Entirely Robot-assisted Total Colectomy/Total Proctocolectomy Compared With a Laparoscopic Approach

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Purpose: Previous robot-assisted total colectomy/total proctocolectomy (TC/TPC) has been mostly confined to completion proctectomy combined with open or laparoscopic colon dissection. This study describes an integrative method of entirely robot-assisted maintaining anatomical dissection with single docking and one-off arm placement.

Materials and Methods: Twenty patients who underwent robot-assisted TC/TPC and 36 who underwent laparoscopic procedures at the Asan Medical Center (Seoul, Korea) were enrolled.

Results: Mean operation time was ~1 hour longer in the robot-assisted than in the laparoscopic group ($P = 0.003$), due primarily to the extra time required for instrument installation and more frequent transient ileal diversion. Three patients (8%) in the laparoscopic group required conversion to open surgery, compared with none in the robot-assisted group. Rates of postoperative adverse events did not differ in the 2 groups ($P = 0.063$). Short (8 cm) ileal pouches were applied to all patients who underwent robot-assisted TPC/ileal-pouch anal anastomosis, but to one patient who underwent laparoscopic surgery. There were no discrepancies of mean daily bowel movement between patients with short and long ileal pouches 6 months after surgery ($P = 0.694$), showing 5 times per day (range: 1 to 10).

Conclusion: The advantages of the boom system and motion-sensitive table were successfully utilized to integrate anatomical dissection with the multiquadrant procedures of TC/TPC, with none of these patients requiring conversion to open surgery. Refinement of these techniques may overcome some of the technical and time-related and cost-related concerns of the robotic approach.

Key Words: total colectomy, total proctocolectomy, robot-assisted, laparoscopy, short ileal pouch

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Over the last 30 years, the laparoscopic approach has optimized many colorectal procedures and enhanced outcomes in patients undergoing minimally invasive surgery. Laparoscopic segmental excision has been expanded to include total colectomy (TC) and total proctocolectomy (TPC). Genetic screening and easy access to colonoscopy have increased the need for TC/TPC by patients with hereditary colorectal cancer (CRC), intractable inflammatory bowel diseases, and other conditions. Although several studies have shown similar short-term outcomes in patients who underwent laparoscopic and open TPC, cumulative studies have found that morbidity rates were lower and postoperative function better in patients who underwent laparoscopic TPC, despite survival outcomes being equivalent.[1,2] Furthermore, infertility rates were lower after laparoscopic TPC with ileal-pouch anal anastomosis (IPAA) than after open surgery,[3] an important advantage, as many patients who require TC/TPC are of fertile age.

Laparoscopic TC/TPC has limitations, however, including incomplete visualization and freedom of motion, because of assistant adjustments and nonarticulated instruments, respectively.[4] The use of robotic platforms in CRC surgery has increased worldwide, eliminating the drawbacks of laparoscopy. However, the use of robotic surgery in multiquadrant procedures for patients undergoing TC/TPC remains challenging.[5] Therefore, most robot-assisted TC/TPC has been restricted to completion proctectomy combined with open or laparoscopic colon dissection.[6] A limited case-series of patients undergoing entirely robot-assisted TC/TPC showed procedural ambiguities to follow.[7] The new da Vinci Xi system, in which all arms are attached to a single boom with automatic targeting and a motion-sensitive table, allows procedures to be performed on all 4 quadrants of the abdomen without re-docking the cart. The current study describes an integrative method of complete robot-assisted TC/TPC, which maintained anatomical dissection by single docking and one-off arm placement. This study compares completely robotic and laparoscopic TC/TPC, including operative and postoperative outcomes, in patients with relevant indications.

