Current Practice in Robotic Gastrointestinal Surgery

Robotik Gastrointestinal Cerrahide Güncel Uygulama

Abstract

General surgical diseases have been long treated via conventional (open) or laparoscopic operations. With the advances in technology, there is a paradigm shift from conventional laparoscopy. As a result, single incision laparoscopic surgery (SILS), natural orifice transluminal endoscopic surgery (NOTES), and robotic surgery have evolved as new treatment options for minimal invasive surgery. It has been shown in many series that a wide variety of procedures of general surgery can be managed safely and effectively by robot assisted laparoscopic surgery (RALS). In this review, current advances and practice in robotics in the most commonly applied gastrointestinal surgical procedures will be emphasized.

Key Words: general surgery; gastrointestinal; robotics

Özet

Cerrahi tedavi gerektiren hastalıklar için, uzun zamandır konvansiyonel (açık) veya laparoskopik ameliyatlar uygulanabilmektedir. Günümüzde teknolojideki hızlı ilerlemeler, bu konudaki araştırmalarda konvansiyonel laparoskopiden farklı yöntemlere de odaklanılmasına neden olmuştur. Bunlar arasında tek kesiden laparoskopik cerrahi *(single incision laparoscopic surgery—SILS)*, doğal menfezden translüminal endoskopik cerrahi *(natural orifice transluminal endoscopic surgery—NOTES)* ve robotik cerrahi, minimal invaziv cerrahi için yeni seçeneklerdir. Birçok çalışmada çeşitli genel cerrahi ameliyatlarının robot yardımlı laparoskopik (ROYAL) cerrahi ile güvenli ve etkin bir şekilde uygulanabildiği gösterilmiştir. Bu derlemede, genel cerrahi alanında en sık uygulanan gastrointestinal operasyonlara yönelik robotik cerrahideki güncel gelişmeler ve uygulamalar irdelenecektir.

Anahtar Kelimeler: genel cerrahi; gastrointestinal; robot

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INTRODUCTION

Minimally invasive operations have led to radical changes in surgery during the past few decades. Since the first successful laparoscopic cholecystectomy in 1987, laparoscopic procedures have gained popularity in many surgical interventions. Less postoperative pain, faster return to daily activities, and better cosmetic results are the main advantages of laparoscopic surgery (1).

With advances in technology, there has been a paradigm shift away from conventional laparoscopy. As a result, single incision laparoscopic surgery (SILS), natural orifice transluminal endoscopic surgery (NOTES), and robotic surgery have evolved as new treatment options for minimally invasive surgery (1).

The Automated Endoscopic System for Optimal Positioning *(AESOP)* was the first robotic surgical system approved by the United States Food and Drug Administration *(FDA)* in 1994. Surgeons obtained great benefit in the facilitation of procedures as AESOP replaced the cameraman and provided a stable platform for the video telescope while transmitting images in response to the surgeon's voice commands (2).

In 2000, the tele-robotic surgical system Da Vinci S® (*da Vinci S® Surgical System-Intuitive Surgical, Sunnyvale, CA, USA)* was approved by the FDA to be utilized in surgery. It was first successfully used in cardiac surgery followed by urological and general surgical procedures. Advanced laparoscopic instruments with enhanced capability of movement also went along with the developing robotic systems. The surgeon utilizes a virtual three-dimensional (3D) operating area and carries out the operation by managing two tele-robotic arms, both of which hold surgical instruments. These tele-robotic arms simulate the movements of the surgeon's hands with six degrees of freedom and two degrees of axial rotation, combining the 3D images and movements that are similar to the manual movements of the surgical instruments (3).

Several studies have shown that the oncological results of open and laparoscopic surgery are fairly similar; however, it is obvious that minimally invasive surgery is still not as commonly chosen for a variety of more complex procedures (4). The number of disadvantageous inherent features of conventional laparoscopic surgery may account for such unfavorable circumstances. Unstable 2D cameras, difficulty in handling the instruments that cause the so-called *'fulcrum effect'* (moving the instruments to the opposite direction of the targeted organ on the monitor) and enhancement of pathological tremor, a limited capacity of maneuvering and articulation, the lack of tactile perception, and the restricted working area are factors which add to the disadvantages of this surgical approach (1).

