Gastrointestinal Robot-Assisted Surgery. A Current Perspective

Sorinel Luncă[1], George Bouras[2], Alexandru Călin Stănescu[2]

1) Emergency Surgical Clinic, University of Medicine and Pharmacy "Gr. T. Popa" Iaşi. 2) IRCAD/EITS, University of Medicine "Louis Pasteur" Strasbourg, France

Abstract

Minimally invasive techniques have revolutionized operative surgery. Computer aided surgery and robotic surgical systems strive to improve further on currently available minimally invasive surgery and open new horizons. Only several centers are currently using surgical robots and publishing data. In gastrointestinal surgery, robotic surgery is applied to a wide range of procedures, but is still in its infancy. Cholecystectomy, Nissen fundoplication and Heller myotomy are among the most frequently performed operations. The ZEUS™ (Computer Motion, Goleta, CA) and the da Vinci™ (Intuitive Surgical, Mountain View, CA) surgical systems are today the most advanced robotic systems used in gastrointestinal surgery. Most studies reported that robotic gastrointestinal surgery is feasible and safe, provides improved dexterity, better visualization, reduced fatigue and high levels of precision when compared to conventional laparoscopic surgery. Its main drawbacks are the absence of force feedback and extremely high costs. At this moment there are no reports to clearly demonstrate the superiority of robotics over conventional laparoscopic surgery. Further research and more prospective randomized trials are needed to better define the optimal application of this new technology in gastrointestinal surgery.

Key words

Robotic surgery - gastrointestinal surgery - da Vinci surgical system

Rezumat

Chirurgia minim invazivă a revoluţionat chirurgia operatorie. Chirurgia computer asistată şi sistemele chirurgicale robotice încearcă să îmbunătăţească actualele tehnici minim invazive şi să deschidă noi orizonturi. Doar câteva centre medicale folosesc curent chirurgia robotică şi publică rapoarte ale acestei activităţi. În chirurgia gastrointestinală, robotica este aplicată pentru numeroase proceduri, dar se află încă la debut. Printre cele mai frecvente operaţii realizate în sfera gastrointestinală se află colecistectomia, fundoplicatura Nissen şi miotomia Heller. Sistemele chirurgicale ZEUS™ (Computer Motion, Goleta, CA) şi da Vinci™ (Intuitive Surgical, Mountain View, CA) reprezintă astăzi cele mai avansate sisteme robotice folosite în chirurgia gastrointestinală. Majoritatea rapoartelor arată că aplicarea roboticii în chirurgia gastrointestinală este sigură şi reproductibilă, furnizează o mai mare dexteritate, o vizualizare mai bună, o precizie mai mare şi o reducere a oboselii atunci când este comparată cu chirurgia laparoscopică convenţională. Principalele dezavantaje ale chirurgiei robotice sunt reprezentate de absenţa feedback-ului forţei şi de costurile extrem de mari. În acest moment nu există nici un studiu care să arate cu certitudine superioritatea chirurgiei robotice faţă de cea convenţional laparoscopică. Noi cercetări şi mai multe studii prospective randomizate sunt necesare pentru a defini mai bine aplicaţiile optime ale acestei noi tehnologii.

Romanian Journal of Gastroenterology
December 2005 Vol.14 No.4, 385-391
Address for correspondence: Sorinel Luncă
Clinica de Urgenţe Chirurgicale
Spitalul Clinic de Urgenţe Iaşi
Str. General Berthelot nr.2
Iaşi, Romania
E-mail: slunca@hotmail.com

Introduction

With the first laparoscopic cholecystectomy performed by Philippe Mouret in 1987, surgery stepped into a new era. Minimally invasive techniques have revolutionized operative surgery and are currently used in most surgical subspecialties. Endoscopic surgery, in particular laparoscopy does however have its drawbacks. The surgical dexterity is reduced through the rigid operative instruments with limited degrees of freedom. Furthermore, the surgeon distances his hands from the operative field with long instruments that magnify natural tremor and reduce appreciation of force feedback and tactile sense. The surgeon is also forced to work with a two dimensional representation of reality instead of the conventional three-dimensions (3-D) of open surgery. Most laparoscopic gastrointestinal operations are difficult to learn, master, and perform routinely and surgeons face a long learning curve (1,2). Poor ergonomic position for the surgeon is another problem for laparoscopic surgery (3,4).

