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ORIGINAL SCIENTIFIC REPORT WITH VIDEO

Standardize the Surgical Technique and Clarify the Relevant Anatomic Concept for Complete Mobilization of Colonic Splenic Flexure Using da Vinci Xi® Robotic System

Jin-Tung Liang[1] · John Huang[1] · Tzu-Chun Chen[1]

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Abstract

Background The present study is to set up a standardized approach for complete mobilization of colonic splenic flexure using da Vinci Xi® robotic system, based on clarification of the mesenteric structures of distal transverse colon.

Methods The surgical outcomes and relevant anatomic structures of 104 consecutive patients undergoing robotic resection of primary colorectal cancer with the intent of complete mobilization of colonic splenic flexure using da Vinci Xi® robotic system were retrospectively reviewed.

Results Complete mobilization of colonic splenic flexure can be efficiently performed by the Xi® robotic system, as demonstrated by short operation time, minimal intra-operative blood loss, and few surgical complications. Xi® robotic system has overcome the drawbacks of Si® robotic system for the mobilization of colonic splenic flexure. The present study defined the following anatomic hallmarks for the colonic splenic flexure: (1) The transverse mesocolon distal to the inferior mesenteric vein adheres to the low border of pancreas by the avascular fibrous connective tissues, which have been inappropriately named as "mesenteric root"; (2) The colonic splenic flexure abuts closely to spleen with an acute angle in 78.85% (n = 82/104); (3) Only a minority of patients presented with the Riolan branch (15.38%, n = 16/104) or the Moskowitz artery (8.65%, n = 9/104).

Conclusion With increased maneuverability of Xi® robotic arms and the clarification of relevant anatomic concept, the surgical technique for the complete mobilization of colonic splenic flexure can be standardized; and the standardization of surgical technique is the first step toward the enhanced automation in the rapidly evolving robotic systems.

Introduction

Splenic flexure takedown is an important surgical step during the resection and reconstruction of left-sided colonic and rectal cancer [1, 2]. The goal of complete liberation of colonic splenic flexure is to achieve adequate oncologic resection of colon cancer and prepare adjacent colonic segments after resection of cancer to ensure a tension-free anastomosis. Therefore, this surgical procedure is frequently indicated in the standard left hemicolectomy for oncologic resection of colon cancer located on distal transverse colon, splenic flexure, descending colon or

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✉ Jin-Tung Liang
jintung@ntu.edu.tw

[1] Division of Colorectal Surgery, Department of Surgery, National Taiwan University Hospital and College of Medicine, No. 7, Chung-Shan South Road, Taipei, Taiwan, ROC

proximal sigmoid colon; anterior resection for sigmoid or upper rectal cancer [1]; and reversal of Hartmann's procedure or total mesorectal excision (TME) for low rectal cancer followed by a tension-free colorectal anastomosis, coloanal anastomosis, or even colonic J-pouch reconstruction.

During the developmental stage of laparoscopic surgery for colorectal cancer, complete takedown of the colonic splenic flexure is generally considered as challenging and technically demanding [3, 4]. However, due to the surgical endeavor of pioneering surgeons, we can currently liberate the colonic splenic flexure laparoscopically with satisfactory surgical efficiency [5–9]. Recently, more and more colorectal cancers have been operated on robotically. However, the da Vinci Si® robotic system is basically not designed for multi-quadrant abdominal dissection, as frequently required in the surgery of left-sided colon or rectal cancer [10, 11]. Therefore, some surgeons developed the dual-docking method to take down the colonic splenic flexure robotically [12], others invented robotic modular approach to improve the efficiency of splenic flexure mobilization [13, 14], and still others even adopted the hybrid technique, in which the rectal cancer was resected robotically and the colonic splenic flexure was mobilized laparoscopically. Remarkably, the da Vinci Xi® robotic system was introduced to the clinical practice in 2014, which was touted to harbor the special design for multi-quadrant surgical access; narrower arms with greater reach, and lighter slimmer endoscopes that can move between ports [15]. In this study, we aimed to testify the surgical efficiency of the da Vinci Xi® robotic system for the complete takedown of colonic splenic flexure and set up a standardized operation procedure. Simultaneously, the mesenteric anatomic structures were scrutinized under the robotic 3D images and correlated with the findings of direct examination on surgical specimens to clarify the anatomic concept related to the complete mobilization of colonic splenic flexure. We believe that such kind of rumination on the surgical anatomy would facilitate innovations of surgical technique, and even the improvements of automation for the robotic systems in the next generation.