The tele-robotic system consists of three main components (2).The first component is the surgeon's console. Here, the surgeon's hands are placed in the controller in order to constitute the surgical interface with the computer. The next part of the console is a 3D imaging system. Two handles and four pedals used to focus the camera and manipulate the robotic arms and instruments are located here (3).

The second component is the imaging system, which consists of a dual light source and dual camera with three integrated circuits. The dual camera is mounted at the tip of the endoscope to provide 3D imaging; a 12mm telescope is accompanied with two independent 5mm telescopes (3).

The final component of the robotic system is the patient-side cart. Three robotic arms holding the instruments and one arm in the center holding the camera are located in this part (2). Four specially designed multi-articulated robotic arms are capable of moving similar to the original human hand. The tips of the instruments are designed to provide surgeons with natural dexterity and a range of motion greater than even the human hand. The detachable instruments allow the robotic arms to maneuver in ways that simulate fine human movements. These instrumental wrists (EndoWristâ) restore full range of motion in 7 dimensions and have the ability to rotate 540 degrees and articulate 180 degrees (1).

The patient-side cart is brought to the operating table and 'docking' takes place by connecting the trocars with the system (2, 5). As the instruments are inserted into the patient, the robotic arms left behind shorten so as to prevent the collision between the arms.

The surgeon is seated in front of the computer console and places his or her fingers in the manipulator that transfers the human movements to the robotic

instruments through a computerized tremor filter. This system provides 3D high-definition (HD) imaging, facilitating the complex procedures such as fine dissections and intra-corporeal anastomosis. Thus, the da Vinci surgical system ensures a far more ergonomic performance for minimally invasive surgery.

Robotic surgery has some disadvantages when compared to conventional laparoscopic surgery. The main drawbacks of the da Vinci robotic surgery include a lack of tactile sensation for the surgeon, which provides a basis for tissue damage during traction, a longer learning period and an obviously high cost of the equipment (1).

ROBOTIC HEPATOPANCREATICOBILIARY SYSTEM SURGERY

Robot-Assisted Cholecystectomy

The first laparoscopic cholecystectomies were performed by Erich Mühe (Germany) in 1985 and Phillipe Mouret (France) in 1987. This procedure became the gold standard for cholecystectomy only five years later. During the following years, remarkable advancements were made in the search to bring new instruments and better imaging modalities to this field. SILS, NOTES, and finally robot-assisted laparoscopic surgery (RALS) were introduced as the latest technological developments (3).

Himpens *et al.* published their first tele-surgery laparoscopic cholecystectomy case, which was performed by the robotic system prototype in 1998 (6). Cholecystectomy has been suggested by a number of centers as the ideal starting operation for RALS (6, 7).

The issue whether RAL cholecystectomy is superior to conventional laparoscopic cholecystectomy is controversial. Comparative studies did not demonstrate any significant difference between the two procedures in terms of complications, hospitalization period and conversion to open, while RAL cholecystectomy tended to be more expensive than the latter (8). RAL cholecystectomy with da Vinci in daily routine does not seem to be practical for at least the next few years due to its longer preparation and operative time compared to conventional laparoscopic cholecystectomy (9).

Gurusamy *et al.* compared the operative time, conversion to open, total hospitalization period, and morbidity between RAL and conventional laparoscopic cholecystectomy and reported that conventional laparoscopic cholecystectomy offered significantly shorter time for instrumentation (10). However, it is not hard to predict quicker docking and shortened operative times as surgeons gain more experience in RALS. Marescaux et al. reported their average operative time for this procedure to be 108 minutes while Cadière et al. demonstrated in their series that this could be reduced to as little as 70 minutes (11, 12).

Overall experience suggested that cholecystectomy can be performed comfortably and safely via RAL. However, routine application of the robotic system in cholecystectomy does not seem to offer superior benefits compared to conventional laparoscopic cholecystectomy.

Robot-Assisted Hepatic and Pancreatic Surgery

When RAL hepatic surgery was new in application, there was a tendency towards the resection of only benign liver lesions; however, with advanced knowledge and experience in time, malignancies comprised almost 70% of the RAL hepatic surgery indications (13, 16). Although many studies indicated that the largest robotically resectable tumor diameter was 6 cm, Giulianotti et al. did not report any size limitation for resectable liver tumors in their studies (14). Hemangiomas, focal nodular hyperplasias, adenomas, hepatocellular carcinomas, primary metastases, colorectal and other metastases are among the indications for RAL hepatic surgery, while the contraindications are as in open surgery (17).