Advances in computer technology and robotic surgery have explored new solutions to such limitations and technology is progressively being introduced into clinical practice. Computer systems facilitate pre-operative planning and instrument positioning while robotic arms improve precision of surgical technique. A robot is defined as "a machine that resembles a human and does mechanical, routine tasks on command" (5). The Czech writer Karel Capek was the first to use the word robot in 1920 in his play "Rossum's Universal Robots", a parody on dehumanization in a technological world. The term robotics, which refers to the study of robots, was used for the first time by Isaac Asimov in his story "Runaround". Asimov expounded robotics laws: robots must obey humans; through inaction they may not allow humans to come to harm, they may not injure a human and humanity must be protected above humans.

Since then, robots have become a reality. Robotic technology has been used for some time to great advantage in non-medical fields, such as automotive construction as well as space, undersea and nuclear exploration. Pioneering work in robotic surgery was done much later in 1985 when an industrial robot, Puma 560, was used by Kwoh to hold instruments during stereotactic biopsy in neurosurgery (6).

Surgical Robotic Systems

Robot-assisted surgery on humans was used for the first time in 1988 by Davies et al (7) who performed a transurethral resection of the prostate using Puma 560. This system eventually led to the development of PROBOT™, a second generation robot designed specifically for transurethral resection of the prostate (8,9). The PROBOT system was equipped with an ultrasound probe at its tips which allowed for a 3-D model of the prostate to be created which facilitated accurate removal of the prostatic tissue. Prostatectomy is considered as the first true robotic operation. In the late 1980s, Integrated Surgical Supplies Ltd. (Sacramento, CA) developed ROBODOC™, a robot used in clinical practice to facilitate cementless total hip replacement (10). ROBODOC was the first surgical robot approved by the Food and Drug Administration in United States.

The application of robotic surgery for abdominal procedures was first seen during the early 1990s (11). In 1994, Computer Motion, Inc. (Goleta, CA; now operated by Intuitive Surgical) introduced a voice-controlled robotic arm called AESOP™ (Automated Endoscopic System for Optimal Positioning) (Fig.1). Further developments led to the AESOP 2000 which was the first voice-controlled robot approved by the Food and Drug Administration (12,13). In 1998, Reichenspurner in Germany introduced the ZEUS™ Robotic Microsurgical System (Computer Motion, Goleta, CA) into clinical practice (14) (Fig.2). Today the most sophisticated surgical robot on the market is the da Vinci™

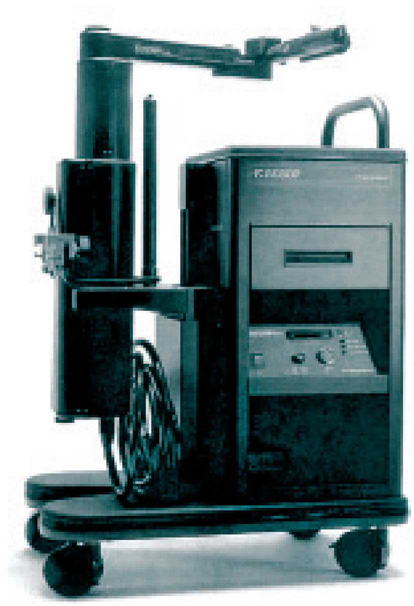

Fig.1 AESOP™ (Automated Endoscopic System for Optimal Positioning) voice-controlled robotic arm.

