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Robotic colorectal surgery: Evolution and future

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ABSTRACT

The introduction of laparoscopic cholecystectomy changed the approach to abdominal surgery revealing the patient-specific advantages of minimally invasive approaches to gastrointestinal diseases. Unfortunately, inherent limitations of laparoscopy impeded widespread utilization of laparoscopic surgery in advanced procedures such as laparoscopic colectomy. Even as prospective and randomized trials demonstrated outcomes advantages for the patient, few surgeons introduced laparoscopic colectomy into their practice. Robotic surgery has offered solutions to these inherent limitations of laparoscopic surgery. Yulan Wang and Computer Motion introduced the first FDA approved robotic surgery assistant, AESOP. This robot responded to foot controls and subsequently oral commands providing tremor free reliable video-laparoscopic camera control. As video-laparoscopic colorectal surgery evolved, Colorectal Surgeons were plagued with the intrinsic limitations of laparoscopic surgery, such as motion reversal and motion amplification of the surgical instruments caused by the fulcrum effect of the abdominal wall trocar. Using Department of Defense grants and venture capital funding, two surgical technology companies, Computer Motion and Intuitive Surgery developed robotic surgical systems to overcome these limitations, Zeus and da Vinci, respectively. Although these robotic surgical systems were intended to perform remote battle-field surgery with the surgeon stationed on an aircraft carrier or remote MASH Hospital, state licensing issues and malpractice concerns prompted both companies to focus on surgery with the patient, surgeon and robot in the same operating room. Zeus gained FDA approval first and Da Vinci followed shortly after. Eventually patent conundrums proved only solvable by Intuitive buying out Computer Motion leading to a consolidation of the technology from both companies into the subsequent generations of Da Vinci. More recently, as Intuitive's patents begin to expire, new robotic surgery companies are entering the market with surgical robots targeting specific niches in the future robotic surgery market. In particular, MedRobotics, for example, will soon introduce a surgical robot given FDA approval for transanal resections of neoplastic lesions. Similarly, Titan will enter the market with a surgical robot at a substantially lower price-point that the da Vinci. Clearly, surgical robotic options for colorectal patients will continue to expand in the near future. The long-term use of these technologies, of course, will require a long period of prospective and randomized clinical trials.

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The evolution of robotic surgery

The advent of laparoscopic surgery—Laparoscopic cholecystectomy

In 1901, the first laparoscopic surgery was performed on a dog by Georg Kelling in Hamburg, Germany.[1] Kelling used the Nitze cystoscope for visualization of the peritoneal cavity. Almost a decade later, Kelling and others performed the first laparoscopic surgeries on human patients; however, the technology was significantly limited by poor visualization. In 1985, the field of laparoscopy was revolutionized by the introduction of the charge couple device (CCD) camera, which allowed for projection of the image onto a video monitor substantially improving visualization of the operative field. Erich Muhe utilized this new innovation to perform the first laparoscopic cholecystectomy in 1985 and was shortly thereafter followed by Philippe Mouret in France in 1987.[2,3] In the United States, Reddick and Olsen[4] developed the techniques generally used subsequently by American Surgeons and opened

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the first laparoscopic training center for General Surgeons in Marietta, GA.

Early experience with laparoscopic colectomy

Jacobs et al.[5] published the first Laparoscopic Right Colectomy in 1991. They predicted: “Although laparoscope-assisted colonic surgery may still be considered a procedure in evolution, we feel that in time it has the potential to be as popular as laparoscopic cholecystectomy.” Shortly after this, Dennis Fowler accomplished the first laparoscopic left colectomy using a proto-type of the Endo-GIA developed by the United States Surgical Corporation.[6]

Early series of laparoscopic colectomy suggested that a laparoscopic approach to colorectal operations would offer specific benefits to patients in terms of short-term clinical outcomes. Our early series of our first 50 laparoscopic colectomies at the West Haven Veterans Health Administration Medical Center indicated that laparoscopic colectomy decreased operative blood loss, decreased post-operative pain as measured by narcotics use, and shortened hospital length of stay compared to open operations.[7] We also demonstrated in a subsequent article that cardiovascular function during laparoscopic colectomy was improved by the mild acidosis associated with the carbon dioxide pneumoperitoneum and the frequent use of the Trendelenberg position.[8] Subsequent, prospective and randomized trials supported these conclusions and also found that patients returned to a normal quality of life more rapidly.[9,10] Long-term follow-up of colonic cancer patients randomized between laparoscopic and open cancer resections did not show a worse outcome for patients treated with laparoscopic operations.[11] Despite the apparent advantages of minimally invasive approaches to colorectal diseases, few colon, and rectal surgeons embraced Laparoscopic Colectomy or introduced it into their clinical practice.

