Robot-Assisted Colorectal Surgery

Young Il Kim
Division of Colon and Rectal Surgery, Department of Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

Minimally invasive surgery for colorectal disease has now become the standard treatment in Republic of Korea. However, there are limitations to the laparoscopic approach, such as an unstable camera support, a limited range of motion, and poor ergonomics. Recent advances in technology have led to the introduction of robotic surgical systems in colorectal surgery to overcome these shortcomings.

Robot-assisted colorectal surgery has clear advantages in many aspects. Surgery involving the rectum benefits the most among colorectal diseases owing to technical difficulties in rectum dissection. The concept of robotic surgery is not different from laparoscopic surgery in that it is a minimally invasive surgery, and abundant research demonstrates comparable results from both modalities for postoperative complications, oncological outcomes, and functional outcomes. However, the cost of robot-assisted surgery limits surgeons to performing robotic surgeries in only selected cases. Improvements regarding cost-effectiveness and more convincing studies that support benefits of robotic surgery are needed to popularize robot-assisted colorectal surgery.

Introduction

Since the introduction of laparoscopic colorectal surgery in the early 1990s, minimally invasive surgery (MIS) for colorectal disease has now become the standard treatment in Republic of Korea (Korea). While the MIS approach was applied for less than 50% of colorectal cancer patients in 2008, it increased to nearly 80% in 2018 [1]. Important randomized controlled trials (RCTs) have presented evidence that laparoscopic surgery is feasible oncologically and technically [2–4]. MIS provides a faster recovery, less postoperative pain, and a reduced risk of surgical site infection compared to open surgery with comparable survival outcomes [5–7]. However, there are limitations to the laparoscopic approach, such as an unstable camera support, a limited range of motion owing to the rigid straight surgical equipment, and poor ergonomics. Constant efforts are ongoing to overcome these problems, and recent advances in technology have led to the introduction of robotic surgical systems in colorectal surgery.

The concept of modern robots first appeared in 1921 where the word “robot” was used in the play R.U.R.: Rossum’s Universal Robots by a Czech novelist Karel Capek. Robot means forced labor in the Czech language [8]. This nomenclature seems well defined in that one of the key advantages of robotic surgery is to aid surgeons during physically demanding procedures. Robotic assistance provides an immersive 3-dimensional view that the operator can control without any additional human assistance, while manipulating articulated surgical instruments for a much more versatile movement. The first robot-assisted surgery performed for colorectal disease was in 2001 with the
Da Vinci telerobotic surgical system. The feasibility of robotic colorectal surgery has been validated by many studies since then and it is now practiced worldwide for various colorectal diseases; malignancies, benign lesions and inflammatory bowel diseases (IBD). This article reviews the clinical impacts of applying robotic surgical systems to treating colorectal diseases.

**Current Evidence for Robotic Surgery in Colorectal Diseases**

Specific features of robot-assisted surgery led to variations in the extent of application of the robotic system according to the target organ. Even though the colon and rectum are both a continuation of the large bowel, each organ has a distinct anatomy and thus benefits from robot-assisted surgery differently. Also, the diverse spectrum of colorectal diseases (malignant, benign, IBD, etc.) presents dissimilar practices and indications for adapting robotic surgery.

1. **Rectal cancer**

   The most widely appreciated site for the application of robotic systems is the rectum. This is due to the anatomical characteristics of the rectum. The rectum is located in a confined compartment constituted by the sacral promontory posteriorly, genitourinary organs anteriorly, and pelvic floor muscles laterally. The bony structure of the pelvis forms a narrow canal, and this feature is particularly prominent in male patients. Operating in such environment is challenging and surgeons often experience limitations of their rigid laparoscopic instruments. Manipulating the rectum in such a narrow pelvis for traction, especially with a bulky tumor, is time consuming and causes surgeons to become exhausted. There are several studies that demonstrated a longer operation time, a worse quality of total mesorectal excision, and a higher rate of postoperative morbidities in patients with a narrow pelvis or a bulky tumor when operated on laparoscopically [9–12].