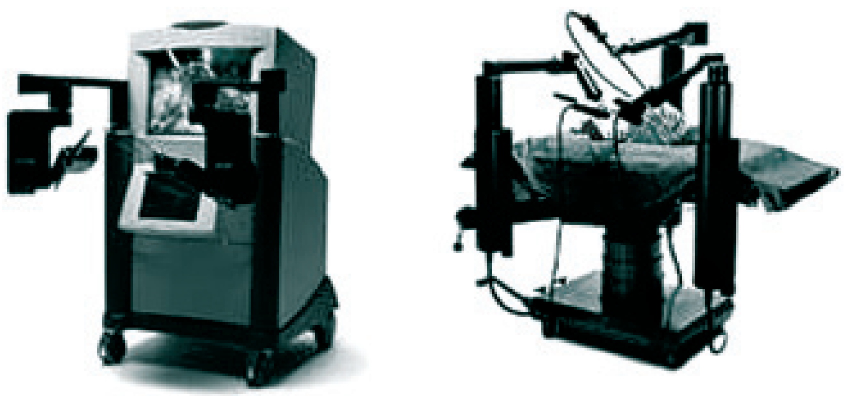

Fig.2 The ZEUS™ robotic microsurgical system. Surgeon's console and surgical cart with the three robotic arms attached to the operating table.

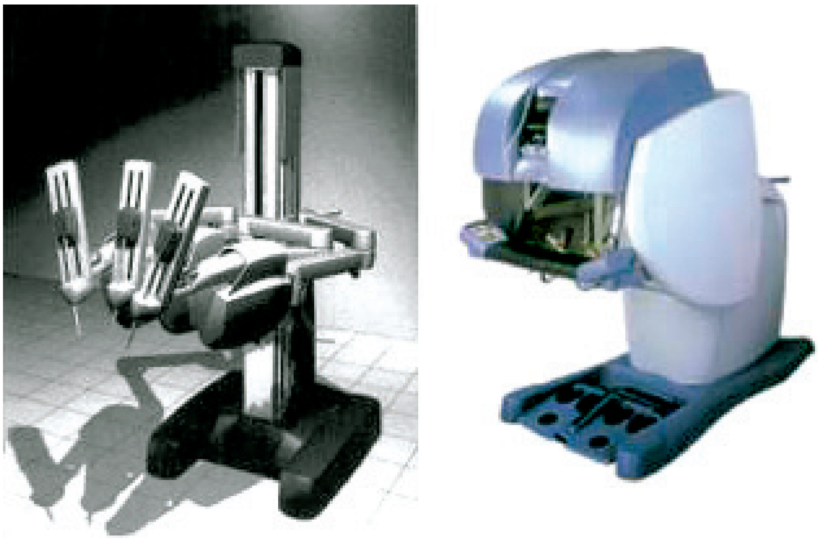

Fig.3 The da Vinci™ surgical robotic cart and console.

Fig.4 Endowrist instrument which translates surgeon's hand and wrist movements into precise laparoscopic instrument movements with 7 degrees of freedom of motion inside the abdomen.

system developed by Intuitive Surgical Inc. (Mountain View, CA) in 1995 (Fig.3). Using the da Vinci system, Carpentier in Paris performed the first robotically assisted cardiac operation, a mitral valve replacement in 1998 (15). In the same year, Mohr (16) in Leipzig performed the first robotically assisted coronary artery bypass graft procedure.

The two systems that are in use today are the ZEUS and the da Vinci robots, both of which are Food and Drug Administration approved for minimal invasive abdominal procedures.

The ZEUS and da Vinci systems are similar in their capabilities but different in their approach to robotic surgery. Both systems are comprehensive master-slave robots with three robotic arms operating remotely from a console with video assisted visualization and computer enhancement. One arm is capable of manipulating the rigid endoscope. For the ZEUS system, a 3-D image is obtained via accessory 3-D glasses while for the da Vinci system this is obtained through the surgeon's console (via a dual light source and dual 3-chip cameras). The other two robotic arms hold specific surgical instruments and have freedom of movement through 7 degrees of freedom, simulating the movement of the human arm, elbow and wrist (Fig.4). The digitalization of surgical gesture has enabled the elimination of surgical tremor and improved motion scaling of up to five times therefore allowing for better operative precision. The computer interface represents the major difference between robotic and conventional surgery. The digitized translation of the surgeon's movements is manipulated by the robot in order to enhance surgical movement. Improved ergonomics is yet another advantage conveyed through such systems. In the da Vinci system, the surgeon is comfortably seated at the console, immersed in the surgical field and therefore less distracted for a longer period of time, which is thought to help surgeon's performance remain optimal for longer time. In terms of the learning curve required to master the use of the robot, Corcione et al. (17) consider that a number of 10 robotic procedures are necessary.