Methods

Patient selection

A retrospective review of the prospectively enrolled data was made on the consecutive patients whose primary left-sided colon or rectal cancer was resected robotically with an intent of complete takedown of colonic splenic flexure using da Vinci Xi® robotic system at the Colorectal Division of National Taiwan University Hospital between January 2015 and December 2017. The inclusion criteria for patient selection were: (1) colonic adenocarcinoma located at the distal transverse colon, splenic flexure, descending colon, or proximal sigmoid colon requiring a standardized left hemicolectomy, which included the complete clearance of lymphatic basins over the left colic artery and the left branch of middle colic artery; (2) low rectal adenocarcinoma requiring a total mesorectal excision; (3) clinically tumor–node–metastasis (TNM) stage I–III cancers; (4) curative and elective surgery; (5) American Society of Anesthesiology (ASA) class I to III patients; (6) age between 18 and 85 years; (7) patients whose complete colorectal mobilization were conducted by the da Vinci Xi® robotic system. The patients were well informed regarding the treatment program and the informed consents were obtained from the institution review board and designated as 201205094RIC.

Surgical strategy

Docking of robotic system

The Xi robotic system was docked at the left lower flank of patients, and four trocars were then inserted obliquely, according to the Universal Port Placement Guidelines for "left lower" abdominal procedure [15]. The camera was inserted from port no. 3, the electrocauterization scissors was inserted from port no. 4, and the fenestrated graspers were inserted from port no. 1 and 2 for swap.

Operative technique

Based on our experiences gained during the prime time of laparoscopic surgery and the Si robotic system [5, 11], we routinely mobilized the colonic splenic flexure using medial-to-lateral approach, which included initial incision on the mesentery medial-to-inferior mesenteric vein (IMV), ligation of vessels in no-touch isolation fashion, subsequent medial-to-lateral extension of retroperitoneal dissection along Gerota fascia, opening of lesser sac by transection of gastrocolic ligament, dissection of mesenteric attachment of distal transverse colon on the ventral surface of pancreas, and the final separation of splenocolic ligament and lateral attachments of proximal descending colon.

The surgical procedures for the complete mobilization of the colonic splenic flexure were detailed in the attached video (file: Robotic Complete Mobilization of Colonic Splenic Flexure.wmv). Specifically, the procedure of complete mobilization of colonic splenic flexure commenced from the initial ligation of inferior mesenteric vein (IMV) and ended in the final separation of the lateral attachment of upper descending colon. We divided the

complete mobilization of the colonic splenic flexure into 3 separate steps as followed:

Step 1 Medial-to-lateral approach (Fig. 1)

We first explored the duodeno-mesenteric fossa, the IMV is identified, ligated and divided at the level of the lower border of the pancreas. The upper border of the pancreas is identified at 2 cm lateral and above the origin of the IMV. A surgical plane is developed along the ventral surface of pancreas aiming toward the lesser sac. Further dissection is continued cephalad and laterally toward the tail of the pancreas. The peritoneum covering the upper edge of pancreas is cut and the lesser sac is entered through this avascular space to expose the posterior wall of stomach followed by the lysis of additional firm adhesions to posterior wall of stomach. This step ended at the division of pancreatico-colic ligament over anterior surface of pancreas tail up to splenic hilum.