MATERIAL AND METHODS

Patients and Eligibility

Twenty patients who underwent robot-assisted TC/TPC at the Asan Medical Center (Seoul, Korea) since 2017, along with 36 patients who underwent laparoscopic procedures during the same period, were enrolled. All patients had familial adenomatous polyposis (FAP), hereditary nonpolyposis CRC (HNPCC), multiple primary CRC, intractable chronic ulcerative colitis (CUC), and other

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TABLE 1. Demographic and Clinical Characteristics of the Patients Included in This Study

Parameters	Robot-assisted TC/TPC, n = 20	Laparoscopic TC/TPC, n = 36	P*
Sex, male/female	13/7 (65/35)	21/15 (57/42)	0.777
Mean age ($M \pm SD$) (y)	48 ± 20	44 ± 18	0.492
ASA physical status I/II/III	4/16/0 (20/80/0)	5/29/2 (14/81/6)	0.494
The Charlson comorbidity index† (mean ± SD)	5.8 ± 3.7	2.7 ± 3	0.001
BMI (kg/m^2) (mean ± SD)	23.7 ± 3.8	22.7 ± 3.9	0.495
Prior abdominal surgery	5 (25)	7 (19)	0.737
Final diagnosis			
Familial adenomatous polyposis	6 (30)	14 (39)	0.571
Hereditary nonpolyposis CRC	4 (20)	1 (3)	0.05
Multiple primary CRC	8 (40)	1 (3)	0.001
Chronic ulcerative colitis	3 (15)	18 (50)	0.011
Accompanying CRC	16 (80)	11 (31)	0.001
Others‡	1 (5)	2 (6)	1

*Categorical parameters were compared using the Fisher exact test with 2-sided verification or the Pearson χ^2 test, and continuous parameters were compared using the Mann-Whitney *U* test.

†The Charlson comorbidity index predicts 1 year mortality in patients with a range of comorbid conditions.[6]

‡Including 1 patient with a giant rectal pseudocyst and bowel malrotation, and 2 patients with intractable slow-transit constipation.

ASA indicates American Society of Anesthesiologists; BMI, body mass index; CRC, colorectal cancer; TC/TPC, total colectomy/total proctocolectomy.

benign diseases (Table 1). One HNPCC patient who previously underwent lower anterior resection was included in the robot-assisted TC/TPC group; patients who underwent completion TC/TPC because of metachronous CRC were excluded. The study protocol was approved by the Institutional Review Board of Asan Medical Center (registration no: 2020-0800). All patients provided written informed consent, and the study protocol conformed to the tenets of the Declaration of Helsinki.

Operative Procedure

All patients in the robotic group underwent TPC or TC using the da Vinci Xi (Intuitive Surgical Inc., Sunnyvale, CA) with TruSystem 7000dV OR Table (GmbH+Co. KG, Saalfeld, Germany), except for the first attempt, which used a previous Si platform accompanied by dual docking with relevant port position alternately adjusted to right and left procedures. The site of the universal port was as previously described,[8] with single docking at the patient's left flank. The 4 arms fixed to the boom utility were rotated for a left-sided or right-sided procedure, alternatively, without arm repositioning. These installations efficiently enabled concurrent 4-quadrant procedures for TC/TPC without any interruption of the operative field and without instrument collisions. The patient was placed in the Trendelenburg position tilted to the right (15 to 20 degrees). Dissection was initiated as preferred by the surgeons, but usually from the main lesion site. Figure 1 shows TPC starting from the left colon to the rectum and completed for the right colon. The left-sided procedure included medial-to-lateral and upward left mesocolic mobilization through central mesocolic excision, followed by excision of the lateral peritoneal fold. Dissection was continued to total mesorectal excision (TME) with rectal resection, as in usual robot-assisted left colectomy and lower anterior resection. The mesocolon was incised along the pancreatic border, transecting the inferior mesenteric vein at the distal pancreatic border and the inferior mesenteric artery, thereby preserving the abdominal aortic plexus and pelvic autonomic nerves. The left procedure is completed with omental excision including phrenocolic, splenocolic, and gastrocolic ligaments, with the table adjusted to the 10-degree reverse Trendelenburg position as needed. Then, the 4 robotic arms were pulled out without arm repositioning and the boom was rotated 180-degree clockwise for the right colon procedure (Fig. 1C). The initial dissection started from the lateral ileocolic border upward to the hepatocolic ligament, exposing the duodenum and right Gerota's fascia. A medial incision was made to expose the superior mesocolic vessels; the ileocolic, right colic, and middle colic vessels were excised, and the vessels were ligated with hemolok by standard R0 resection. The remnant gastrocolic and hepatocolic ligaments were excised to mobilize the entire colon and rectum. A salient procedure is shown in the Supplemental video-clip (Supplemental Digital Content 1, http://links.lww.com/SLE/A260).