An important drawback of robotic systems is the loss of haptic feedback to the surgeon from the tissues. Neither the ZEUS nor da Vinci systems have force feedback mechanisms, although a computerized force feedback endoscopic surgical grasper has been recently developed with promising results (18). The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) has suggested that the most significant limitation of surgical robotics is the high cost of this technology (19). In 2004 the cost of a da Vinci robotic system was 1.25 million US dollars. At this, we have to add maintenance costs and costs of semi reusable instruments. It is estimated that the cost of an anti-reflux procedure using the da Vinci system adds up to 2,000 US dollars (20). Bulky equipment with limited mobility and limited teaching capacity are other limitations of the da Vinci system. The da Vinci system is rather cumbersome; it fills a large operating room, and its use in smaller rooms is therefore impractical (21,22). Furthermore, the robot is very heavy, making it difficult to move it around the room and even more difficult to transfer it to another operating room (21, 23). Changing the setup of the operating room according to the type of operation being performed (achalasia or colon surgery requires a different setup from cholecystectomy, for instance) is time consuming and tiring. Moreover, because da Vinci was designed specifically for cardiac surgery, the requirements for abdominal surgery were not taken into account (3,4,24). As a result, the use of a da Vinci robot for abdominal surgery presents a variety of challenges. The instrumentation available is limited; the robotic arms are bulky and are not attached to the operating table (25). Large excursion arcs of the arms lead to frequent collisions. Another limitation is the large diameter of the instruments (8 mm) and the limited number of robotic arms (maximum three) (21). These system limitations are often the cause of conversions, because it is difficult to manage a bleeding episode with only two operating instruments.

Reports in the literature show that compared to conventional laparoscopic surgery, although the da Vinci offers better visualization, improved dexterity, reduced fatigue and high level of precision, it is associated with higher costs.

Gastrointestinal clinical applications

In clinical surgical practice, robotics has been used in almost all surgical subspecialties including neurosurgery, cardiac and vascular surgery, orthopedics, general surgery, urology and gynecology. Most of the experience is from cardiovascular and urological surgery. The application of robotics in gastrointestinal surgery is relatively new. So far, robots have been used to facilitate laparoscopic cholecystectomy, antireflux surgery, obesity surgery, intestinal and esophageal surgery as well as splenic and pancreatic surgery.

The first robot-assisted laparoscopic cholecystectomy was reported by Himpens in March 1997 (26). He used a MONA system (Intuitive Surgical Inc., Mountain View, CA), a precursor of the da Vinci, and completed the surgery in 82 min. In 2001, Cadiere et al (27) performed 48 cholecystectomies among 146 nonconsecutive patients using the da Vinci system with a median operation time for the last 35 cases of 70 minutes (range 25-120). Four of the cases were operated for acute cholecystitis. Peri-operative bleeding necessitating transfusion was encountered in one case. The median hospital stay was 2 days (range 1-15). Cadiere et al found that improved dexterity, optimized ergonomics and increased mobility of the instrument tips were beneficial while operating time and hospital stay were within acceptable limits. Marescaux et al. (28) in 2001 reported a series of 25 cholecystectomies using the ZEUS system (breakdown: 20 - symptomatic cholelithiasis, 4 - acute cholecystisis and one polyp). The outcomes from this series were good with conversion to open surgery necessary in only one case. Because all information exchanged between surgeon and patient during robotic surgery is digitized, surgical robotics has also ushered in the era of telesurgery. In September 2001, robotic applications in abdominal surgery traversed the Atlantic. Following experimentation on pigs, Marescaux performed the first transatlantic robotically assisted cholecystectomy (Lindberg operation). Using the ZEUS system which was manipulated from New York, he performed a cholecystectomy on a patient located in Strasbourg, France, in 54 minutes (29). Marescaux concluded that there were no significant advantages to the patient from this type of surgery as the operative time was not significantly shorter nor did the surgeon notice any improvements in dexterity or outcome. Overall, for laparoscopic cholecystectomy, robotic surgery is found to be safe and feasible with outcomes similar to that of conventional laparoscopic surgery.

