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# Robotic Low Ligation of the Inferior Mesenteric Artery for Rectal Cancer Using the Firefly Technique

Sung Uk Bae,[1] Byung Soh Min,[2] and Nam Kyu Kim[2]

[1]Division of Colorectal Surgery, Department of Surgery, School of Medicine, Keimyung University and Dongsan Medical Center, Daegu;
[2]Division of Colorectal Surgery, Department of Surgery, Colorectal Cancer Clinic, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea.

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Corresponding author: Dr. Nam Kyu Kim,
Division of Colorectal Surgery,
Department of Surgery,
Colorectal Cancer Clinic,
Severance Hospital,
Yonsei University College of Medicine,
50-1 Yonsei-ro, Seodaemun-gu,
Seoul 120-752, Korea.
Tel: 82-2-2228-2117, Fax: 82-2-313-8289
E-mail: namkyuk@yuhs.ac

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**Purpose:** By integrating intraoperative near infrared fluorescence imaging into a robotic system, surgeons can identify the vascular anatomy in real-time with the technical advantages of robotics that is useful for meticulous lymphovascular dissection. Herein, we report our initial experience of robotic low ligation of the inferior mesenteric artery (IMA) with real-time identification of the vascular system for rectal cancer using the Firefly technique. **Materials and Methods:** The study group included 11 patients who underwent a robotic total mesorectal excision with preservation of the left colic artery for rectal cancer using the Firefly technique between July 2013 and December 2013. **Results:** The procedures included five low anterior resections and six ultra-low anterior resections with loop ileostomy. The median total operation time was 327 min (226–490). The low ligation time was 10 min (6–20), and the time interval between indocyanine green injection and division of the sigmoid artery was 5 min (2–8). The estimated blood loss was 200 mL (100–500). The median time to soft diet was 4 days (4–5), and the median length of stay was 7 days (5–9). Three patients developed postoperative complications; one patients developed anal stricture, one developed ileus, and one developed non-complicated intraabdominal fluid collection. The median total number of lymph nodes harvested was 17 (9–29). **Conclusion:** Robotic low ligation of the IMA with real-time identification of the vascular system for rectal cancer using the Firefly technique is safe and feasible. This technique can allow for precise lymph node dissection along the IMA and facilitate the identification of the left colic branch of the IMA.

**Key Words:** Robotics, colonic neoplasm, colectomy, blood supply, fluorescence, indocyanine green

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## INTRODUCTION

Anastomotic leaks are a dreaded complication in colorectal surgery and lead to increased length of stay and higher local recurrence and mortality rates.[1,2] While high ligation of inferior mesenteric artery (IMA) has some technical merits, the procedure may compromise the blood supply of the left colon, which can increase the leakage rate. Therefore, we have preserved the left colic artery (LCA) to maintain the blood supply to the proximal sigmoid colon during lymph node dissection around the IMA.

Laparoscopic lymph node dissection around the IMA with preservation of the LCA is technically demanding and requires a long procedure time because of the inherent drawbacks of laparoscopic surgery. Some technical advantages of robotic systems over traditional laparoscopy are especially useful when meticulous lymphovascular dissection around the IMA and preserving the LCA is performed.

Recently, the intraoperative near infrared fluorescence (INIF) imaging system (Firefly™, Intuitive Surgical Inc., Sunnyvale, CA, USA) installed on a robotic system was introduced and allowed surgeons to identify intravascular NIF signals in real time. The indications for the use of INIF imaging include assessment of tissue perfusion, visualization of hepatobiliary anatomy, sentinel lymph node biopsy, and visualization of vascular structures. This prospectively designed study aimed to systematically assess the possible value of fluorescence imaging in the identification of the LCA from the IMA within the mesenteric tissue and the identification of the collateral artery around the inferior mesenteric vein (IMV) and pancreas during robotic left-sided colorectal resection. Herein, we report our initial experience of robotic low ligation of the IMA with real-time identification of the vascular system for rectal cancer using the Firefly technique.

## MATERIALS AND METHODS

Between July 2008 and January 2013, the study group included 11 patients who underwent a robotic total mesorectal excision (TME) with preservation of the LCA for rectal cancer using the Firefly technique. All procedures were performed using the da Vinci Si surgical system (Intuitive Surgical, Sunnyvale, CA, USA) that incorporates a fluorescence-capable da Vinci Si HD vision system (Firefly technique).