Four aspects of the TPC procedure required special attention: mesocolic excision along the pancreatic tail, preservation of the aortopelvic autonomic nerves, complete exposure of the duodenum, and omental excision as a consecutive bundle (Fig. 2). The resected bowel was exteriorized at the umbilicus or by an incision in the right lower quadrant (length: ~5 cm). After rectal mucosectomy, a short ileal-pouch (8 cm) was constructed using a linear cutter and IPAA was performed in all patients who underwent robot-assisted TPC. In contrast, ileorectal and short ileal-pouch rectal anastomoses were performed in all patients who underwent TC and TC with partial proctectomy, respectively. In most patients, transient diverting ileostomy was combined and restored 2 to 3 months after TPC/IPAA.

A similar method was utilized for laparoscopic TC/TPC, exclusive of port sites and surgeon positions according to the right-sided and left-sided procedure, alternatively. In addition, long ileal-pouch (15 cm) was mostly constructed in all but one of these patients in the laparoscopic approach. All robot-assisted procedures were performed by a single surgeon with experience performing > 1000 robot-assisted CRC operations. Laparoscopic TC or TPC was performed by 5 surgeons, each of whom had experience performing at least 100 laparoscopic colectomies per year for at least 5 years.

Follow-up and Statistical Evaluation

All patients were re-examined postoperatively every 3 to 6 months for the first 2 years and annually thereafter. Comorbidity was measured by the Charlson comorbidity index based on clinical conditions and associated scores.[9] General surgical complications were evaluated throughout

