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Editor's Introduction

The Pitfalls of Laparoscopic Surgery: Challenges for Robotics and Telerobotic Surgery

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Summary: After its debut in 1988, laparoscopic cholecystectomy rapidly became the standard of care for cholelithiasis, yet very few surgeons use minimally invasive techniques for other abdominal operations. Why do most surgeons continue to perform traditional open gastrointestinal operations? We believe that the answer to this question lies in the fact that advanced laparoscopic operations are difficult to learn, perform, and master. A number of inherent pitfalls of laparoscopy hinder the performance of these operations even after the surgeon has accumulated years of experience. These pitfalls include an unstable video camera platform, limited motion (degrees of freedom) of straight laparoscopic instruments, two-dimensional imaging, and poor ergonomics for the surgeon. Inexperienced or bored laparoscopic camera-holders move the camera frequently and rotate it away from the horizon. The long, straight laparoscopic instruments are limited in their motion by the fixation enforced by the abdominal wall trocars. Similarly, the standard two-dimensional video imaging used in most laparoscopic operations impedes the surgeon's depth perception, compounding the limitations of laparoscopic instruments. In addition, surgeons are forced to assume ergonomically awkward stances in performing many laparoscopic operations. These four factors hinder a surgeon's efforts to learn and to perform advanced laparoscopic operations, significantly lengthening the learning curve. The articles presented in this issue suggest that robotics and telerobotics offer solutions to these nagging pitfalls of laparoscopic surgery. **Key Words:** Laparoscopic—Robotics—Telerobotics—Telesurgery.

Laparoscopic cholecystectomy is the standard surgical treatment for cholelithiasis, yet very few other gastrointestinal operations with minimally invasive techniques are performed routinely. As a result, many patients are forced to endure the increased pain, blood loss, wound complications, and hospital stay associated with traditional open operations. Many surgeons have been reluctant to spend the time required to master advanced laparoscopic operations. The intrinsic pitfalls of laparoscopy hinder the surgeon's acquisition of the requisite skills for these procedures. Shortly after the widespread adoption of laparoscopic cholecystectomy (1,2), surgeons began proposing that robotics offers solutions to the limitations of laparoscopy. In this article we review the specific pitfalls of laparoscopic surgery that have contributed to surgeons' slow rate of adoption of minimally invasive techniques for operations such as bowel resection, nephrectomy, and cardiac surgery. The intent of this introduction is to familiarize readers with the specific problems that the surgical robots have been designed to address and to enable consideration of the potential role of robotics and telerobotics in the surgical theater of the twenty-first century.

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THE EMERGENCE OF LAPAROSCOPY

The Early Years of Laparoscopy

It took most of the twentieth century for laparoscopy to become successfully developed and clinically accepted. Dimitri Ott, a German gynecologist, accomplished the first endoscopic examination of the peritoneal cavity in 1901 (3). He described a technique that he called "ventroscopy" in which a speculum was introduced through an incision in the posterior vaginal fornix. Ott wore a head mirror to reflect light into the peritoneum. In the same year, George Kelling, a German surgeon, used a cystoscope to examine the intra-abdominal viscera of a dog after insufflating the abdominal cavity with air (4,5). In 1910, Jacobeus accomplished the first celioscopy in a patient. He advocated the technique for evaluation of ascites. In 1911, Bernheim reported his clinical experience with laparoscopy in an article entitled "Organoscopy" (6). Nadeau and Kampmeier published an early review of laparoscopy in 1925, using the term "abdominoscopy" (7). Estes proposed a role for laparoscopy in the evaluation of trauma patients in 1942 (8). Few surgeons used laparoscopy, however, because the technique was primitive and of questionable safety.

Laparoscopy Initially Limited to Diagnosis

Clinical laparoscopy, however, did not become practical until 1966, when Kurt Semm introduced an automatic device for insufflation of the abdomen. In the subsequent decades, Semm developed successful techniques for various gynecologic procedures (9). General surgeons ventured slowly into the arena of laparoscopy; it was viewed exclusively as a tool for diagnosis of abdominal disease. In 1973 Berci et al. proposed the use of "peritoneoscopy" as a diagnostic aid for surgeons (10). In 1974, Cuschieri proposed a role for laparoscopy in the diagnosis of hepatobiliary disease (11). In 1975, two articles suggested the clinical utility of laparoscopy in the diagnosis of acute abdominal pain (12,13). By the early 1980s a number of randomized studies had established the importance of laparoscopy in the evaluation of young, fertile women with right-lower-quadrant pain (14). In the early 1980s, Lightdale (15) and Saleh (16), both gastroenterologists in New York City, advocated laparoscopy for evaluation of liver disorders. In the mid-1980s surgeons at the Massachusetts General Hospital also explored the diagnostic capabilities of laparoscopy. Warshaw and associates used laparoscopy for staging pancreatic cancer in 1986 (17). Throughout the 1980s, a number of surgeons continued to champion laparoscopy as an important part of surgical practice, but few surgeons even learned how to perform a laparoscopy (18,19).

