

Robotic Colorectal Surgery

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Robotic colorectal surgery has gradually been performed more with the help of the technological advantages of the da Vinci[®] system. Advanced technological advantages of the da Vinci[®] system compared with standard laparoscopic colorectal surgery have been reported. These are a stable camera platform, three-dimensional imaging, excellent ergonomics, tremor elimination, ambidextrous capability, motion scaling, and instruments with multiple degrees of freedom. However, despite these technological advantages, most studies did not report the clinical advantages of robotic colorectal surgery compared to standard laparoscopic colorectal surgery. Only one study recently implies the real benefits of robotic rectal cancer surgery. The purpose of this review article is to outline the early concerns of robotic colorectal surgery using the da Vinci[®] system, to present early clinical outcomes from the most current series, and to discuss not only the safety and the feasibility but also the real benefits of robotic colorectal surgery. Moreover, this article will comment on the possible future clinical advantages and limitations of the da Vinci[®] system in robotic colorectal surgery.

Key Words: Robotic surgery, colorectal surgery, laparoscopy, da Vinci[®] system

HISTORY OF ROBOTIC COLORECTAL SURGERY

The first robot for clinical use in general surgery was the automated endoscopic system for optimal positioning (AESOP) (Computer Motion, Santa Barbara, CA, USA). In 1994, the Food and Drug Administration (FDA) approved AESOP for clinical use as a robotic camera holder. After then, Computer Motion invented the Zeus surgical system with hand like motions. However, the use of the Zeus system is limited until now because Zeus is

currently approved by the FDA for use only as a surgical assistant but not as an operating surgeon. Meanwhile, the da Vinci[®] robotic system (Intuitive Surgical Inc., Sunnyvale, CA, USA) is the first telerobotic manipulation system approved by the FDA for intraabdominal surgery in the United States. Since then, robotic colorectal surgery was first performed in 2001.¹ Thus, robotic colorectal surgeries were performed usually using the da Vinci[®] system. In 2002, Weber et al.² reported three robotic right and sigmoid colectomies for benign disease using the da Vinci[®] robotic system. In 2003, Delaney et al.³ compared robotic assisted laparoscopic colectomy with case-matched results using standard laparoscopic approaches focusing on clinical outcomes. However, only six robotic colectomies were performed between December 2001 and April 2002 even though there were conclusions of feasibility and safety of the da Vinci[®] system. In 2004, D'Annibale et al.⁴ reported fifty three robotic colorectal surgeries from May 2001 to May 2003 and twenty two cases of malignant colorectal disease were contained. They concluded that robotic techniques could achieve the same operative and postoperative results compared to conventional laparoscopic techniques. In Germany, five robotic colorectal surgery cases were reported in 2005.⁵

The concept of robotic total mesorectal excision for rectal cancer was first reported by Pigazzi et al. in 2006.⁶ They compared short-term outcomes between robotic total mesorectal excision and laparoscopic total mesorectal excision. In that study, they concluded that robotic low anterior resection with total mesorectal excision and autonomic nerve preservation was feasible.

In the era of robotic colectomies, Rawlings et al.⁷ reported thirty consecutive robotic cases. They

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reported seventeen robotic right hemicolectomies and thirteen robotic anterior resections with the conclusion of technical feasibility of using the da Vinci[®] system. In 2007, they reported the results between robotic colectomies and laparoscopic colectomies.⁸ The comparison groups were similar.

One year later since Pigazzi et al.⁶ reported their first six robotic total mesorectal cases compared to conventional laparoscopic surgeries, they also reported a series of thirty nine consecutive unselected patients with primary rectal cancer.⁹ They concluded that robotic-assisted surgery for rectal cancer could be carried out safely.

In Asia, Baik et al.¹⁰ reported the first Asian experience of robotic total mesorectal excision for rectal cancer patients in 2007. It was performed in June 2006. Since then, they reported simultaneous robotic total mesorectal excision, total abdominal hysterectomy for rectal cancer and uterine myoma in 2007.¹¹ In that case report, they reported that simultaneous robotic surgeries were feasible and safe using the da Vinci[®] system. The case of robotic abdominoperineal resection in Asia was first performed in Hong Kong in August 2006¹² and also other types of robotic general surgeries began to be reported.^{13,14}

In 2008, Spinoglio et al.¹⁵ reported their initial first fifty cases of robotic colorectal surgeries. They compared the fifty cases of robotic resection with one hundred and sixty one cases of laparoscopic resections. Their conclusion was that robotic colon surgery was feasible and safe but a longer operating time was needed.