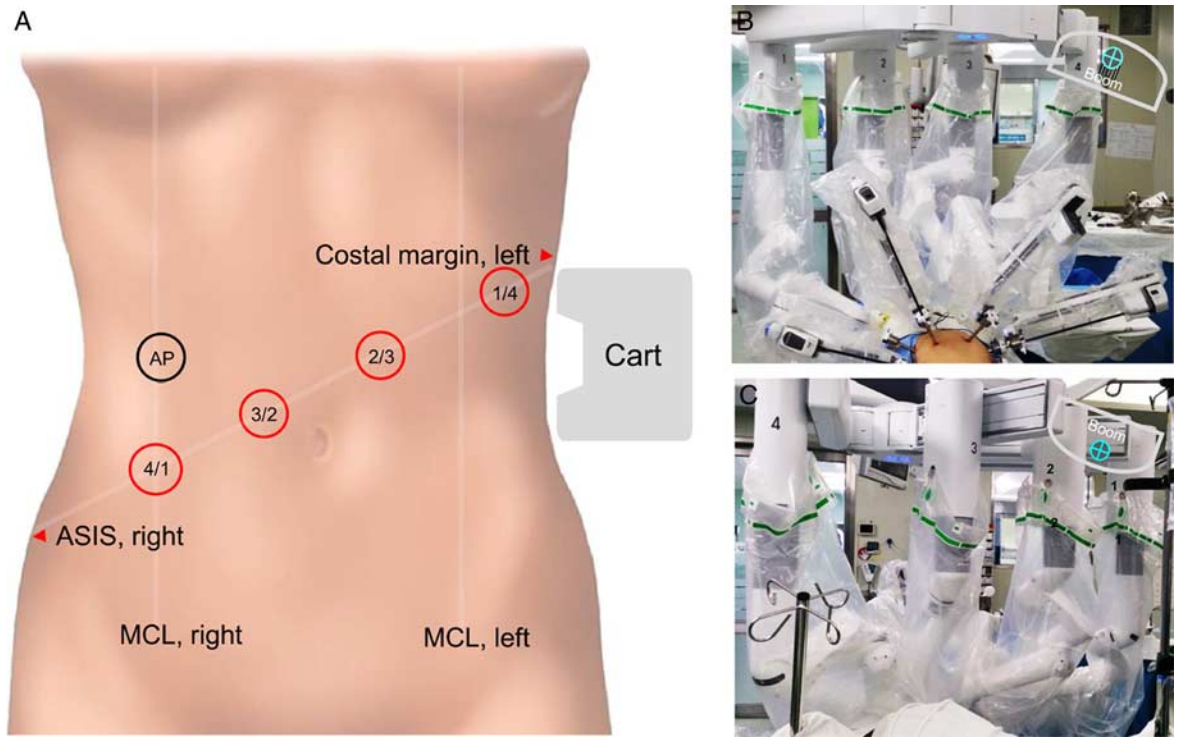

FIGURE 1. Universal port placement using da Vinci Xi system (A): a circle "1/4" 2 cm from the left MCL used as a retractor port, a circle "3/2" 1 cm above and to the right of the umbilicus used as an endoscope port, a circle "2/3" 6 to 8 cm apart from circle "1/2" used as a grasper port (also for a needle holder), and a circle "4/1" at the crossing point of the right MCL and the ASIS used as a scissor port (also for a needle holder). The number in the circle designates the arm number, that is, left column for the left procedure (B) and right column for the right procedure (C), with respective boom directions indicated as a simple diagram. The arms attached to the boom enable left to right procedures (or vice versa) without instrument replacement of each arm. ASIS indicates anterior superior iliac spine; MCL, mid-clavicular line.

follow-up. Pain on the first postoperative day was assessed using a visual analog scale. Bowel habits and incontinence were assessed 6 months after surgery. The median follow-up periods in the robot-assisted and laparoscopic TC/TPC groups were 18 months [interquartile range (IQR), 1 to 27 mo] and 19 months (IQR, 9 to 28 mo), respectively.

Physical and clinicopathologic parameters in the 2 groups were appropriately compared by cross-table analysis using the Fisher exact test with 2-sided verification or the Pearson χ^2 test for categorical variables, and unpaired Student t test or the Mann-Whitney U test for continuous variables. A 2-sided P-value of <0.05 indicated statistical significance. All analyses were performed using SPSS version 21 (SPSS Inc., Chicago, IL).

RESULTS

Patient and Clinical Characteristics

The physical and clinical characteristics of patients in the 2 groups, including indications for TC and TPC, are shown in Table 1. The main diseases consisted of medically intractable ulcerative colitis (CUC) and FAP. Accompanying CRC was significantly more frequent in the robot-assisted than in the laparoscopic group (80% vs. 31%, $P=0.001$), whereas CUC was present in 50% of the patients in the laparoscopic group ($P=0.001$). The Charlson comorbidity score was significantly higher in the robotic group, likely because of the higher percentage of patients with accompanying CRC ($P=0.001$).

Operative Parameters and Postoperative Outcomes

More than half the patients in each group underwent TPC (Table 2). Three (8%) in the laparoscopic group, compared with none in the robotic group, required conversion to open surgery and were excluded from this study. These 3 patients required conversion because of tumor invasion, abscess formation, and poor visualization because of severe colonic obstruction (n=1 each). In addition, a 60-year-old woman with HNPCC underwent simultaneous robotic hysterectomy with bilateral salpingoophorectomy. Rates of anastomosis modes (end-to-end ileorectal vs. ileal-pouch anal or ileal-pouch rectal anastomosis) did not differ in the 2 groups, whereas short ileal-pouch was significantly more frequent in the robot-assisted group (13 vs. 1, $P<0.001$). Mean operation time was ~1 hour longer in the robot-assisted than in the laparoscopic group ($P=0.003$).