For anti-reflux surgery, the first robot-assisted Nissen procedures were reported by Cadiere in 1999 (30). The only randomized study for robotic application in general surgery comes from antireflux surgery (30). Cadiere operated on 10 patients using the MONA system and on 11 patients using conventional laparoscopy. There were no conversions and the mean operative time was significantly longer in the robotic group (76 vs. 52 minutes) while mean hospital stay was similar. The authors noted feasibility, but stated that there were no clear benefits from robotic assistance.

Melvin et al (31) in a series of 20 patients and Hanly and Talamini (32) in 57 patients experienced findings similar to that of Cadiere et al: robotic anti-reflux surgery is safe and feasible but necessitates longer operative time and is more expensive. Hanly and Talamini (32) believe that among the patients with large hiatal hernias, a technically better repair is possible using the robot than in conventional laparoscopic surgery. They think that this better repair could translate into lower long-term recurrence rate. At the current level of technology and experience, robotic antireflux surgery appears to offer little advantage over standard laparoscopic approach (31).

In obesity surgery, Cadiere et colab. were the first to apply robotics in 1999 when they performed a gastric banding (33). Jacobsen et al. (34) published a series of 107 patients on which an R-en-Y gastric bypass was performed with robotic assistance. The advantages found by the authors included easier hand-sewing during gastro-jejunal anastomosis, avoidance of mechanical stapler and construction of a smaller proximal gastric pouch.

Only a few cases are reported for splenic, pancreatic, intestinal and esophageal surgery using robotic assistance. The use of robots in liver surgery is still under evaluation.

Melvin and colleagues (35) pioneered robotic assistance in pancreatic surgery by performing the first resection of a neuroendocrine pancreatic tumor along with the spleen using the da Vinci system in 2003. Giulianotti and colleagues (36) reported a series of 8 patients in whom pancreatico-duodenectomy was performed during which the hepatico-jejunostomies and gastrojejunostomies were hand-sewn intracorporeally. The lack of haptic feedback may preclude safe utilization of robots in complex pancreatic procedures such as Whipple's operation during which palpation to facilitate careful dissection of the portal vein is essential.

Hashizume et al (37), Hanly and Talamini (32) and Chapman et al (38) reported few cases of robot assisted splenectomies. The authors found that the da Vinci system improves the ability to clarify vessel architecture and to delineate the spleen's relation to the pancreas as well as offering more precision of instruments to facilitate exposure of the splenic vessels. Talamini et al. (39) reported 2 conversions in 7 procedures due to surgical difficulties, suggesting that splenectomies are not ideal indications for the robotic system. Bodner et al. (40) performed laparoscopic splenectomies with the da Vinci operating robot in 7 patients. Indications for splenectomy were immune thrombocytopenic purpura in four patients and hypersplenism in three patients. Median dimensions of the resected spleens were 140 ± 34 mm x 80 ± 11 mm x 50 ± 17 mm and median weight was 307 ± 193 g. Median total operative time was 147 ± 58 minutes including 107 ± 49 minutes for the robotic act. There were no intraoperative complications and no conversions to open surgery. The authors suggest that robotic splenectomy with the da Vinci surgical system is technically feasible, safe and it provides an alternative to the conventional laparoscopic procedure. However, the authors found that one limitation of the current da Vinci system is the lack of sophisticated dissection and stapler devices. Therefore, the surgical control of the splenic hilum must be performed with conventional staplers by the tableside surgeon. The ligation of splenic vessels by means of telemanipulation is also found extremely time-consuming.

In a multicenter series of 211 robot assisted operations, the Academic Robotics Group reported only 17 bowel resections (39). The main indication was Crohn's disease. Following the bowel hand over hand from one end to other, hand-sewing of anastomoses and suturing of enteric feeding tubes were found to be easier using robots than by conventional laparoscopic techniques.