The first prospective randomized trial comparing robotic low anterior resection and laparoscopic low anterior resection was launched by Baik et al.¹⁶ in 2006. They reported the short-term outcome of a pilot study in 2008. Eighteen cases of robotic low anterior resection were compared with eighteen cases of laparoscopic low anterior resection. The results showed the feasibility and safety of robotic low anterior resection and better mesorectal grade in the robotic low anterior resection group even though they could not find statistical differences between the groups.

The da Vinci[®] SURGICAL SYSTEM

The da Vinci[®] surgical system is a robotic surgical system that was designed to compensate the limitations of both open and laparoscopic surgery. The da Vinci[®] surgical system consists of three separate components (Fig. 1).^{17,18} The first is the surgeon's console where the surgeon sits. The second component is a cart with four robotic arms and the third is an electronic tower holding video and air inflation equipment. The surgeon performs the surgery by manipulating the robotic controls in the console. A cart is the robot itself which performs the operation according to the signals from the first component. Thus, the robot in the da Vinci[®] surgical system is a slave robot. It has no intelligence and no ability to perform the operation by itself. A binocular camera system is attached for insertion through the laparoscopic port and pro-

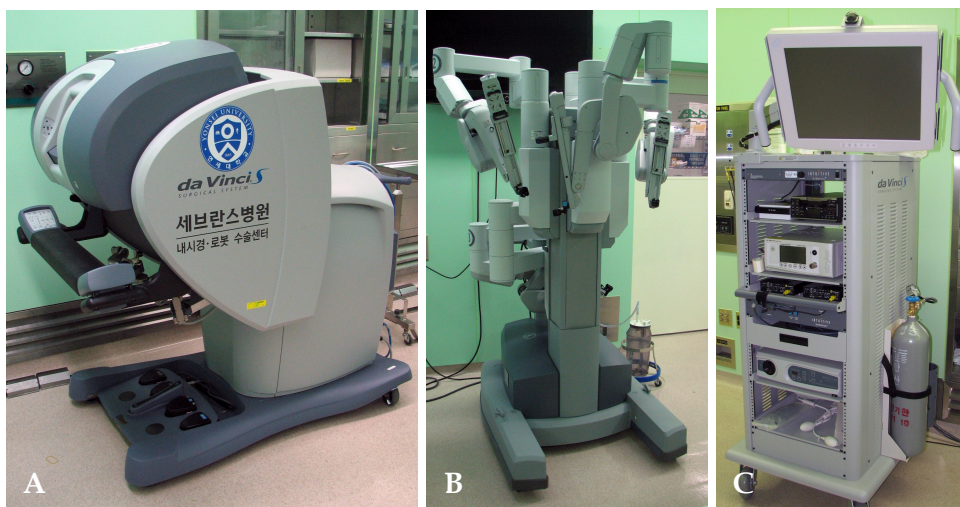


Fig. 1. Three components of the da Vinci[®] surgical system. (A) the surgeon's console, (B) a cart with robotic arms, (C) an electronic tower holding video and air inflation equipment.

vides three-dimensional images to the surgeon.

The da Vinci[®] surgical system has several core technologies compared to conventional laparoscopic instruments. The surgical view is provided to the surgeon as a true three-dimensional imaging system. Robotic interface can downscale movements (5:1-2:1), filter physiologic tremor and perform intuitive movement between the surgeon's hand and four robotic arms. The central robotic arm holds the camera and the three robotic arms hold the surgical instruments which have special articulated functions. The tips of the instruments of a robotic arm have an endowrist which has functions of seven degrees of freedom, one hundred and eighty degrees articulation and five hundred and forty degrees rotation. Its function is the most important technological advantage for precise dissection and intracorporeal suturing.

However, the robotic system has several drawbacks. The biggest drawback is a lack of both tactile sensation and tensile feedback to the surgeon. Thus, tissue damage can occur easily during traction by the robotic arm and during movement of the robotic instrument. Moreover, suture material can be cut frequently because of no tensile feedback during suturing using the robotic instrument. These technological disadvantages can be overcome by visual sense. However, experience is necessary. The second drawback is that the docking and separation procedure of a robotic cart from the patient is a time consuming procedure. Especially, delayed separation of a robotic cart can make a problematic situation sometimes when prompt open conversion is necessary to immediately control serious bleeding during an operation. The third drawback is the high cost in using the robotic system. The price of one robotic system is more than 2,000,000 US dollars. Moreover, the usual cost of disposable instruments is more than 2,000 US dollars from our experiences. These high costs are considerable issues and may be debated for cost-effectiveness.