Initial Triumph of Laparoscopy

The major paradigm shift occurred at the end of the 1980s. Erich Mohe of Boblingen performed the first laparoscopic cholecystectomy on September 12th, 1985, but this was poorly received by other German surgeons (20). When Mouret accomplished his laparoscopic cholecystectomy in 1987, the era of minimally invasive surgery began (21). McKernan and Saye performed the first laparoscopic cholecystectomy in the United States in 1988, but Reddick and Olsen soon popularized the technique (22). Many surgeons in the United States learned the techniques of these surgeons at their training facility in Marietta, Georgia: the Advanced Laparoscopy Training Center. In a short time, laparoscopic cholecystectomy became the standard of care for symptomatic cholelithiasis (23). Many of the pioneers of laparoscopic surgery expected that surgeons would rapidly apply these techniques to other abdominal operations. This expectation proved unfounded.

Laparoscopic Colectomy

The slow acceptance of laparoscopic colectomy illustrates the reluctance of surgeons to apply minimally invasive techniques to other gastrointestinal and abdominal conditions. A few surgeons in the United States rapidly applied these new techniques to colorectal surgery. Moises Jacobs performed the first laparoscopic right hemicolectomy in June 1990, Dennis Fowler the first sigmoid resection in October 1990 (24), Patrick Leahy the first low anterior resection in November 1990, Robert Beart the first abdominal perineal resection in 1991, Steven Wexner and David Jagelman the first total abdominal colectomy in August 1991, and Garth Ballantyne the first anterior resection for rectal prolapse in November 1991 and the first transverse colectomy in February 1992 (25,26). Surgeons had published reports of large clinical series of laparoscopic colectomies by 1992 (27). Although controversy circulated about the use of laparoscopic colectomy for colorectal cancer (28,29), by 1994 it was well established that outcomes were better for patients undergoing these procedures than for those undergoing open operations (30). The available data strongly suggested that laparoscopic bowel resection would greatly benefit those patients requiring resection for benign diseases such as diverticulitis, rectal prolapse, colonic volvulus, and colorectal polyps (31–35). However, although a decade has passed since the introduction of laparoscopy and the fear of port-site recurrences is fading into oblivion (36), <3% of colon resections in the United States in the year 2000 involved the use of this technique (37). Why have surgeons failed to

embrace minimally invasive colon surgery despite the obvious advantages to their patients?

THE PROBLEMS

Pitfalls of Laparoscopic Surgery

Laparoscopic colectomy is a difficult operation to learn, master, and perform routinely. It illustrates the problems inherent in laparoscopic surgery in general. It has a long learning curve that has discouraged many surgeons from making the effort to master it (38–41). A number of inherent pitfalls of laparoscopy hinder the performance of laparoscopic colectomy and other advanced laparoscopic operations. These pitfalls include an unstable video camera platform, limited motion (degrees of freedom) of straight laparoscopic instruments, two-dimensional imaging, and poor ergonomics for the surgeon.

Unstable Camera Platform

Laparoscopic colectomy is a difficult operation. During the surgeon's early experience, the procedure is longer than open operations. The anatomy is complex, and the surgeon must see the anatomy clearly to perform the operation safely. The cameraperson—usually a medical student or junior resident unfamiliar with laparoscopic anatomy—often must stand in an uncomfortable position. She or he may become bored or distracted (such as by telephones or vibrating pagers) or may try to be helpful by rapidly moving the camera from one position to another. These factors often cause an unstable videoscopic view that is rotated away from the horizon and drifts away from the salient structures. Indeed, this wandering view often generates motion sickness in one or more of the operating team members. In private practice, surgeons are often reluctant to subject their partner to this thankless and often unreimbursed task.