In March 2001, Weber reported the first two colectomies using a robot (41). Since then, a wide range of operations have been performed in colorectal surgery including right and left colectomy, sigmoid resection, proctopexy, low anterior resection, abdomino-perineal resection, cecostomy and total colectomy. These procedures were performed mainly for non-malignant conditions such as diverticulitis, polyps and rectal prolapse. Rockall and Darzi (42) focused their robotic colon surgery effort on the pelvis, using the robot exclusively for the pelvic dissections in proctopexies, low anterior resections, and abdominoperineal resections which have been well described. Munz et al. (43) compared 6 robotic non-resection proctopexies with conventional laparoscopic controls. With a follow up of 6 months they found no peri-operative morbidity, no recurrent prolapse and no constipation compared with 19% morbidity in the same author's historical control series. Robotically assisted surgery seems to be beneficial in cases where extensive dissection of the pelvis is required particularly when a more focused surgery is necessary. D'Annibale et al. (44) compared the outcome of 53 colorectal procedures performed by means of the robotic system (31 benign diseases and 22 malignancies) with the results obtained in 53 colorectal procedures performed through use of conventional laparoscopic techniques (11 benign diseases and 42 malignancies) during a period of two years. The study found no significant difference in specimen length, number of lymph nodes retrieved, vascular control and intraoperative blood loss between robotic approach and standard laparoscopy for colorectal surgery. The two techniques are comparable in terms of surgical accuracy and oncologic radicality and, as expected, the postoperative results did not differ between the two groups. The only significant difference between the two groups was in the term of time required to set up the operating room: 18 ± 7 minutes in the laparoscopic group vs. 24 ± 12 minutes in the robotic group. The authors consider that the dexterity and flexibility of the da Vinci™ system may be useful in certain stages of the surgical procedure: splenic flexure takedown, dissection of the inferior mesenteric artery with identification of the nervous plexus, and dissection of a narrow pelvis. In addition, the dexterity of the da Vinci system was found to facilitate handsewn anastomosis.

In 2004, Jacobsen and colleagues (45) in Chicago reported 35 Heller myotomies, 4 total esophagectomies, 1 excision of esophageal leyomyoma and 3 epiphrenic diverticulectomies. There were no perforations in Heller myotomy and this was attributed to the greatly enhanced visualization of the esophageal musculature offered by the robot's magnified 3-D view as well as the enhanced range of motion the Endowrist affords. The myotomy time was found to be significantly shorter compared with conventional laparoscopy. For total esophagectomies, Horgan et al. (46) emphasized that a near bloodless dissection of the esophagus is possible due to the 3-D image and articulating wrists. An individual cautery hook enables accurate cauterization and division of each peri-esophageal attachment.

There is accumulating evidence for the use of robots in minimally invasive gastrointestinal surgery. Most reports highlight the feasibility of robotic surgery although at present, its superiority over conventional laparoscopic surgery has not been clearly demonstrated. More prospective randomized trials evaluating efficacy and safety of robotic digestive surgery must be undertaken.

Advancements in information technology are changing the way we practice abdominal surgery and the application of robotic surgery is growing exponentially. Although the ZEUS and the da Vinci systems are the most sophisticated robots currently used, there is still space for future improvements. Telesurgey is on the horizon although only a few of the most renowned surgeons have proved its feasibility. Overall, robotic technology has already proved its potential value and is likely to revolutionalize the way we perform surgery by improving and expanding laparoscopic procedures and treatment modalities beyond the limits of human ability. The major drawback to this technology is its cost. Developments in technology will lead to smaller, less expensive, more mobile robots which are able to provide force feedback and are likely to replace conventional laparoscopic surgery.