ROBOTIC COLON SURGERY

Since Weber et al. performed the first robotic colectomies in 2001, the incidence of robotic colectomies has been growing.^{1,2} Previous clinical

studies show the feasibility and safety of robotic colectomies in the era of not only benign disease but also malignant disease.⁴

Spinoglio et al.¹⁵ compared 18 cases of robotic right hemicolectomy and 10 cases of robotic left hemicolectomy to 50 cases of laparoscopic right hemicolectomy and 73 cases of laparoscopic left hemicolectomy. In this study, the data were analyzed with 19 cases of robotic anterior rectal resection, three cases of other types of robotic operations. However, we can consider that these data are related to robotic colectomy because the main portion of this study was based on the comparison between robotic and laparoscopic colectomy. The conclusion of this study is that robotic colon surgery is feasible and safe but a longer operating time is needed. The same conclusion was reported by Delaney et al.³ before the Spinoglio et al.'s study.¹⁵ Moreover, Rawlings et al.⁸ reported that the clinical outcomes were similar between robotic and laparoscopic colectomies and the robotic cases were significantly longer for right colectomies. They commented the etiology of the longer operation time of robotic right hemicolectomy was the intracorporeal anastomosis instead of the extracorporeal anastomosis performed in standard laparoscopic colectomy. Intracorporeal anastomosis can be facilitated using the robotic system because robotic instruments have endowrist technology. However, there is no evidence that intracorporeal anastomosis is a better anastomosis procedure than extracorporeal anastomosis in the era of colectomy. According to these previous reports, we can find that the feasibility of robotic colectomy but cannot find better clinical results even though there are technological advantages of the robotic system compared to standard laparoscopic instruments. Thus, we have to consider the relationship between the technological advantages of the robotic system and the anatomic characteristics during a colectomy. One of the anatomical characteristics of a colectomy is a large surgical field. One of the technological advantages of the da Vinci[®] surgical system is excellent visualization of the operative field using the three-dimensional imaging system. A three-dimensional ten-fold magnification view can be provided to the surgeon. However, two-fold magnification view of the standard laparoscopic instrument may be enough

in performing a right hemicolectomy because the surgical field is large.

The surgeon has control over the camera by toggling a switch with the foot peddle during robotic surgery. This technological advantage provides a proper stable surgical view to the surgeon. However, a well-trained assistant can also control the laparoscopic surgical in a stable manner according to the surgeon's commands.

Two more degrees of freedom of the robotic instrument can facilitate the fine dissection of the ileocolic trunk and other vascular structures. However, easy and proper traction using standard laparoscopic instruments can compensate for the two more degrees of freedom of the robotic system during a colectomy because the surgical field is large and is not confined by any bony structure, such as the pelvis.

Beyond the short term postoperative clinical outcomes, the oncologic results should be considered. Until now, there are no previous data related to robotic colectomy. However, oncologic results may be surrogated by the post operative pathologic results.

The most important pathologic result for better survival is en-bloc and proper lymph node dissection. The COST study demonstrated no inferiority in standard laparoscopic colectomy compared with open colectomy for overall or disease-free survival and reported that the extent of resection and median number of harvested lymph nodes ($n = 12$) were comparable in the two groups.¹⁹ The easiest surgical procedure for proper resection margin and harvested lymph node is open colectomy. The COST study reports that standard laparoscopic colectomy is comparable in the era of resection margin and harvested lymph nodes.¹⁶ Thus, we can postulate that the technical advantage of the da Vinci[®] system does not contribute to a better survival benefit compared to the open or laparoscopic procedure in the era of the colectomy.

We can infer that the robotic technology is still in its infancy to obtain better clinical and oncologic outcomes of robotic colectomy compared to standard laparoscopic colectomy regarding these aspects. Therefore, many advanced technologies are necessary in the future such as tactile feedback, and a specifically designed instrument for proper traction of a redundant colon. Moreover, improve-

ment of the extracorporeal robotic arm's freedom will be essential technology for colon surgery because collisions between the robotic arms occur frequently because the traction of a redundant colon needs extracorporeal movement of the robotic arm.