Postoperative recovery, including pain score and bowel function, did not differ between the 2 approaches. Bowel movement was regulated to a mean of 2 times per day (range: 1 to 10 times per day) in all patients 6 months after surgery. Similarly, there were no discrepancies between patients with short and long ileal pouches ($P=0.694$). Anorectal function did not differ by sex, age, operation type, or FAP versus CUC.

Postoperative adverse event rates were almost equivalent in the 2 groups. None of these patients experienced anastomotic leakage, but 1 patient in the robotic group experienced an anal stricture, which was treated by balloon dilatation. All adverse events were grade I or II, and were managed

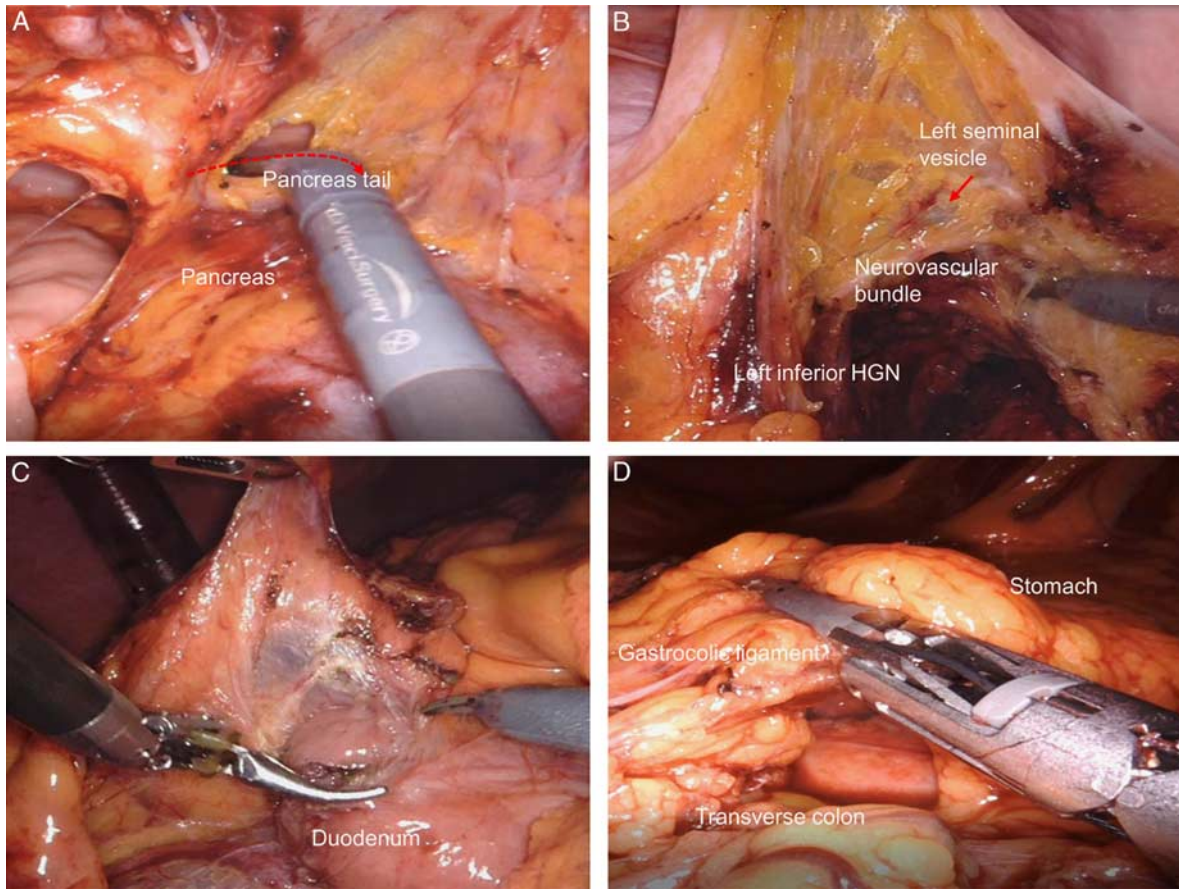

FIGURE 2. Several technical tips or cautions that may enhance safe and competent operation. A, Entrance into the lesser sac dividing the mesocolon completely along the tail part of the pancreas. B, Rectal TME preserving the pelvic autonomic nerves particularly at the neurovascular bundle to the seminal vesicle, prostate, and urinary bladder. C, Inferomedical dissection of the right colon completely exposing the third to first portions of the duodenum. D, Omental excision starting from the division of the gastrocolic ligament as a bundle. HGN indicates hypogastric nerve; TME, total mesorectal excision.

conservatively without operative interventions. No patient had a desmoid tumor, and none died within 1 month after surgery. Total hospital charges were 1.6 times greater in the robot-assisted than in the laparoscopic approach (US$23,300 vs. US $14,4000; $P < 0.001$), but most expenses in the robot-assisted group were reimbursed by private insurance.

DISCUSSION

We implemented the first attempt of robot-assisted TPC by using Si platform, evaluating its feasibility, especially the accompanying cumbersome and time-consuming procedures required for dual docking and arm repositioning. The boom-attached Xi system with adjustable table motion enabled right and left colectomy to be performed conveniently. The robotic approach has unique potential for rectal surgery because of its wide range of motion relative to constraints of the pelvis.