Information regarding patient demographics and perioperative and pathologic outcomes were obtained from the Yonsei Colorectal Cancer Database and was prospectively collected. The statistical analyses were performed with IBM SPSS 20.0 software (SPSS Inc., Chicago, IL, USA).

### Robotic TME using the firefly technique

Our technique for robotic TME (i.e., the single docking dual phase technique) using the da Vinci system has been described previously.[3] The Firefly technique in this study involves the identification of the LCA around the origin of the IMA and the identification of the collateral artery near the IMV and pancreas. The lymphovascular dissection time was measured from the lymph node dissection around the IMA until the sigmoid artery was divided.

#### *Installation of the robotic system and preparation of ICG*

For bowel preparation, colonic lavage was performed the day before the operation using 4 L of Colyte and the patient was given antibiotic prophylaxis. The operation was carried out under general anesthesia with the patient in the lithotomy position. The patient was placed in the Trendelenberg position at 30° and tilted right-side-down at an angle of 10–15°. A total of five robotic ports (one for a 12 mm camera and four for 8 mm robotic ports) and one assistant port were placed (Fig. 1A). The robotic surgical cart was then placed oblique to the surgical table, and docking of the robotic ports was completed. Indocyanine green (ICG; Akorn,

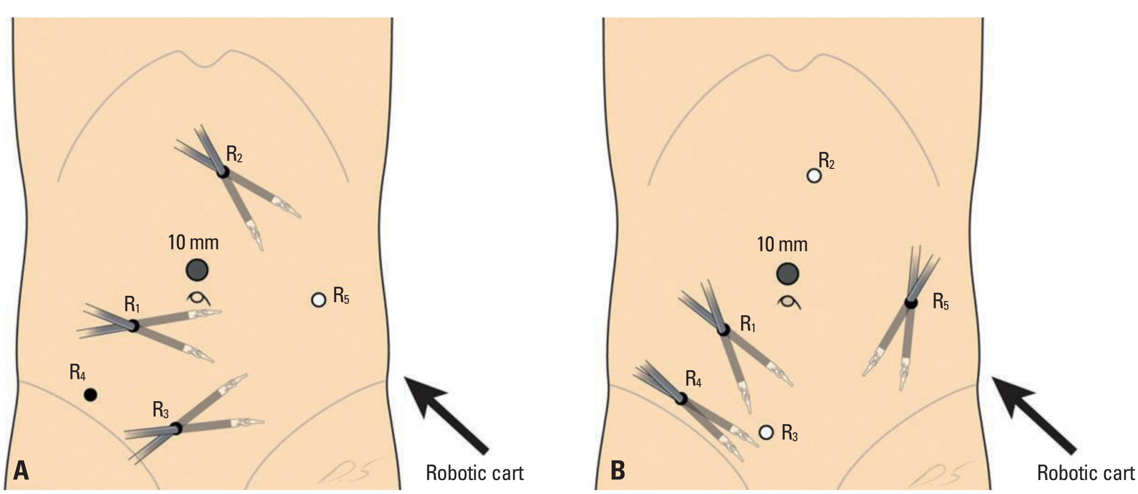


**Fig. 1.** Port placement for totally robotic rectal surgery using the single docking dual phase technique. (A) Port placement in the colonic stage. (B) Port placement in the pelvic stage.

Lake Forest, IL, USA) was prepared in a 2.5 mg/mL solution at the beginning of each case. The maximum dose that can be delivered is 2 mg/kg of body weight. In this study, 5 mg of ICG was immediately injected by an anesthesiologist prior to INIF imaging to identify the vessels. After 5 mg of ICG was delivered prior to INIF, the 12 mL of saline flush was then injected to deliver the ICG as a rapid bolus into the blood stream. The time of the ICG injections as well as the decision-making were recorded.

*INIF for low ligation of the IMA*

The peritoneum was incised at the level of the sacral promontory below the aortic bifurcation. Medial-to-lateral dissection of the sigmoid and descending colon along the avascular plane with autonomic nerve preservation and dissection of the lymph nodes around the root of the IMA were performed (Fig. 2A). ICG was injected immediately prior to INIF imaging to identify the LCA around the origin of the IMA, and the optimal point of division was then chosen by the surgeon under INIF imaging. After the lymph nodes and fatty tissue around this area were further dissected under white light (Fig. 2B and C), low ligation of the IMA that preserved the left colic branch was carried out (Fig. 2D and E). At this point, the fixed retraction on the IMA pedicle by the 3rd robotic arm and the retraction on the IMV pedicle by the assistant surgeon significantly facilitated surgical access and visualization ("y-shape") (Fig. 2D). The blood flow of the LCA was confirmed after low ligation under INIF imaging (Fig. 2F).