   Robot-assisted surgery provides a comfortable environment for surgeons. The fully wristed robot instruments and stable 3-dimensional camera vision that can be controlled by the operator enables a much more versatile movement in narrow spaces [13]. The difficulty of the pelvic anatomy does not result in an overly prolonged operation time, and Baek et al. reported a shorter operation time even in patients with a narrow pelvis when using a robotic system [14]. This advantage of robotic surgery for rectal cancer also leads to better preservation of urinary and sexual functions. Identifying pelvic autonomic nerves and not damaging the nerves is extremely important during total mesorectal excision for rectal cancer [15]. The nerves are at risk of transection or thermal injury during the ligation of the inferior mesenteric artery, dissection of the mesorectum at the level of the sacral promontory, and dissection of the antero-lateral planes of the rectoprostatic/rectovaginal (Denovilliers') fascia. Although a laparoscopic camera provides a more magnified vision compared to open surgery, the robotic system is equipped with an immersive 3-dimensional camera, which allows for identification and direct observation of these important structures in greater detail. Previous studies have shown higher rates of preserved physiological functions after robot-assisted rectal surgery compared to laparoscopic surgery [16].

   All of these benefits of robotic systems would not be acceptable without oncological safety. A series of RCTs from various centers worldwide, along with numerous retrospective studies over the past 20 years of clinical practice, have presented unified results of comparable survival outcomes of robot-assisted rectal cancer surgery with laparoscopic surgery (Table 1) [17–21]. Confidence from accumulated experience has led to the adaption of robotic surgery to even more complicated and advanced cases of rectal cancer [22–26].
2. Colon cancer

Surgery for colon cancer is not fundamentally different from rectal cancer in that the principle concept is to excise the mesocolon along with the draining vessels and lymphatics from the primary tumor, defined as complete mesocolic excision. This surgical objective is equivalent to TME for rectal cancer and is known to be essential for an optimal survival outcome [27,28]. However, the anatomical distinction between the colon and rectum makes surgery on the colon less challenging; nevertheless, it requires additional caution during dissection. The colon is not confined within a limited compartment, and the surgical field is much broader and more open. Basically, the whole intraperitoneal space can be used to manipulate the instruments. Therefore, the advantages of robotic surgery may not be as prominent during colon resection.

This is supported by a RCT from Park et al., which compared robotic-assisted colectomy with traditional laparoscopic-assisted colectomy in right-sided colon cancer [29]. The length of hospital-stay, postoperative morbidity, and the number of harvested lymph nodes were comparable between the two groups, but the operation time was significantly longer in the robot-assisted colectomy group (195 min versus 130 min, P<0.001). The overall medical cost was also significantly higher in the robot-assisted surgery group and there were no benefits in the long-term survival outcomes [30]. Choi et al. concluded that there were no clinical benefits of robot surgery in right-sided colon cancer that outweighs the high costs [1]. However, to date, there are not enough studies with a large sample size and statistical power to strongly contraindicate robot-assisted colectomy.

Recent technological advances in robotic systems have led to the development of single-platform robot systems since 2018 (da Vinci SP) (Fig. 1). The operator can perform reduced port surgeries more comfortably with fully wristed robotic instruments through a single-port compared to the conventional single-incision laparoscopic surgery. Single-incision laparoscopic surgery is known to be beneficial in terms of cosmetic aspects but it is usually only used for...
highly selected patients due to technical difficulties [31]. The utility of a robotic system for single-port surgery may become a safer and more practical approach for surgeons to perform colon cancer resection [32–34].

3. Ventral rectopexy

The perineal or a transabdominal approach are both available treatment modalities for pelvic organ prolapses. In particular, abdominal ventral mesh rectopexy is an effective approach for treating rectal prolapse and MIS has shown benefits of a low complication rate and recurrence rate, with improved symptoms of fecal incontinence and obstructed defecation syndrome [35–37]. The key procedures of ventral mesh rectopexy are similar to rectum resection in that the dissection of the rectum down to the rectovaginal or rectoprostatic septum is essential. Therefore, patients indicated for ventral mesh rectopexy can also benefit from robot-assisted surgery, similar to patients with rectal cancer. Theoretically, suturing the mesh to the anterior wall of the lower rectum can be performed readily with the fully wristed robotic instruments.

A RCT comparing robot-assisted ventral mesh rectopexy (RVMR) to laparoscopic ventral mesh rectopexy demonstrated no difference in operation time or postoperative complications. The RVMR group showed a trend of less residual rectocele postoperatively in terms of amount and size [38]. However, there are mixed results regarding the operation time in retrospective studies and RVMR should be applied to selected patients depending on the cost-effectiveness and surgeon compatibility [39,40].