ROBOTIC RECTAL SURGERY

Robotic low anterior resection was performed relatively infrequently than the other kinds of robotic colorectal surgeries.^{2,4,6-8,10,11,20,21} Rectal surgery is a more difficult surgical procedure compared to colon surgery because of the anatomical characteristics of the rectum and the pelvis. In rectal cancer surgery, total mesorectal exision (TME) is the standard technique and concept.²²⁻²⁴ The principle underlying TME is precise dissection of an avascular plane between the presacral fascia and the fascia propria of the rectum. Thus, the surgical field is limited within the pelvis during TME and TME may be more difficult when the pelvis is very narrow. The pelvic size is a direct relating factor to the quality of the resected rectum.²⁵ The quality of the resected specimen after rectal cancer surgery can be measured by a pathologist in evaluation of the mesorectal grade and the harvested lymph node number. The most important factor relating to secure rectal dissection is the mesorectal grade and it is closely related to oncologic outcome.²⁶ Thus, TME is a technically demanding procedure and obtaining an optimal surgical view is a very challenging problem. However, proper surgical view is a mandatory factor for successful rectal cancer surgery.

The da Vinci[®] surgical system provides several advantages in the narrow pelvic cavity. These are a three-dimensional view, hand tremor filtering, fine dexterity, and motion scaling. Baik et al.²⁷ reported robotic TME for rectal cancer using four robotic arms (Fig. 2). They reported that these technological advantages provided an absolute benefit compared with conventional laparoscopic surgery and were especially useful when the operative field was small and sharp precise dissection was necessary. In that study, the instruments used for dissection were a Cadiere grasper, a Precise[™] Bipolar grasper and a permanent cautery spatula.



Fig. 2. The operating theater with the da Vinci[®] system. Total mesorectal excision is performed using the da Vinci[®] system.

A Cadiere grasper provides the first traction and a Precise[™] Bipolar grasper provides the second proper traction. Moreover, shapes of these graspers can be changed to an L-shape small retractor using the endowrist function which is the core technology of the da Vinci[®] Surgical System. Thus, the robotic instrument can be used not only in proper traction of tissue but also pushing of the tissue in the narrow pelvic space. The harmonic combination of various tractions and pushing using the robotic instruments can provide an excellent surgical view during the rectal dissection. At this time, we can postulate that the technological advantages provide real benefits to the patients.

However, until now, there are few reports about robotic rectal surgery. D'Annibale et al.⁴ reported twelve robotic rectal surgeries compared to laparoscopic rectal surgeries in 2004. Their study demonstrated that robotic and laparoscopic techniques could achieve the same operative and postoperative results. Two years later, Pigazzi et al.⁶ compared robotic low anterior resection to laparoscopic low anterior resection with six robotic and laparoscopic cases, respectively. Their conclusion was the feasibility of the robotic low anterior resection. Also, they reported that short term outcomes after robotic-assisted TME for rectal cancer of consecutive 39 patients who underwent robotic low anterior resection with the conclusion of feasibility of the robotic system.⁹ These studies did not comment on the real benefits of the robotic system in rectal cancer surgery even though they described the technological advantages of the robotic

system. During the same period, Baik et al.¹⁶ launched the prospective randomized trial for evaluation of clinicopathological outcome of robotic low anterior resection compared to laparoscopic low anterior resection. They compared the operative clinical results, postoperative complications and pathologic details between 18 robotic and 18 laparoscopic low anterior resection cases. Clinical results and post-operative complications were comparable. In the pathologic results, the harvested lymph nodes, distal and proximal resection margin showed no significant statistical difference between robotic and laparoscopic low anterior resection group. However, macroscopic grading of the robotic group was complete in 17 cases and nearly complete in 1 case. This result may imply the real benefit of the robotic system even though that result did not reach the statistical difference. The ability of sharp dissection is the core advantage in which the surgeon can feel during using the robotic system. Better mesorectal grade may be the real beneficial result in robotic rectal cancer surgery regarding the technological characteristics of the robotic system. Moreover, precise dissection, which is performed using the robotic system, may be related to better autonomic nerve preservation during pelvic dissection.

Until now, most studies relating to robotic low anterior resection were their initial experiences. Also, the sample sizes were very small. Thus, much larger studies are necessary to assess not only the feasibility of the robotic system but also the real benefits of the robotic system compared to conventional laparoscopic surgery.

SUMMARY

The da Vinci[®] surgical system has been used in colorectal surgery because of several technological advantages compared to standard laparoscopic surgery. Robotic surgery has shown technical feasibility and safety in both colon and rectal surgery. The incidence of robotic colorectal surgery will be increased according to the advanced technological development of the robotic system.

The feasibility and the safety of the robotic system has been considered thus far, but a more important issue is investigation of the real benefits

of the robotic system in colorectal surgery. Therefore, future larger studies are necessary for evaluation of these aspects and those results will justify the use of robotic system despite the high cost.

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