*INIF for high ligation of the IMV*

After assessing the anatomical blood supply around the pancreas and IMV under white light (Fig. 3A), 5 mg of ICG dye was injected prior to INIF imaging to identify the collateral artery near the IMV and pancreas. The optimal point of IMV ligation was then chosen by surgeon under INIF imaging (Fig. 3B and C). IMV ligation was performed under white light with careful skeletonization (Fig. 3D).

*Colonic mobilization and pelvic phase*

The left paracolic gutter was dissected, and the greater omentum of the transverse colon was detached. Complete splenic flexure mobilization was performed for a tension-free anastomosis. After completion of the colonic phase, the da Vinci arms were undocked and the 2nd robotic arm was moved from R2 to R5 and the 3rd robotic arm was moved from R3 to R4 (Fig. 1B). Rectal dissection using TME principles with autonomic-nerve preservation was performed. The specimen was extracted through the left lower trocar incision and end-to-end intracorporeal anastomosis was carried out with a double stapling technique. A suction drain was placed in the pelvic cavity. The anastomosis was then tested via an air-leak test.

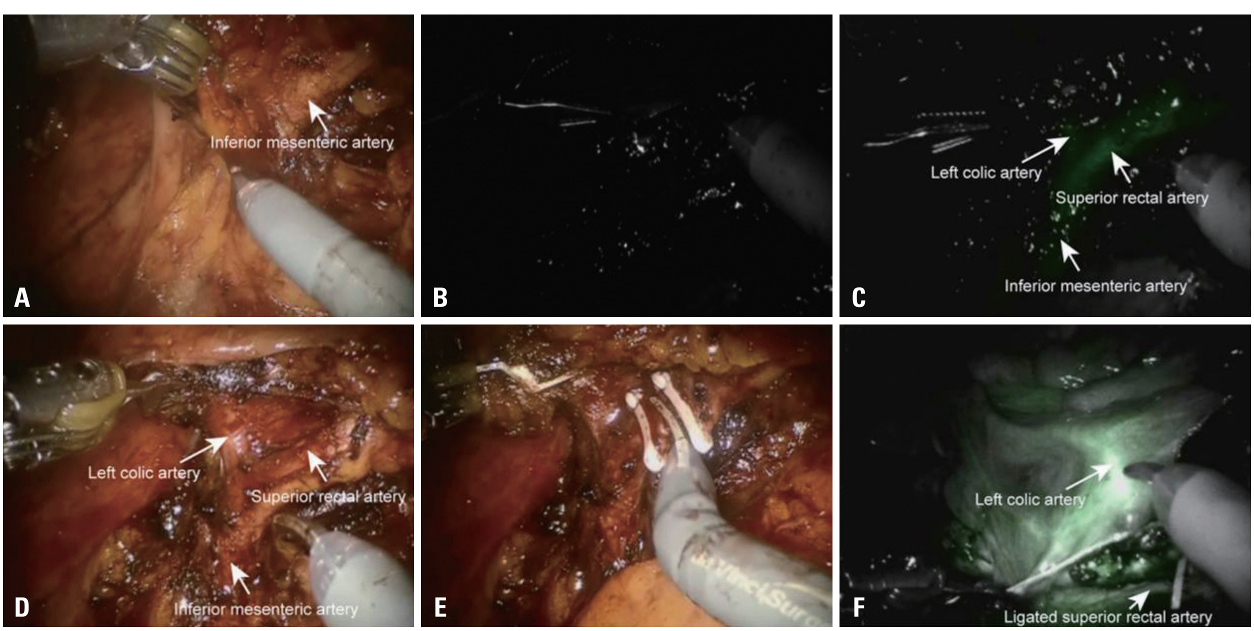


**Fig. 2.** Robotic-assisted lymph node dissection around the IMA with preservation of the LCA using the Firefly technique. (A) Dissection around the root of the IMA (white light image). (B) INIF image before visualizing the LCA by excited fluorescence. (C) INIF image of visualizing the LCA by excited fluorescence. (D) Skeletonization of the LCA and SRA from the IMA. (E) Low ligation of the IMA preserving the left colic branch. (F) Confirmation of blood flow of the LCA by INIF imaging. IMA, inferior mesenteric artery; LCA, left colic artery; INIF, intraoperative near infrared fluorescence; SRA, superior rectal artery.