Wedge resections and segmentectomies are the most commonly reported procedures in RAL hepatic surgery; left lateral sectorectomies and right hepatectomies follow in the list (14, 18-20). Peckiam et al. recorded an average operation time of 175 and 188 minutes, respectively, in their study comparing RAL and conventional laparoscopic left lateral sectorectomy (21).

Studies comparing the blood loss in RAL hepatic surgery demonstrated that the average amount of bleeding in cirrhotic patients was 400 ml with a range of 100-1800 ml. (This was higher than in non-cirrhotic patients which varied from 50 to 280 ml with range of 5-2000 ml) (14, 16, 22). No significant difference was found between robotic and laparoscopic procedures

regarding the amount of blood loss (21).

Postoperative complications are classified as hepatic (bile leakage, transient hepatic failure, ascites, etc.), surgical (pleural effusion, wound infection, ileus, bladder injury, thoracic empyema, etc.), and general (transient ischemic attack, deep vein thrombosis, etc.) complications, bile leakage being the most commonly seen (17). Ji et al. reported lower complication rates in RAL hepatic surgery compared to laparoscopic and open surgery (7.8% vs. 10% and 12.5% respectively) (22). Yu et al. from Korea compared the surgical outcomes of 206 patients who underwent left hemihepatectomy or left lateral sectionectomy via robotic and laparoscopic liver surgery. They recorded no significant differences in perioperative outcome such as operative time, intraoperative blood loss, postoperative liver function tests, complication rate, and hospital stay between robotic and laparoscopic liver resection. However, the medical cost was higher in the robotic group (23).

Pancreatic resections are known to be the most enduring among the abdominal operations. Even highly qualified experienced centers report a 30 to 40% morbidity and 2% mortality for the conventional open surgery (24, 25). Even the studies in which the authors declared that laparoscopic surgery of this region in selected patients can be performed safely demonstrated morbidity rates of 16 to 40% (26-30).

Malignancies comprise 72.4% of the main indications for RAL pancreatic surgery (31). Reviews on robotic pancreatectomies report the average operative time for these operations to be 404 ± 102 minutes, average blood loss 328 ± 334 ml., conversion to open rate 10.6%, and a complication rate of 30.7% (31-34).

Robotic technology obviously offers advantages such as 3D high-resolution view, tremor filtering and very delicate instrumentation facilitating the surgeon's work in highly complex procedures such as pancreaticoduodenectomy (PD).

Mortality and morbidity rates of robotic PD have been shown to be similar to laparoscopic and open surgical techniques with decreased mean blood loss compared to open surgery (35, 36). To sum up, although it has not been clearly shown whether RAL hepatic and pancreatic surgery are superior to the laparoscopic technique in selected patients, authors report that the robotic technique can be performed safely in

hepatic and pancreatic surgery. More expert studies in this field are necessary to better evaluate the long term oncological results and cost analyses of RAL hepatic and pancreatic surgery (37).

ROBOTIC GASTRIC SURGERY

Current treatment of gastric cancer is gastrectomy with lymphadenectomy. Most centers prefer D_2 lymph node dissection as gold standard although some authors are still debating the issue (38, 39). The main advantage of this approach is correct staging and enhanced survival. The surgical procedure can be managed by both open and laparoscopic techniques. The first laparoscopic gastric surgery was performed by Kitano et al. in 1991 (40). A number of centers reported that laparoscopic surgery is feasible for early gastric tumors, as fairly similar results regarding the oncological principles are obtained when compared to open gastric surgery (4, 41, 42). In addition, laparoscopic surgery has been shown to offer better postoperative comfort to the patient.

Kim et al. compared groups with laparoscopic and open gastrectomy in 2010 and reported that intraoperative blood loss and hospitalization period were significantly less in the laparoscopic group while the oncological outcomes were similar (43). A recent meta-analysis evaluated 5 randomized controlled studies comparing laparoscopic and open gastrectomies, demonstrating that while the recurrence and mortality rates of the two techniques were similar, patients operated with the laparoscopic technique had less intraoperative bleeding, less complications, and earlier oral intake than the other group. Operative time in the laparoscopic group was significantly longer, although the difference declined as the surgeons' laparoscopic experience improved. The number of lymph nodes dissected was lower in the laparoscopic group; nonetheless, there was no difference between the groups with respect to 5 year survival rate (44).