4. Inflammatory bowel disease

Extensive studies still need to be conducted to prove the feasibility of robotic surgery in IBD patients. A retrospective study analyzed the perioperative outcomes of 108 patients with Crohn's disease who received robotic-assisted ileocolic resection and compared the results to open cases. The robot-assisted cases had a significantly shorter hospital stay by 2 days (P<0.0001) with a lower 30-day complication rate (24% versus 38%, P=0.039), but they required a mean of 60 min additional operation time (P<0.0001) [41].

Two case-matched comparison studies of robotic versus laparoscopic proctectomy for IBD patients presented similar complication rates, short-term functional results, conversion rate, and length of stay for both groups, but the robotic group had a longer operative time [42,43]. Robot-
assisted surgery can have advantages in pelvic nerve preservation during proctectomy, but further research is warranted as surgeons adapt to robotic surgery for IBDs [44].

Cost-Effectiveness of Robot-Assisted Surgery

The biggest obstacle to the nationwide adaption of robot-assisted colorectal surgery in Korea is the cost benefit ratio. Since the first approval of robot-assisted surgery in the year 2005 by the Ministry of Food and Drug Safety of Korea, robot surgery has been classified as non-reimbursable. All citizens of Korea are obligated to obtain national health insurance and essential medical services are generally covered by this national health insurance system. While robot-assisted surgery has been praised for its minimally invasive approach and shortened hospital stay, its cost-effectiveness has been considered unclear for coverage by the national health insurance system. This results in a roughly 2- to 4-fold higher operative cost for patients receiving robot-assisted surgery compared to laparoscopic surgery in Korea [45,46]. The national insurance policy differs in each country but robotic surgery is universally accepted to be more expensive compared to laparoscopic surgery (Table 2) [19,30,45–48]. This is the core issue why robot-assisted surgery, while presenting comparable postoperative outcomes and survival outcomes to laparoscopic surgery, still cannot be the standard treatment for colorectal diseases.

Conclusion

Robot-assisted colorectal surgery has clear advantages in many aspects. Surgery involving the rectum benefits the most among colorectal diseases owing to technical difficulties in rectum dissection. The fundamental concept of robotic surgery is not that different from laparoscopic surgery in that it is a minimally invasive approach, and abundant research demonstrates comparable results from both modalities for postoperative complications, oncological outcomes, and functional outcomes.

However, the cost of robot-assisted surgery limits surgeons to performing robotic surgeries in only selected cases. Currently, few patients meet the indications to justify the high costs of

| Table 2. Studies analyzing cost of robot-assisted surgery for colorectal disease |
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| Study (Ref.) | Design | Diagnosis | Operation | Study arms | Costs | P-value |
| Baek et al., 2012 [45] | Retrospective | Rectal cancer | All rectal resection (AR, LAR, ISR, APR, TPC) | Robot | $14,647 | 0.001 |
| | | | | Laparoscope | $9,978 | |
| Park et al., 2015 [46] | Prospective | Rectal cancer | LAR | Robot | $12,742 | <0.001 |
| | | | | Laparoscope | $10,101 | |
| Jayne et al., 2017 [19] | RCT | Rectal cancer | All rectal resection (AR, LAR, APR) | Robot | $13,668 | 0.02 |
| | | | | Laparoscope | $12,556 | |
| Morelli et al., 2016 [48] | Retrospective | Rectal cancer | All rectal resection (AR, LAR, ISR, APR) | Robot | Euro 12,283 | <0.001 |
| | | | | Laparoscope | Euro 7,619 | |
| Park et al., 2019 [30] | RCT | Colon cancer | Right colectomy | Robot | $12,235 | 0.013 |
| | | | | Laparoscope | $10,320 | |

AR, anterior resection; LAR, low anterior resection; ISR, intersphincteric resection; APR, abdominoperineal resection; TPC, total proctocolectomy; RCT, randomized controlled trial.
Robot-assisted surgery. Further advances in robotic surgical systems may improve the cost-effectiveness of robotic surgery and influence national insurance policies to provide a more comprehensive indication criterion for applying robot-assisted surgery in colorectal diseases.

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Conflict of Interest
No potential conflict of interest relevant to this article was reported.

ORCID iD
Young Il Kim : https://orcid.org/0000-0002-0212-9196

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