## RESULTS

### Patient characteristics

The baseline demographics of the patients are tabulated in Table 1. The median age of the 11 patients was 42 years (range, 31–55), with five women and six men who had a median body mass index of 22.9 (17.6–31.2). Based on the American Society of Anesthesiologists classification of physical status, six patients were class I (54%) and five patients were class II (46%). The median tumor distance from the anal verge was 4 cm (range, 2–12). Preoperative chemoradiotherapy was performed in seven cases (73%), and a history of abdominal surgery was associated with eight cases (13%).

### Perioperative clinical outcomes

All 11 procedures were technically successful without the need for conversion to open or laparoscopic surgery (Table 2). The procedures included five (45.5%) low anterior resections, five (45.5%) ultra-low anterior resections with coloanal anastomosis, and one (9.0%) ultra-low anterior resection with intersphincteric resection. Four patients (36.4%) underwent protective defunctioning ileostomy. The median total operation time, first docking time, console time for the colonic phase, second docking time, and console time for the pelvic phase were 327 min (226–490), 5 min (4–10), 88 min (68–160), 3 min (1–7), and 70 min (40–100), respectively. The estimated blood loss was 200 mL (100–500). The median times to first flatus and soft diet were 4 days (2–5) and 4 days (4–5), respectively. The median time to the removal of urinary catheter was 4 days (2–5) and the median length of stay was 7 days (5–9). Three patients (27%) developed postoperative complications; one patient developed anastomotic stenosis, one developed paralytic ileus, and one developed intra-abdominal fluid collection. No anastomotic leakage occurred. There was no incisional or port site hernia.

### Intraoperative outcomes related to INIF imaging

There were no complications associated with ICG dye administration. During low ligation of the IMA, INIF imaging allowed surgeon to identify the left colic branch of the IMA within the mesenteric tissue. Low ligation of the IMA was performed in all patients. The median low ligation time was