The inherent limitations of laparoscopic colectomy

Despite the patient-specific outcome advantages of minimally invasive colectomy, few surgeons introduced Laparoscopic Colectomy into their practice. The increased complexity of colectomy compared to cholecystectomy, amplified the practical problems of laparoscopic techniques making the learning curve for laparoscopic colectomy long and steep.[12–14]

Two-dimensional imaging

The CCD camera, instrumental in accelerating the adoption of Laparoscopy Cholecystectomy because of its better visualization ultimately limited adoption of Laparoscopic Colectomy. The laparoscopic video image is two dimensional. Many surgeons are hesitant to approach the complex anatomy of colorectal operations relying only on a two-dimensional image. Although the surgeon can learn to compensate for the loss of binocular vision through depth cues such as lighting, known size of objects in relation to one another and texture gradients, many were reluctant to learn these new skills and to subject their patients to prolonged operations during their learning curve.[15] Studies by Birkett[16] documented the increased stress and tension experienced by surgeons when using two-dimensional video images to perform complex tasks such as laparoscopic operations. Humans evolved dependent on binocular stereoscopic vision. Although the cerebral cortex can perceive three dimensions from two-dimensional images, it requires excessive “processing time” leading to stress, tension and fatigue.[16,17]

Motion reversal

As mentioned above, the laparoscopic trocars through which surgical instruments are introduced during laparoscopic operations act as a fulcrum and reverse the motions of the instruments (Ballantyne). As a result, movement of the instrument handle down causes the tip of the instrument to move up. Many surgeons found this paradoxical motion difficult to overcome and increased their reluctance to adopt laparoscopic colorectal surgery.

Motion amplification

The fulcrum effect of the trocars also adds an additional hindrance to surgical technique. Typically, about two-third of the laparoscopic surgical instrument is within the abdomen and about one-third outside. As a result, a 1-in downward motion of the instrument handle in this case generates a 2-in upward deflection of the instrument's tip. Similarly, this fulcrum effect amplifies any resting tremor present in the surgeon's hands. This motion amplification also contributed in the reluctance of surgeons to perform advanced laparoscopic operations.

Parallel instruments

The trocars add still an additional limitation in the use of the laparoscopic instruments. Because the trocars are fixed in place, they limit the mobility of the laparoscopic instruments. Ergonomics for the laparoscopic instruments require that the two working instruments approach either other at near a right angle. And about 45° above the horizon. Since the trocars cannot move, two laparoscopic instruments only meet at or near these angles in a small sphere within the abdomen. In laparoscopic cholecystectomy this is only a minimal nuisance since the trocars can be positioned such that this ideal sphere of function can readily be centered around the structures of Calot's triangle. When doing a colectomy which involves dissection throughout half of the abdomen or more, the two instruments spend significant periods of time outside of this sphere of ideal performance and are often nearly parallel making cutting, tying, and dissection difficult.

Ergonomics

There is a growing literature regarding orthopedic injuries sustained by laparoscopic surgeons, because of the ergonomically incorrect postures they must often assume in performing laparoscopic operations.[18,19] Often the laparoscopic surgeon finds himself looking at a monitor in one direction while his instruments are pointed in another. Similarly, the surgeon often must elevate his hands and shoulders because of the length of the instruments. All of these unnatural motions lead to muscle fatigue and often orthopedic injuries.

Loss of proprioception

In open operations, surgeons use a full array of senses to discern and understand the three-dimensional anatomy and pathology on which they are operating. As mentioned above, surgeons loose three-dimensional imaging. In addition, as their hands are no longer within the abdomen, they also loose proprioception, a loss of three-dimensional orientation. One often sees a laparoscopic surgeon struggling to find the location of a newly inserted instrument.

Increased motions to accomplish tasks

Ara Darzi at Imperial College in London performed motion analysis of simple surgical tasks being performed using open techniques and instruments versus the same tasks being performed laparoscopically and with laparoscopic instruments.[20] These studies found that these tasks could be performed with the same degree of precision with either technique but that