Loss of Degrees of Freedom

In open operations, surgeons use short instruments that are afforded a wide range of movement through the flexibility of their hands, wrists, shoulders, and hips. In contrast, laparoscopic instruments are long and straight so that they can fit through trocars and reach remote anatomic structures within the abdomen. These trocars confine the long, straight traditional laparoscopic instruments to motion within a cone. The apex of this cone is fixed in space by the trocar. This restricts the potential motions of the instruments, i.e., decreases their degree of freedom (42). In colectomies, the laparoscopic instruments must traverse the full length and width of the abdomen. This often forces the instruments into nonadvantageous angles of use. Tasks such as suturing that may be feasible in one area of the abdomen may become nearly impossible in another because of the changed relation of the straight instruments (43). Although these limitations of laparoscopic instruments have been recognized for a long time, surgeons continue to struggle with laparoscopic colectomy with long, straight, rigid instruments (44).

Three-dimensional Video Imaging

Most surgeons perform laparoscopic surgery with two-dimensional video imaging systems. The video image is projected from a television-like monitor or flat computer screen. The gallbladder is a small organ that occupies a relatively flat plane on the inferior surface of the liver. As a result, laparoscopic cholecystectomy can be accomplished safely with conventional two-dimensional imaging systems. In contrast, the colon wanders around the full abdomen in a serpentine pattern. It assumes complex three-dimensional relations with all of the other intra-abdominal organs. This causes the two-dimensional video imaging systems generally used for laparoscopy to hinder the surgeon's perception of this complex three-dimensional anatomy and impedes the surgeon's ability to perform the required complex dissections. Although three-dimensional video laparoscopy equipment has been available since at least 1993, few hospitals have purchased it (45). Indeed, I used a three-dimensional imaging system in the early 1990s to facilitate preceptoring other surgeons during their initial experience with laparoscopic colectomy (46). Even seemingly simple tasks are severely impeded by a two-dimensional perspective. Many surgeons struggle for years trying to master knot-tying, a task greatly simplified when viewed three-dimensionally (47). Thus, two-dimensional imaging compounds the limitations of laparoscopic instruments, adding to the learning curve for advanced laparoscopic operations.

Adverse Ergonomics

The placement of trocars and the length of laparoscopic instruments often force surgeons into uncomfortable and awkward stances (48). The surgeon's arms and shoulders are often elevated. The surgeon often leans across obese patients. In difficult procedures such as laparoscopic colectomy, this leads to surgeon fatigue (49). This may prolong the operation even further and may diminish the surgeon's dexterity. Moreover, various nerve palsies, finger numbness, and eye fatigue afflict many surgeons after difficult laparoscopic operations (50). Clearly, the current laparoscopic surgical theater is configured in a way that injures many surgeons

and adversely affects their ability to perform difficult operations.

THE SOLUTION?

Robotics and Telerobotics

Laparoscopy dragged the staid surgical suite of the nineteenth century into the computer age (51,52). Surgeons have speculated since the introduction of laparoscopic cholecystectomy that computers, three-dimensional imaging, and robotics could overcome the pitfalls of laparoscopy listed above (53–55). As Talamini recently stated: "Laparoscopic surgery has hit a roadblock somewhere between the technical expertise required for a cholecystectomy and anti-reflux surgery. Only select surgeons are moving beyond these to more technically difficult operations. Robots offer the promise of improvements to laparoscopic surgery that will allow most surgeons to perform more difficult technical operations" (56).

The series of articles presented in this issue of *Surgical Laparoscopy, Endoscopy & Percutaneous Techniques* reviews clinical experience with robots in the surgical theater. In the article by Merola and colleagues, the robot AESOP (Computer Motion, Inc., Santa Barbara, CA, U.S.A.) proved useful for replacing the camera operator and providing a stable camera platform. In addition, AESOP facilitated solo surgeon laparoscopic colectomy. The remainder of the articles report on early clinical forays of telerobotics into abdominal and cardiac surgery. In telerobotics, the surgeon sits at a computer console that is remote from the patient. The computer console translates the motions of the surgeon and controls the action of the robot that is performing the operation. The surgeon in telerobotics or telesurgery acts as the master and the robot as the servant. These articles report the authors' early experience with ZEUS (Computer Motion, Santa Barbara, CA, U.S.A.) and da Vinci (Intuitive Surgery, Moutainview, CA, U.S.A.) in abdominal and cardiac surgery. They indicate that robotics and telerobotics solve many of the pitfalls of laparoscopy and that this technology may facilitate the wider acceptance of minimally invasive surgical techniques by general surgeons, urologists, gynecologists, and cardiothoracic surgeons.