Step 2 Supracolonic or superior approach

In the condition such as TME, when complete colonic splenic flexure mobilization is only for a upcoming tension-free colorectal anastomosis, the omentum was separated from the left half of transverse colon at the fibrous avascular attachment over the colonic upper edge, and we named this procedure as the supracolonic approach (Fig. 2a). The robotic arm R1 retracted the descending colon downward. Dissection is carried out using R2 and R4, while the assistant retracted the ptotic transverse colon toward the pelvis with the atraumatic bowel grasper to ensure the dissection was within the reach of R4. Dissection starts from middle transverse colon and advanced laterally. The aim is to separate the embryonic avascular plane that exists between the greater omentum and the transverse colon. The lesser sac is entered from the above and dissection is continued toward the splenic hilum where splenocolic ligament is encountered.

In contrast, for patients with colon cancer over distal transverse colon, splenic flexure or descending colon, who require a standard left hemicolectomy, in which the left half of greater omentum was included in the extent of oncosurgery, we performed the complete mobilization of colonic splenic flexure with the superior approach (Fig. 2b), that is, the gastrocolic ligament was divided below the gastroepiploic arcade and advanced from the medial side toward splenic hilum until gastrosplenic ligament and splenocolic ligament were encountered.

Step 3 Lateral approach (Fig. 2c)

During this step, lateral colonic mobilization is commenced by dividing the lateral peritoneal reflection, which can be performed in the top-down or bottom-up fashion. To ensure the splenocolic ligament and phrenico-colic ligament can be reached by the robotic arm 4, adequate traction and countertraction provided by the patient-side assistant was very important. Dissection is continued toward the splenic flexure till the splenocolic attachment is divided. At this point, further separation of the residual fibrous tissues of pancreatico-colic ligament and reno-colic ligament was frequently required. The plane of dissection was finally joined the previous dissection developed in step 2 and resulted in the complete mobilization of colonic splenic flexure.

Evaluation of surgical outcomes

We measured the surgical outcomes using parameters including successful rate, length of operation time, blood loss, anastomotic leakage, and surgical complications. Anastomotic leakage was defined by the presence of clinical features of peritonitis and bowel contents in the drainage. We defined a successful complete mobilization colonic splenic flexure as the operation was conducted smoothly from the initial dissection of IMV to the final separation of lateral peritoneal attachment of the proximal descending colon; the length of operation time and the amount of blood loss were calculated in this operation interval accordingly. We measured the blood loss by weighing the blood-soaked gauzes and SURGICEL® Original Absorbable Hemostat, and the amount of blood in the suction bottle.

Dissection of mesenteric attachment of distal transverse colon (Fig. 3)

A dissection of the mesenteric attachment of distal transverse colon was performed from the origin of IMV to pancreas tail. The anatomic structures were scrutinized and compared between the 3D robotic images and surgical specimens.

Investigation of the vascular supply of colonic splenic flexure (Fig. 1)

Based on previous studies [16–19], the vascular arcades over the colonic splenic flexure were defined as: (1) Marginal artery of Drummond: the nearest arcades to colonic margin; (2) Riolan's arch: the meandering artery which connects the ascending branch of the left colic artery (LCA) and left branch of middle colic artery (MCA); and (3) Artery of Moskowitz: the artery which travels just above the ventral edge of pancreas, connecting the origin of MCA and the ascending branch of the LCA.

Technically, we first traced and dissected the route of the ascending branch of the LCA upward to the colonic splenic flexure. If the ascending branch of the LCA joined