Robot-assisted laparoscopic gastrectomy has been reported as a safe alternative to conventional laparoscopy or open approach for treating early gastric carcinoma. To date, however, only a limited number of published reports is available in the literature. The first successful RAL gastrectomy was reported from Japan

in 2002, and usability of the robotics in gastric surgery has risen since then (45).

Song et al. compared their first 20 and last 20 laparoscopic gastrectomies and 20 RAL gastrectomies in their study, recording average operative times of 289.5, 134.1, and 230.0 minutes, respectively. There was no conversion to open. Average numbers of dissected lymph nodes were 31.5±17.1, 42.7±14.9, and 35.3±10.5; average hospitalization period was reported to be 7.7, 6.2, and 5.7 days, respectively. In addition, Song et al. declared in this study that the learning curve of the experienced laparoscopic surgeons appeared to be shorter with robotic gastric surgery (46).

According to a recent study comparing the learning curves of conventional laparoscopic and RAL gastric surgery, laparoscopic surgery seems to have a steeper learning curve, and in fact RALS is more readily adaptable due to easier maneuvering, which enhances the surgeon's speed and productivity (47).

Minimally invasive total and subtotal gastrectomies are complex and enduring operations. Lymph node dissections must be completed appropriately especially at the stations 1, 2 and 11. Laparoscopic lymph node dissection at the stations 10 and 11 without resecting the distal pancreas is truly challenging due to the localization of the pancreas, spleen and the splenic vessels in this area. In gastric surgery, the biggest advantage of robotic surgery is the ease and reproducibility of D_2 lymphadenectomy. This is important because the application of minimally invasive surgery is limited by the complexity of performing a D_2 lymphadenectomy.

With RALS, even the minute branches of splenic vessels can be deliberately displayed and protected during spleen-preserving D_2 lymphadenectomies. Robotic instrumentation promotes the isolation of diaphragmatic crura and *en bloc* resection of the lymph nodes around the cardia. A mini laparotomy is essential to safely bring out the stomach, omentum and lymph node stations. This mini laparotomy does not deduct the advantages of laparoscopy, as the incision size is usually tolerable compared to the specimen size (47, 48, 49). The benefits of a robotic approach have been shown to be more evident in high body mass index (BMI) patients than in normal BMI patients when performing distal subtotal gastrectomy with D2

lymphadenectomy, in terms of blood loss and quality of lymphadenectomy (50). Furthermore, robot-assisted surgery for gastric cancer has been demonstrated to be safe and effective even in patients above eighty years of age (51).

ROBOTIC COLORECTAL SURGERY

Colorectal cancer is one of the most common malignancies seen in developed countries. Its current treatment is based on a multidisciplinary approach entailing surgery, chemotherapy, and radiotherapy. Surgery can be performed with open and minimal invasive methods. Laparoscopic surgery for colorectal cancer has gained acceleration since the promising results of the first laparoscopic colectomy in 1991 (52). Compared to colectomy, rectal surgery is obviously more demanding and enduring due to the localization of the rectum and the narrow anatomical structure of pelvis. In spite of numerous remarkable developments in instrumentation and imaging techniques, laparoscopic total mesorectal excision (TME) for rectal cancer in the narrow pelvis is still arduous and challenging because of the use of non-articulated laparoscopic instruments (53).

Compared to conventional laparoscopic surgery, the advantage and superiority of robotic surgery, especially in narrow areas such as the pelvis, has been shown in many studies. It is a safe and feasible method. First and foremost, the surgeon can control the stable camera delivering magnified, full HD and 3D imaging that facilitates visualization of the vital anatomical structures, which is critical in performing safe surgery. Second, robotic surgery offers a large range of motion and freedom for maneuvering even in very narrow anatomical spaces. Third, the robotic system manipulates the instruments with a tremor filter, which prevents any undesired hazard caused by human tremor. Fourth, the surgeon manipulates the ergonomic camera with foot pedals, which makes the surgeon unconstrained of camera positioning. One of the most remarkable aspect of this technology is that the robotic arms can maneuver in ways that simulate fine human movements. Instrumental wrists possess a full range of motion in 7 dimensions and an ability to rotate 540 degrees and articulate 180 degrees; thus, dissection be-

tween the visceral and the parietal fascia around the mesorectum is facilitated (54, 55). Furthermore, in case of middle and low rectal cancers, mobilization of the entire rectum is readily achieved with the advent of the longer arm of *da Vinci S* robot, which reaches the pelvic floor. These advantages cause less intraoperative bleeding, less conversion to open, less bladder dysfunction, less sexual dysfunction, and offer a shorter learning curve when compared to conventional laparoscopic surgery (56). Although only a small number of very experienced laparoscopic surgeons can go beyond the traditional borders of laparoscopic surgery, the steeper and shorter learning curve of robotic surgery could motivate more surgeons to perform complex procedures beyond these borders (57).