REFERENCES

1. Green PE, Piantanida TA, Hill JW, et al. Telepresence: dexterous procedures in a virtual operating field [abstract]. *Am Surg* 1991; 57:192.
2. Satava RM. Surgery 2001: a technologic framework for the future. *Surg Endosc* 1993;7:111–3.
3. Ott D. Die direkte Beleuchtung der Bauchhole der Hamblase, des Dickdarms und des Uterus zu diagnostichen Zwecken. *Rev Med Tech (Prague)* 1909;2:27–30.
4. Kelling G. Zur coelioskopie. *Arch Klin Chir* 1923;126:226–9.
5. Litynski GS. *Highlights in the history of laparoscopy*. Frankfurt: Barbara Bernert Verlag, 1996.
6. Bernheim BM. Organoscopy [abstract]. *Ann Surg* 1911;53:764.
7. Nadeau OE, Kampmeier OF. Endoscopy of the abdomen: abdominoscopy. A preliminary study, including a summary of the literature and description of the technique [abstract]. *Surg Gynecol Obstet* 1925;259:259.
8. Estes WL. Nonpenetrating trauma of the abdomen. *Surg Gynecol Obstet* 1942;70:419–24.
9. Semm K (Frederich ER, trans). *Operative manual for endoscopic abdominal surgery*. Chicago: Year Book Medical Publishers, 1987.
10. Berci G, Shore JM, Panish J, et al. The evaluation of a new peritoneoscope as a diagnostic aid for surgeons. *Ann Surg* 1973;178: 37–44.
11. Cuschieri A. Value of laparoscopy in hepatobiliary disease. *Br J Surg* 1974;61:318–9.
12. Sugarbaker PH, Bloom BS, Sanders JH, et al. Preoperative laparoscopy in diagnosis of acute abdominal pain. *Lancet* 1975;1: 442–5.
13. Anteby SO, Schenker JG, Polishuk WZ. The value of laparoscopy in acute pelvic pain. *Ann Surg* 1975;181:484–6.
14. Paterson-Brown S, Dudley HAF. The acute abdomen. In: Ballantyne GH, Leahy PF, Modlin IM, eds. *Laparoscopic surgery*. Philadelphia: WB Saunders, 1994:327–31.
15. Lightdale CJ. Laparoscopy and biopsy in malignant liver disease [abstract]. *Cancer Suppl* 1982;11:2672.
16. Saleh JW. *Laparoscopy*. Philadelphia: WB Saunders, 1988.
17. Warshaw AC, Tepper JE, Shipley WU. Laparoscopy in staging and planning therapy for pancreatic cancer [abstract]. *Am J Surg* 1986; 151:76.
18. Berci G, Cuschieri A. *Practical laparoscopy*. London: Ballierre Tindall, 1986.
19. Salky B, Bauer J, Gelernt I, et al. Laparoscopy for gastrointestinal diseases. *Mt Sinai J Med* 1985;2:228–32.
20. Reynolds W Jr. The first laparoscopic cholecystectomy. *Journal of the Society of Laparoendoscopic Surgeons* 2001;5:89–94.
21. Dubois F, Icard P, Berthelot G, et al. Celioscopic cholecystectomy: preliminary report of 36 cases. *Ann Surg* 1990;211:60–2.
22. Reddick EJ, Olsen DO. Laparoscopic laser cholecystectomy: a comparison with nonlaparoscopic cholecystectomy. *Surg Endosc* 1989;3:131–3.
23. NIH consensus statement: gallstones and laparoscopic cholecystectomy. *JAMA* 1993;269:1018–24.
24. Fowler DC, White SA. Brief clinical report: laparoscopic-assisted sigmoid resection [abstract]. *Surg Laparosc Endosc* 1991;1:183.
25. Ballantyne GH. Laparoscopically assisted anterior resection for rectal prolapse [abstract]. *Surg Laparosc Endosc* 1992;2:230.
26. Sgambati SA, Ballantyne GH. History of minimally invasive surgery. In: Jager RM, Wexner SD, eds. *Laparoscopic colorectal surgery*. New York: Churchill Livingstone, 1996:13–23.
27. Phillips EH, Franklin M, Carroll BJ, et al. Laparoscopic colectomy. *Ann Surg* 1992;216:703–7.
28. Cirocco WC, Schwartman A, Golub RW. Abdominal wall recurrence after laparoscopic colectomy for colon cancer. *Surgery* 1994; 116:842–6.
29. Wexner SD, Cohen SM. Port site metastases after laparoscopic colorectal surgery for cure of malignancy. *Br J Surg* 1995;82: 295–8.
30. Ballantyne GH. Laparoscopic-assisted colorectal surgery: review of results in 752 patients. *Gastroenterologist* 1995;3:75–89.
31. Chen HH, Wexner SD, Weis EG, et al. Laparoscopic colectomy for benign colorectal disease is associated with a significant reduction in disability as compared with laparotomy. *Surg Endosc* 1998;12: 1397–400.