[8] Although a previous systematic analysis showed that robot-assisted right colectomy was feasible with good oncologic outcomes, operation time and economical affordability did not show any superiority compared with those of laparoscopic one.[10] Robot-assisted left colectomy is uncommon because of the relatively low incidence and procedural complexity, as well as the absence of a technical standard. Experienced laparoscopic colorectal surgeons consider the descending and distal transverse colon, including the splenic flexure, as the most difficult areas to perform colectomy.[11] We previously reported difficulties with left colectomy that can be solved using the Xi platform.[12] These individual procedures involving the right and left colon and the rectum could be efficiently integrated into the current procedure for TC/TPC, utilizing the boom system and universal port placement.

Robot-assisted and laparoscopic procedures have been applied to various indications. A recent meta-analysis involving 1510 TME procedures found that completeness was more frequent using the robotic approach.[13] Guidelines of individual indications for TC/TPC recommend that patients with FAP undergo TPC as soon as possible after puberty to avoid malignant changes until age 40 years.[14] Because the life time risk of CRC is ~60% in patients with HNPCC, timely surgical intervention requires colonoscopic surveillance every 1 to 2 years. The 5-fold greater risk of metachronous CRC after segmental resection indicates the need for total or subtotal colectomy, along with simultaneous hysterectomy and bilateral salpingoophorectomy in women aged above 40 years.[15] TC/TPC is performed mostly in patients with intractable CUC and premalignant/malignant changes in the colon.

On the basis of the instrumental physics of the Xi platform equipped with the boom system, procedures were

TABLE 2. Relationship of Operative Components With Postoperative Outcomes, and Pathologic Features in Patients With Colorectal Cancer