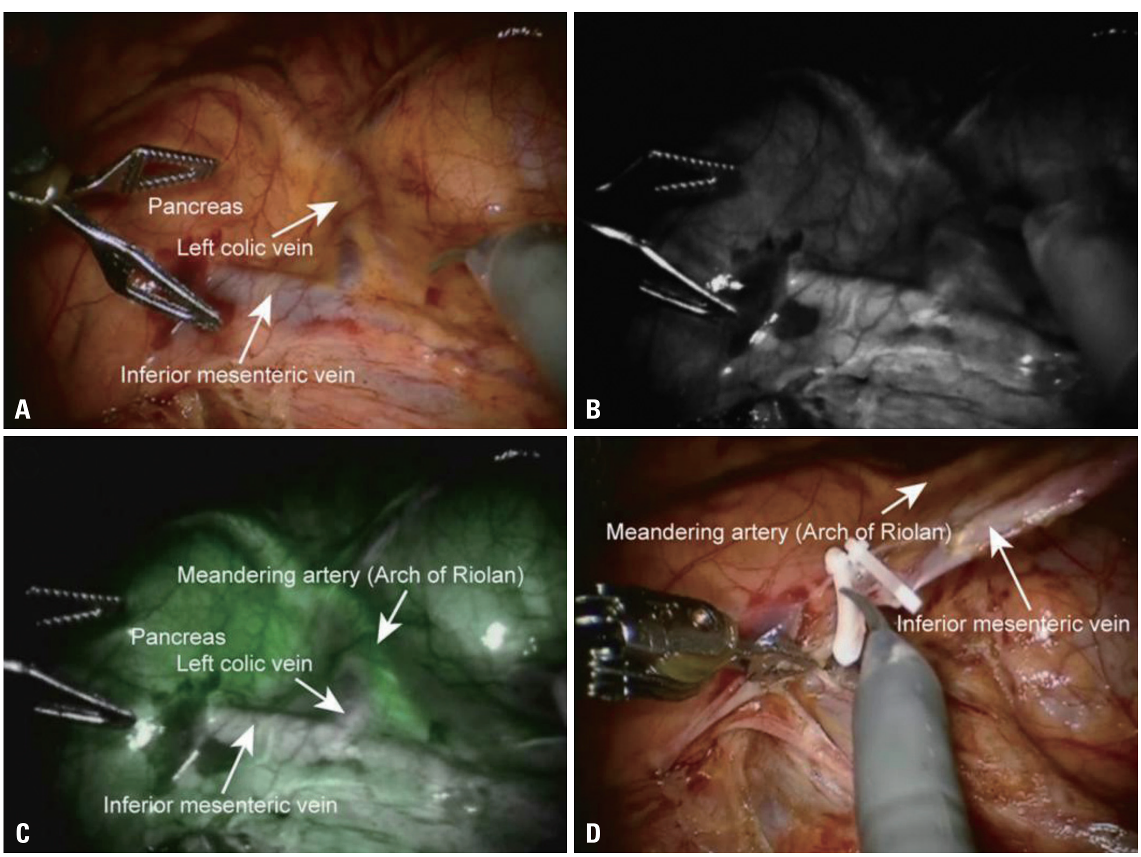


**Fig. 3.** Identification of the collateral artery near the IMV and pancreas. (A) Assessing the anatomical blood supply around the pancreas and IMV (white light image). (B) INIF imaging before visualizing the vascular flow by excited fluorescence. (C) INIF image of visualized arterial flow by excited fluorescence. (D) High ligation of the IMV with avoidance of injury to collateral vessels. IMV, inferior mesenteric vein; INIF, intraoperative near infrared fluorescence.

10 min (6–20), and the time interval between ICG injection and the division of the superior rectal artery was 5 min (2–8). During high ligation of the IMV, the collateral arteries (if present) and the IMV were clearly visualized by excited fluorescence immediately after the injection of the ICG. In all patients, the low border of the pancreas, followed by the collateral artery and the IMV, appeared in consecutive order within 5 s of the ICG injection (Fig. 3). INIF imaging allowed surgeon to assess anatomical blood flow and ligate the IMV with careful skeletonization.

**Table 1.** Patient Characteristics

| | |
|---|---|
| Patient number | 11 |
| Sex, n (%) | |
| Male | 6 (54) |
| Female | 5 (46) |
| Age (yrs), median (range) | 42 (31–55) |
| Body-mass index ($kg/m^2$), median (range) | 22.9 (17.6–31.2) |
| ASA score, n (%) | |
| 1 | |
| 2 | |
| 3 | |
| Distance from anal verge (cm), median (range) | 4 (2–12) |
| Preoperative chemoradiation, n (%) | 7 (73) |
| Preoperative CEA (ng/mL), median (range) | 1 (1–52) |
| History of abdominal surgery, n (%) | 8 (13) |

ASA, American Society of Anesthesiologists; CEA, carcinoembryonic antigen.

**Table 2.** Perioperative Outcomes

| | |
|---|---|
| Types of operations, n (%) | |
| LAR | 5 (45.5) |
| Ultra-LAR with colo-anal anastomosis | 5 (45.5) |
| Ultra-LAR with intersphincteric resection | 1 (9.0) |
| Total operation time (min), median (range) | 327 (226–490) |
| 1st docking time (min), median (range) | 5 (4–10) |
| 1st console time (min), median (range) | 88 (68–160) |
| 2nd docking time (min), median (range) | 3 (1–7) |
| 2nd console time (min), median (range) | 70 (40–100) |
| Low ligation of IMA, n (%) | 11 (100) |
| Time of low ligation, median (range) | 10 (6–20) |
| Time from ICG injection to clipping of SRA | 5 (2–8) |
| Blood loss (mL), median (range) | 200 (100–500) |
| Conversion, n (%) | 0 (0) |
| Protective diverting ileostomy, n (%) | 4 (36.4) |
| Days to 1st flatus (day), median (range) | 4 (2–5) |
| Days to 1st soft diet (day), median (range) | 4 (4–5) |
| Days to removal of the urinary catheter, median (range) | 2 (2–5) |
| Hospital stay, median (day) | 7 (5–9) |
| Morbidity within 30 days after surgery, n (%) | 3 (27) |
| Anal stricture | 1 (9) |
| Ileus | 1 (9) |
| Intraabdominal fluid collection | 1 (9) |
| Mortality, within 30 days after surgery, n (%) | 0 (0) |

LAR, low anterior resection; IMA, inferior mesenteric artery; ICG, indocyanine green; SRA, superior rectal artery.