References

1. Gould JC, Melvin WS. Telerobotic foregut and esophageal surgery. Surg Clin North Am 2003; 83: 1421–1427.
2. Merola S, Weber P, Wasielewski A, Ballantyne GH. Comparison of laparoscopic colectomy with and without the aid of a robotic camera holder. Surg Laparosc Endosc Percutan Tech 2002; 12: 46–51.
3. Ballantyne GH. Robotic surgery, telerobotic surgery, telepresence, and telementoring. Review of early clinical results. Surg Endosc 2002; 16: 1389–1402.
4. Ruurda JP, Broeders IA. Robot-assisted laparoscopic intestinal anastomosis. Surg Endosc 2003; 17: 236–241.
5. Merriam-Webster's Unabridged Dictionary, Springfield Mass. Merriam-Webster Inc, 2000.
6. Kwoh YS, Hou J, Jonckheere EA, Hayati S. A robot with improved absolute positioning accuracy for CT guided stereotactic brain surgery. IEEE Trans Biomed Eng 1988; 35: 153–160.
7. Davies BL, Hibberd RD, Coptcoat MJ, Wickham JE. A surgeon robot prostatectomy—a laboratory evaluation. J Med Eng Technol 1989; 13: 273–277.
8. Davies BL, Hibberd RD, Ng WS, Timoney AG, Wickham JE. The development of a surgeon robot for prostatectomies. Proc Inst Mech Eng 1991; 205: 35–38.
9. Davies B. A review of robotics in surgery. Proc Inst Mech Eng 2000; 214: 129–140.
10. Paul HA, Bargar WL, Mittlestadt B et al. Development of a surgical robot for cementless total hip arthroplasty. Clin Orthop Relat Res 1992: 57–66.
11. Satava RM. Surgical robotics: the early chronicles: a personal historical perspective. Surg Laparosc Endosc Percutan Tech 2002; 12: 6–16.
12. Kavoussi LR, Moore RG, Adams JB, Partin AW. Comparison of robotic versus human laparoscopic camera control. J Urol 1995; 154: 2134–2136.
13. Partin AW, Adams JB, Moore RG, Kavoussi LR. Complete robot-assisted laparoscopic urologic surgery: a preliminary report. J Am Coll Surg 1995; 181: 552–557.
14. Boehm DH, Reichenspurner H, Gulbins H et al. Early experience with robotic technology for coronary artery surgery. Ann Thorac Surg 1999; 68: 1542-1546.
15. Carpentier A, Loulmet D, Aupecle B et al. Computer assisted open heart surgery: first case operated on with success. C R Acad Sci III 1998; 321: 437-442.
16. Mohr FW, Falk V, Diegeler A, Autschback R. Computer-enhanced coronary artery bypass surgery. J Thorac Cardiovasc Surg 1999; 117: 1212-1214.
17 Corcione F, Esposito C, Cuccurullo D et al. Advantages and limits of robot-assisted laparoscopic surgery: preliminary experience. Surg Endosc 2005; 19: 117–119.
18. Rosen J, Hannaford B, MacFarlane MP, Sinanan MN. Force controlled and teleoperated endoscopic grasper for minimally invasive surgery—experimental performance evaluation. IEEE Trans Biomed Eng 1999; 46: 1212–1221.
19. Hanly EJ, Zand J, Bachman SL, Marohn MR, Talamini MA. Value of the SAGES Learning Center in introducing new technology. Surg Endosc 2005; 19:477-83.
20. Costi R, Himpens J, Bruyns J, Cadiere GB. Robotic fundoplication: from theoretic advantages to real problems. J Am Coll Surg 2003; 197: 500–507.
21. Ballantyne GH, Moll F. The da Vinci telerobotic surgical system: the virtual operative field and telepresence surgery. Surg Clin North Am 2003; 83: 1293–1304.
22. Ruurda JP, Broeders IA, Simmermacher RP, Rinkes IH, Van Vroonhoven TJ. Feasibility of robot-assisted laparoscopic surgery: an evaluation of 35 robot-assisted laparoscopic cholecystectomies. Surg Laparosc Endosc Percutan Tech 2002; 12: 41–45.
23. Sung GT, Gill IS. Robotic renal and adrenal surgery. Surg Clin North Am 2003; 83: 1469–1482.
24. Kim VB, Chapman WH, Albrecht RJ et al. Early experience with telemanipulative robot-assisted laparoscopic cholecystectomy using da Vinci. Surg Laparosc Endosc Percutan Tech 2002; 12: 33–40.
25. Stylopoulos N, Rattner D. Robotics and ergonomics. Surg Clin North Am 2003; 83: 1321–1337.
26. Himpens J, Leman G, Cadiere GB. Telesurgical laparoscopic cholecystectomy. Surg Endosc 1998; 12: 1091.
27. Cadiere GB, Himpens J, Germay O et al. Feasibility of robotic laparoscopic surgery: 146 cases. World J Surg 2001; 25: 1467–1477.
28. Marescaux J, Smith MK, Folscher D, Jamali F, Malassagne B, Leroy J. Telerobotic laparoscopic cholecystectomy: initial clinical experience with 25 patients. Ann Surg 2001; 234: 1-7.
29. Marescaux J, Leroy J, Gagner M et al. Transatlantic robot-assisted telesurgery. Nature 2001; 413: 379-380.
30. Cadiere GB, Himpens J, Vertruyen M et al. Evaluation of telesurgical (robotic) Nissen fundoplication. Surg Endosc 2001; 15: 918–923.
31. Melvin WS, Needleman BJ, Krause KR, Schneider C, Ellison EC. Computer-enhanced vs. standard laparoscopic antireflux surgery. J Gastrointest Surg 2002; 6: 11–16.
32. Hanly EJ, Talamini MA. Robotic abdominal surgery. Am J Surg 2004; 188: 19S-26S.
33. Cadiere GB, Himpens J, Vertruyen M, Favretti F. The world's first obesity surgery performed by a surgeon at a distance. Obes Surg 1999; 9: 206-209.
34. Jacobsen G, Berger R, Horgan S. The role of robotic surgery in morbid obesity. J Laparoendosc Adv Surg Tech A 2003; 13: 279–283.