Parameters	Robot-assisted TC/TPC, n = 20	Laparoscopic TC/TPC, n = 36	*P**
Operation, TC vs TPC	8 vs 12 (40 vs 60)	8 vs 28 (22 vs 78)	0.219
Anastomosis†, IRA vs IPAA/IPRA	6 vs 13 (32 vs 68)	8 vs 26 (24 vs 77)	0.535
Ileal-pouch, short (8 cm) vs long (15 cm)	13 vs 0 (100 vs 0)	1 vs 25 (4 vs 96)	< 0.001
Transient ileal diversion, yes	16 (84)	22 (65)	0.205
Conversion to open surgery	0	3 (8)	0.544
Total operative time, min, $M \pm SD$	281 ± 51	223 ± 68	0.003
Console time, min, $M \pm SD$	152 ± 41	NA	NA
Estimated blood loss, ml	54 ± 64	39 ± 51	0.345
Pain score, VAS 1 d after surgery	4 ± 2	5 ± 2	0.519
Flatus passage, d after surgery	2 ± 1	2 ± 1	0.381
Oral feeding, d after surgery	4 ± 1	4 ± 2	0.187
Hospitalization, d	10 ± 3	10 ± 7	0.807
Bowel movement/d, $M \pm SD$, ~6 m of surgery	4.6 ± 2.8	5.4 ± 2.1	0.337
Short vs long ileal-pouch (≤ 5 times/d, %)	4.6 ± 2.7 (75)	5.4 ± 2.2 (61)	0.694 (0.346)
FIS‡, $M \pm SD$, ~6 m of surgery	0.4 ± 1.1	1.8 ± 3.9	0.454
Complications§, ≤ 6 m of surgery	2 (10)	12 (33)	0.063
Ileus	1 (5)	10 (28)	0.076
Surgical site infection	0	1 (3)	1
Others‖	2 (10)	1 (3)	0.288
Mortality, ≤ 1 mo of surgery	0	0	1
AJCC stage¶, 0/I/II/III/IV	2/6/2/6/0 (13/38/13/38/0)	0/3/2/5/1 (0/27/18/46/9)	0.513
Harvested lymph nodes¶, $M \pm SD$	47 ± 28	55 ± 49	0.593

*Categorical parameters were compared using the Fisher exact test with 2-sided verification or the Pearson χ^2 test, and continuous parameters were compared using unpaired the Student t test or the Mann-Whitney U test.

†Permanent ileostomy was installed in 3 patients, that is, 1 with HNPCC and lower rectal cancer in the robot-assisted group, 1 with chronic ulcerative colitis and rectal stricture in the laparoscopic group, and 1 with FAP and multiple primary CRC in the laparoscopic group.

‡Measured using a fecal incontinence score by Jorge and Wexner.

§All surgical complications were grade I or II by the Dindo classification.

‖Including 1 patient each with deep vein thrombosis and anal stricture in the robot-assisted group, and 1 with pulmonary embolism in the laparoscopic group.

¶Confined to patients with CRC.

AJCC indicates American Joint Committee on Cancer (8th ed., 2017); CRC, colorectal cancer; FAP, familial adenomatous polyposis; HNPCC, hereditary nonpolyposis colorectal cancer; IPAA/IPRA, ileal-pouch anal anastomosis/ileal-pouch rectal anastomosis; IRA, ileorectal anastomosis; NA, not applicable; TC/TPC, total colectomy/total proctocolectomy; VAS, visual analog scale.

considered left or right sided as determined by an imaginary line connecting the left costal margin and the right anterior superior iliac spine. This dichotomous division enables wide ranges of motion through single docking for the left half, consisting of left colectomy and lower anterior resection, and for the right half, consisting of right colectomy, in contrast to previous platforms requiring dual docking. In addition, installation of a universal port takes advantage of one-off arm positioning without repositioning or collision between instruments.[8] The operative sequence starts with removal of the malignant colon, facilitating R0 resection with complete central mesocolic excision and TME at the intact fascial structure, obviating unnecessary excision of branching vessels. The key factors in robotic TC/TPC include 4 areas: the splenic flexure, periaortocaval and pelvic cavities, duodenum, and omentum. First, mesocolic excision opens the lesser sac, completely exposing the tail of the pancreas and the spleen during medial-to-lateral mobilization of the left colon, preventing accidental injury to the splenic hilum. Second, the autonomic nerves of the periaortocaval and pelvic cavities must be preserved to maintain bowel and urogenital functions, especially as many patients are in their fertile periods. Third, the duodenum must be completely exposed, from its third to first parts, during inferolateral dissection of the right colon, thereby avoiding possible injury to the duodenum and tributaries of the superior mesenteric vein. Fourth, the omentum should be consecutively divided as a bundle, grasping the epicolic and epigastric parts and preserving the right and left gastroepiploic vessels. The omentum tends to be multifolding or adherent, making it prone to unnecessary duplicate excision accompanied by bleeding.