### Postoperative pathologic outcomes

Pathologic characteristics are listed in Table 3. Five patients (45.5%) had stage 0 tumors, three (27.5%) had stage I tumors, two (18.2%) had stage II tumors, and one (9.1%) had stage III tumors. The median tumor size was 2 cm (0.5–3.0), and the total number of lymph nodes harvested was 17 (9–29). The median proximal and distal resection margins were 14 cm (6–28) and 1 cm (0.5–4), respectively. Circumferential resection margin involvement was found in one case (9%).

## DISCUSSION

Lymph node involvement is the most important prognostic factor for survival after rectal cancer surgery.[4,5] Several studies have shown the importance of thorough lymph node dissection up to the root of the IMA for accurate staging and better survival.[6,7] Kanemitsu, et al.[6] indicated that high ligation of the IMA allowed long-term survival in patients with colorectal cancer, and Kang, et al.[8] demonstrated the prognostic impact of IMA lymph node metastasis. From these oncologic considerations, many surgeons apply high ligation of the IMA (level of the root of the IMA).

Anastomotic leaks are a dreaded complication in colorec-

**Table 3.** Postoperative Pathologic Outcomes

| | |
|---|---|
| TNM stage, n (%) | |
| Stage 0 | 5 (45.5) |
| Stage I | 3 (27.3) |
| Stage II | 2 (18.2) |
| Stage III | 1 (9.1) |
| Histology, n (%) | |
| Well-differentiated | 1 (9.1) |
| Moderately-differentiated | 8 (72.7) |
| Mucinous | 1 (9.1) |
| Tumor size (cm), median (range) | 2 (0.5–3.0) |
| Total retrieved LNs, median (range) | 17 (9–29) |
| PRM (cm), median (range) | 14 (6–28) |
| DRM (cm), median (range) | 1 (0.5–4) |
| CRM positivity, n (%) | 1 (9) |

LNs, lymph nodes; PRM, proximal resection margin; DRM, distal resection margin; CRM, circumferential resection margin.

tal surgery and account for significant postoperative morbidity and mortality. Despite adhering to recommended surgical principles, such as tension-free anastomosis, low ligation (to preserve the LCA), and the use of a rectal drain (to decrease intraluminal pressure) of maintaining a good blood supply, some anastomoses do leak, especially those placed in low anterior resections. While high ligation of the IMA has some technical merits, including a better lymph node harvest and more complete mobilization of the left colon for a tension-free colorectal anastomosis, high ligation may compromise the blood supply of the left colon, which can increase the leakage rate, especially in older patients or those with atherosclerotic disease. Komen, et al.[9] compared anastomotic perfusion between a high ligation group and a low ligation group by measuring with laser Doppler flowmetry and suggested that anastomoses might benefit from better perfusion with low ligation. Hellan, et al.[10] studied the impact of fluorescence imaging on the visualization of perfusion and the subsequent change of the transaction line during left-sided robotic colorectal resections. For malignant cases, they performed high ligation of the inferior mesenteric/superior rectal or sigmoidal arteries, as determined by the location of the cancer. For benign cases, high ligation of the sigmoidal branches was performed. They reported that the location of the proximal transection was changed in one patient (1/12; 8.3%) with a benign pathology and in 15 patients (15/28; 53.6%) with malignant disease ($p$=0.0122). These results seem to be associated with hemodynamic instability of high ligation of the IMA. Furthermore, high ligation can lead to damage of the sympathetic nerves because the superior hypogastric plexus forms a dense network around the IMA at a distance of 5 cm from the aorta.[11,12] Therefore, we preserved the LCA to maintain the blood supply to the proximal sigmoid colon and preserved the autonomic nerve system during lymph node dissection around the IMA.

In laparoscopic surgery, some surgeons employ the technique of lymph node dissection around the IMA with preservation of the LCA.[13,14] However, this procedure is technically demanding and requires a long procedure time because of the inherent drawbacks of laparoscopic surgery including unstable camera platforms, instrument tremors, two-dimensional imaging, rigid instrumentation, and ergonomic discomfort for the surgeon.[14] Many surgeons prefer high ligation of the IMA laparoscopically because of its presumed advantage of more easily creating mesenteric windows. Robotic systems have technical advantages over traditional laparoscopy including increased maneuverability of the instruments, fixed stable traction by the third robotic arm, a stable camera platform, the filtering of physiologic tremors, less physician strain, a 3-dimensional high definition screen, and an increased precision and accuracy of anatomical dissection. These characteristics are especially useful in precise lymphovascular dissection around the IMA while preserving the LCA and minimizing blood loss.