35. Melvin WS, Needleman BJ, Krause KR, Ellison EC. Robotic resection of pancreatic neuroendocrine tumor. J Laparoendosc Adv Surg Tech A 2003; 13: 33–36.
36. Giulianotti PC, Coratti A, Angelini M et al. Robotics in general surgery: personal experience in a large community hospital. Arch Surg 2003; 138: 777–784.
37. Hashizume M, Shimada M, Tomikawa M et al. Early experiences of endoscopic procedures in general surgery assisted by a computerenhanced surgical system. Surg Endosc 2002; 16: 1187–1191.
38. Chapman WH 3rd, Albrecht RJ, Kim VB, Young JA, Chitwood WR Jr. Computer-assisted laparoscopic splenectomy with the da Vinci surgical robot. J Laparoendosc Adv Surg Tech A 2002; 12: 155–159.
39. Talamini MA, Chapman S, Horgan S, Melvin WS: the Academic Robotics Group. A prospective analysis of 211 robotic-assisted surgical procedures. Surg Endosc 2003; 17: 1521–1524.
40. Bodner J, Lucciarini P, Fish J, Kafka-Ritsch R, Schmid T. Laparoscopic splenectomy with the da Vinci robot. J Laparoendosc Adv Surg Tech 2005; 15: 1-5.
41. Weber PA, Merola S, Wasielewski A, Ballantyne GH. Telerobotic assisted laparoscopic right and sigmoid colectomies for benign disease. Dis Colon Rectum 2002; 45: 1689–1694.
42. Rockall TA, Darzi A. Robot-assisted laparoscopic colorectal surgery. Surg Clin North Am 2003; 83: 1463–1468.
43. Munz Y, Moorthy K, Kudchadkar R et al. Robotic assisted rectopexy. Am J Surg 2004; 187: 88–92.
44. D'Annibale A, Morpurgo E, Fiscon V et al. Robotic and laparoscopic surgery for treatment of colorectal diseases. Dis Colon Rectum 2004; 47: 2162–2168.
45. Jacobsen G, Elli F, Horgan S. Robotic surgery update. Surg Endosc 2004; 18: 1186-1191.
46. Horgan S, Berger R, Elli EF, Espat NJ. Robotic-assisted minimally invasive transhiatal esophagectomy. Am Surg 2003; 69: 624-626.