. Unfortunately, very little has been published about it to date. This device allows the surgeon to control its movements with his or her head. A device that emits infrared rays is worn by the surgeon. When the surgeon points the infrared beam to the point on the video monitor that he or she wishes to see, the robot adjusts the camera to view this area.

From the Hotel-Dieu de Montreal Hospital, Gagner et al. reported three laparoscopic cholecystectomies that they performed with a prototype of a robotic surgical assistant [19]. The robotic arm moved with six degrees of freedom. It was controlled with a joystick by a surgeon in a remote room who viewed the operation on a monitor. In 1995, they updated their experience with this device [20]. Between 1 September 1993 and 10 October 1994, they successfully accomplished eight laparoscopic cholecystectomies with cholangiography in humans using this device. Total anesthesia time for these operations averaged 63 min. They concluded that their study “represented a first step toward the introduction of robotic technology in laparoscopic surgery.”