A number of studies in the literature have compared open and laparoscopic techniques for colon and/or rectum cancer surgery. Laparoscopic colonic resection offers superior perioperative results compared to open surgery. Its benefits include shorter hospitalization, reduced postoperative pain and quicker return to daily life (57). Results of the COST trial, which demonstrated the oncological equivalence of open and laparoscopic resection of colon cancer, were published in 2004, and since then, laparoscopic techniques in colon cancer surgery have gained popularity while also including rectal cancer patients (57, 58). In addition, the COLOR and CLASICC trials did not reveal any significant difference between open and laparoscopic surgery regarding the oncological outcomes (58). CLASICC included 268 open vs. 526 conventional laparoscopic procedures; although overall survival and local recurrence rates were similar, higher positivity of circumferential resection margin was reported for the laparoscopy group (59). Conversion to open was recorded in 143 of 488 (29.3%) colorectal surgery cases (60). In a review evaluating 4224 cases with rectal cancer, comparison of short-term outcomes of laparoscopic and open low anterior resection (LAR) revealed that the laparoscopic group had less blood loss, needed less blood transfusion and less narcotic usage, suffered less pain and achieved a quicker resumption of normal diet. However, the operative time was longer and overall expenses were greater in the laparoscopic LAR group. There was no significant difference with respect to the length of resected margins and number

of lymph nodes. Mortality and leakage rates in both groups were approximately 1-2%, and 5-year survival rates were 62-92% (61).

A three-center study on RAL-LAR with 143 rectal cancer patients found 4.9% conversion to open, average blood loss of 283 ml, average operative time of 297 minutes, average number of dissected lymph nodes of 14.1±6.5, distal surgical margin of 2.9±1.8 cm, negative radial surgical margin in 142 cases, 3-year survival rate of 97%, and anastomotic leakage of 10.5%. No isolated local recurrence was found after 17.4 months of follow-up (62). Baik et al. compared 56 RAL and 57 laparoscopic rectal cancer cases and declared that the average operative times were 109.1±45.0 minutes and 191.1±65.3 minutes, respectively. There was no conversion to open in the RAL group, while 10.5% of the laparoscopic group was converted to open. Morbidity rates were 5.4% and 19.3%, respectively, in the RAL and laparoscopy groups (63). Cho et al. compared the long-term oncologic outcomes of patients with rectal cancer who underwent either laparoscopic or robotic TME to those patients who underwent open TME. They found no differences in the oncologic outcomes between minimally invasive and open surgery within a follow-up period of 64 months (64). Hellan et al. analyzed the retrospective data of 425 patients who underwent robotic tumor-specific mesorectal excision for rectal lesions in a large multicenter study. Operative times were significantly longer and re-admission rate was higher for the obese population, with all other parameters being comparable. Ultra-low resections also had longer operative times. The authors concluded that BMI seemed to play a minor role in influencing outcomes (65).

In summary, robot-assisted surgery for rectal cancer can be carried out safely and in accordance with oncological principles. Single site dissections in a narrow space such as the pelvis would obviously obtain the best results from robotic surgery (66).

CONCLUSION

Surgeons have reported great clinical experiences with Da Vinci. Robotic surgical systems overcome some of the limitations inherent in traditional laparoscopic surgery, which could motivate more surgeons

to perform complex procedures in the future. Robotic laparoscopic abdominal surgery is safe, feasible, and its initial oncological results are similar to those obtained from traditional laparoscopic surgery; however, RALS is not to be seen as a less invasive technique compared to conventional laparoscopic surgery. In addition, with respect to the patients' benefits, RALS has not been proven to be unsurpassable. More prospective randomized studies used robotics in larger case numbers should be carried out in order to establish the favorable oncological and functional outcomes of RALS such as long-term survival, in addition to its obviously observed advantages.

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