32. Muckleroy SK, Ratzer ER, Fenoglio ME. Laparoscopic colon surgery for benign disease: a comparison to open surgery. *Journal of the Society of Laparoendoscopic Surgeons* 1999;3:33–7.
33. Tuech JJ, Pessaux, Rouge C, et al. Laparoscopic vs open colectomy for sigmoid diverticulitis: a randomized prospective study in the elderly. *Surg Endosc* 2000;14:1031–3.
34. Delgado S, Lacy AM, Garcia Valdecasas JC, et al. Could age be an indication for laparoscopic colectomy in colorectal cancer? *Surg Endosc* 2000;14:22–6.
35. Stocchi L, Nelson H, Young-Fadok TM, et al. Safety and advantages of laparoscopic vs open colectomy in the elderly: matched-control study. *Dis Colon Rectum* 2000;43:326–32.
36. Zmora O, Gervaz P, Wexner SD. Trocar site recurrence in laparoscopic surgery for colorectal cancer. *Surg Endosc* [serial online]. 2001:15.
37. Lo P, Ahmed N, Chung RS. Which laparoscopic operations are the fastest growing in residency programs? [abstract P206]. Presented at the annual meeting of The Society of American Gastrointestinal Endoscopic Surgeons, St. Louis, April 2001. *Surg Endosc* 2001;15(Suppl 1):S145.
38. Wishner JD, Baker JW Jr, Hoffman GC, et al. Laparoscopic-assisted colectomy: the learning curve. *Surg Endosc* 1995;9: 1179–83.
39. Senagore AJ, Luchtefeld MA, Mackeigan JM. What is the learning curve for laparoscopic colectomy? *Am Surg* 1995;61:681–5.
40. Bennett CL, Stryker SJ, Ferreira MR, et al. The learning curve for laparoscopic colorectal surgery: preliminary results from a prospective analysis of 1194 laparoscopic-assisted colectomies. *Arch Surg* 1997;132:41–4.
41. Schlachta CM, Mamazza J, Seshadri PA, et al. Defining a learning curve for laparoscopic colorectal resections. *Dis Colon Rectum* 2001;44:217–22.
42. Mack MJ. Minimally invasive and robotic surgery. *JAMA* 2001; 285:568–72.
43. Hanna GB, Shimi S, Cuschieri A. Optimal port locations for endoscopic intracorporeal knotting. *Surg Endosc* 1997;11:397–401.
44. Mueglitz J, Kunad G, Dautzenberg P, et al. Kinematic problems of manipulators for minimally invasive surgery. *Endosc Surg* 1993; 1:160–4.
45. Birkett DH. 3-Dimensional imaging in gastrointestinal laparoscopy. *Surg Endosc* 1993;7:556–7.
46. Sgambati S, Ballantyne GH. Preceptoring laparoscopic colectomy [abstract]. *Surg Endosc* 1994;8:261.
47. Birkett DH, Josephs LG, Este-McDonald J. A new 3-dimensional laparoscope in gastrointestinal surgery. *Surg Endosc* 1994;8: 1448–51.
48. Patkin M, Isabel L. Ergonomics and laparoscopic general surgery. In: Graber JN, Schultz LS, Pietrafitta JJ, et al., eds. *Laparoscopic abdominal surgery*. New York: McGraw-Hill, 1993:83–8.
49. Berguer R. Surgical technology and the ergonomics of laparoscopic instruments. *Surg Endosc* 1998;12:458–62.
50. Hemal AK, Srimvas M, Charles AR. Ergonomic problems associated with laparoscopy. *J Endourol* 2001;15:499–503.
51. Satava RM. Nintendo surgery. *JAMA* 1992;267:2329–30.
52. Zucker KA. Laparoscopy and robotic surgery. 2nd ed. In: Zucker KA, ed. *Surgical laparoscopy*. Philadelphia: Lippincott Williams & Wilkins. 2001:803–8.
53. Satava RM. Surgery 2001: a technologic framework for the future. *Surg Endosc* 1993;7:111–3.
54. Satava RM, Simon IB. Teleoperation, telerobotics, and telepresence in surgery. *Endosc Surg* 1993;1:151–3.
55. Satava RM. High tech surgery: speculations on future directions. In: Hunter JG, Sackier JM, eds. *Minimally invasive surgery*. New York: McGraw-Hill, 1993:339–47.
56. Talamini MA. Surgery in the 21st century [editorial]. *Ann Surg* 2001;234:8–9.