INIF imaging uses laser technology to activate an ICG, an intravenously delivered agent, which rapidly binds to plasma proteins and emits an infrared signal when excited by laser light *in situ*. INIF imaging has been used clinically for a variety of procedures in other surgical fields such as for the evaluation of tissue perfusion in partial nephrectomies and reconstructive flaps, visualization of the liver and the extrahepatic biliary tree, and lymph-node mapping during oncologic resections.[15-17] Recently, an INIF imaging system installed on robotic systems has been introduced and has allowed surgeons to identify intravascular NIF signals in real time. Surgeons can quickly switch between normal visible light and INIF imaging by pressing the pedal on the surgical console. Although the average distance between the root of the IMA and that of the LCA has been estimated to be 4.0 cm,[14] there can be some variations in distance, which can make lymph node dissection around the IMA difficult until the LCA is identified. The information obtained from INIF imaging can be used to confirm the transection location of the superior rectal artery. In our study, INIF imaging allowed the surgeon to effectively identify the left colic branch of the IMA within the mesenteric tissue, and the application of this technology consumed very little time: the median low ligation time was 10 min and the time interval between ICG injection and division of the superior rectal artery was 5 min, in comparison to the overall operative time of 327 min. Additionally, we could confirm the blood flow of the LCA after low ligation by INIF (Fig. 2F).

In the present study, high ligation of the IMV near the lower border of the pancreas was routinely performed to gain more medial mobilization for tension-free colorectal anastomosis during low ligation. The collateral artery, the arc of Riolan, or a meandering mesenteric artery may cross the IMV near the lower border of the pancreas. During IMV ligation, extreme caution should be taken to prevent inadvertent ligation of the collateral artery around the IMV root, which might result in compromised blood supply to the left colon. In this study, the optimal point of IMV ligation was chosen by the surgeon under white visible light after INIF imaging. The lower border of the pancreas, the collateral artery (if present), and the IMV appeared in consecutive order within 5 s of ICG injection. It is important to observe INIF imaging in real time with the time interval between the arterial and venous flow of the ICG for anatomical differentiation.

The current study demonstrated that robotic low ligation of the IMA with real-time identification of the vascular system for rectal cancer using the Firefly technique could be safely performed. There was no morbidity associated with lymph node dissection including bleeding due to vessel injury and there were no adverse reactions to ICG dye injection as measured by vital signs, liver function tests, or serum creatinine. None of the robot-assisted procedures had to be converted to an open or laparoscopic approach. Three patients (27%) developed postoperative complications and no anastomotic leak occurred. One patient developed anastomotic stenosis 5 weeks after surgery and was treated by an endoscopic dilation. Paralytic ileus occurred in one patient and was treated with conservative management with intravenous fluids, bowel rest, and nasogastric aspiration. One patient developed intra-abdominal fluid collection and was treated with percutaneous drainage.

In this study, we presented a technique that allows for effective robotic-assisted low ligation of the IMA. Although Liang and Lai.[18] have reported good results with robotic D3 lymph node dissection with low ligation of the IMA for distal rectal cancer using a three-armed method, we used a four-armed technique, with fixed retraction on the IMA pedicle by the third robotic arm. Lifting up the IMV with the double-fenestrated grasper on the third robotic arm facilitated the development of the retroperitoneal space between the mesocolon and the retroperitoneal structures including the left ureter, gonadal vessels, lower border of the pancreas, and Gerota's fascia. Additionally, the retraction of the IMV pedicle by a assistant surgeon significantly facilitated surgical access and visualization ("y-shape").

Our study has several limitations, including its retrospective nature, small size, and lack of a control group. A randomized prospective comparative study is needed to demonstrate a significant benefit of this technique in patients with rectal cancer. From the limited information available in a single center, we can suggest the following advantages of robotic low ligation of the IMA with real-time identification of the vascular system for rectal cancer using the Firefly technique:

1. To allow safe and precise lymph node dissection along the IMA.
2. To facilitate identification of the LCA around the origin of the IMA.
3. To identify collateral artery near the IMV and pancreas.
4. To allow confirmation of blood flow of the LCA after low ligation.

In conclusion, robotic low ligation of the IMA with real-time identification of the vascular system for rectal cancer using the Firefly technique is safe and feasible. This technique can allow precise lymph node dissection along the IMA and can facilitate the identification of the left colic branch of the IMA. However, further large-scale comparative studies are needed to prove the advantages of this procedure.

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