Three (8%) patients who underwent laparoscopic surgery required conversion to open surgery, compared with none who underwent robot-assisted surgery. Universal port placement using the Xi platform with synchronous table motion further enables one-off positioning, along with the unrestricted wrist motion and surgeon-controllable 3D visualization of the robotic system. These advantages overcome issues of exposure during abdominal operations, including multiquadrant procedures. The current type of installation allowed hysterectomy with salpingoophorectomy to be combined with TC in a female HNPCC patient without additional ports or dual docking. Other studies have shown that rates of conversion are lower in patients undergoing robotic (0% to 10%) than laparoscopic (6% to 15%) colectomy.[3–5,16] The prolonged operation time required for robotic procedures may be because of the extra time required for instrument installation and more frequent transient ileal diversion, as the time at the console for the main procedure constituted a little more than half the total operation time. The percentage of malignant lesions was higher in the robot-assisted group as our public insurance covers nearly 95% of all follow-up expenses.

Pouch failure mostly ended with removal and permanent ileostomy which had been previously experienced in our open procedure because of severe pouchitis with perforation and vaginal fistula. In the current study, 8 of 12 patients with short pouches had fewer than 5 bowel movements with competent continence. Frequency of bowel movement and incontinence

scores were satisfactory in patients with both short- and long-pouches. A recent case-control study reported similar outcomes in patients with short (8 cm) and long (17 cm) pouches, as assessed using the Short Form-36 Health Survey (SF-36) and Öresland scores.[17] In addition, short pouches can be applied to patients with thickened or adherent mesocolons, maintaining ileal redundancy without multiple excision of ileal vasculature. A systematic review found that volume was not the only predictor of good function, but that other important determinants included anal sphincter function, small bowel motility, dietary intake, pelvic sepsis, bacterial overgrowth, pouch evacuation, and villous atrophy index.[18]

None of the 20 FAP patients in this study experienced a desmoid tumor during limited periods of follow-up, in contrast to 18 of 75 (24%) FAP patients who underwent open surgery previously and were followed up for a median of 76 months.[19] Minimally invasive approaches have been shown to reduce desmoid tumor rates, which are higher in women, in patients with *APC* mutation site 3' to 1440 and in patients who have undergone previous abdominal surgery.[20,21] Rates of postoperative adverse events were similar in the robotic and laparoscopic groups. Multicenter and systematic analyses have reported that rates of ileus are generally equivalent in patients undergoing TC/TPC through open and minimally invasive approaches, despite the latter entailing fewer manipulative procedures.[11,22] None of these patients experienced anastomotic leakage, except for 1 patient with anastomotic stricture, and none of these patients died within 1 month after surgery.

This study had several limitations, including the small number of patients and the relatively short follow-up periods, although the current study was primarily focused on an introduction of an integrative technique. Moreover, as this study was retrospective, there may have been bias in selection of patients for robotic and laparoscopic procedures. Concerning anastomotic method, intracorporeal pouch construction and anastomosis was not conducted in our procedures which might be, hopefully, added henceforth.

CONCLUSION

This study introduced a totally robot-assisted TC/TPC technique through universal port placement and single docking with one-off arm placement. None of these patients required conversion to open surgery. The advantages of the boom system and motion-sensitive table were utilized for integrative anatomical dissection of multiple quadrants of the abdomen. Sharing of new knowledge facilitates even faster and refined technique to overcome some of technical and cost-related concerns of the robotic approach.

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