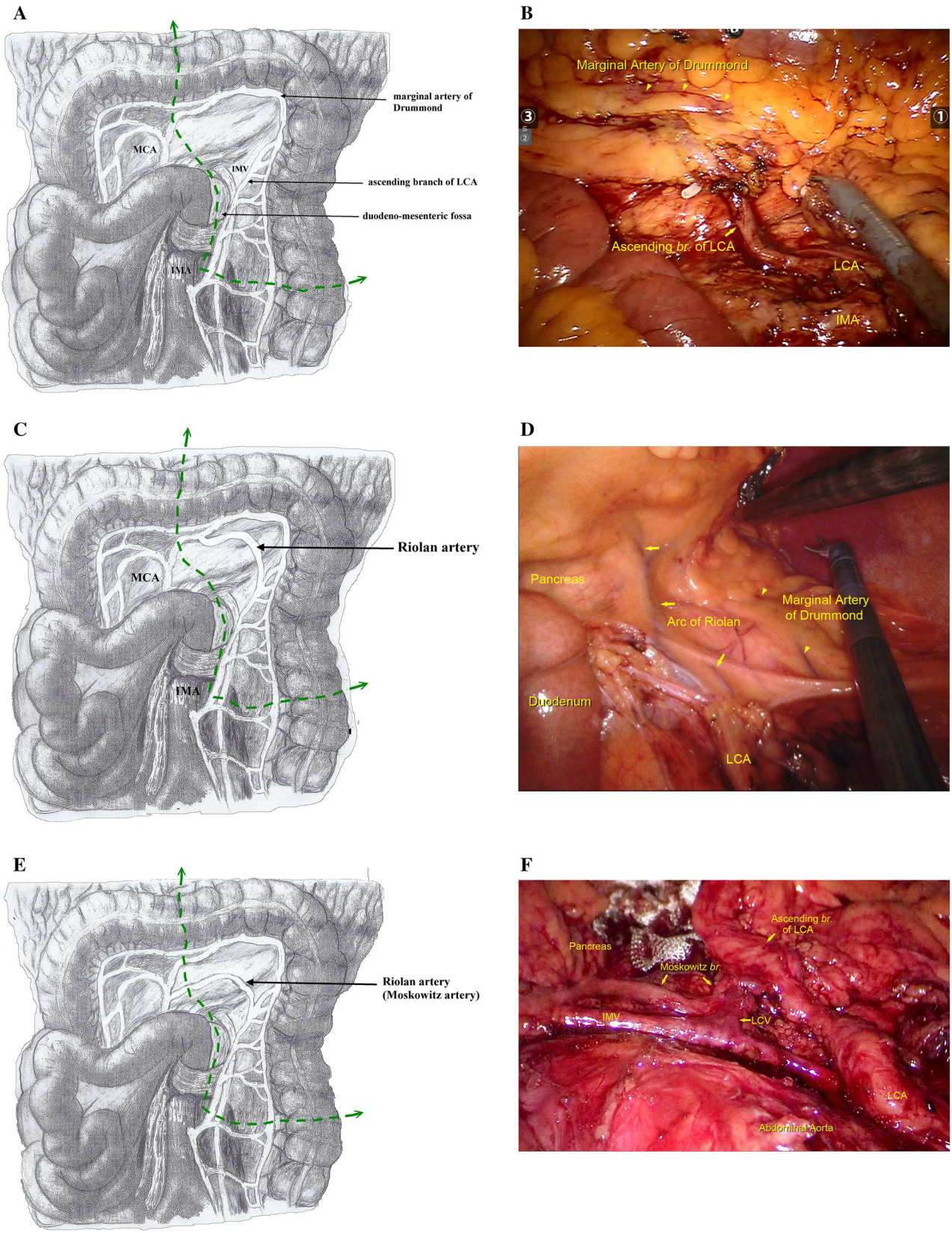

Fig. 1 Medial-to-lateral mesenteric liberation of colonic splenic flexure, with the highlight of three types of vascular arch between middle colic artery (MCA) and inferior mesenteric artery (IMA): **a**, **b** Highlight the marginal artery of Drummond; **c**, **d** Highlight Riolan arch; and **e**, **f** highlight artery of Moskowitz

marginal artery of Drummond, the dissection is halted. Otherwise, if we find the ascending branch of LCA branches in the medial zone of mesentery over the ventral surface of pancreas, we then continue to trace and explore the arterial arc toward the left branch of MCA or even toward the trunk of MCA to confirm the presence of Riolan's arch or Moskowitz artery.

Immediate after the operation, the surgical specimens were examined and correlated with the intro-operative findings in robotic 3D images.

Results

During the 2-year study period, we recruited 104 consecutive patients undergoing robotic resection of the primary colorectal cancer with the intent of complete mobilization of colonic splenic flexure (Table 1). The present case series showed that previous three-step approach [8, 13, 14] for complete mobilization of colonic splenic flexure developed in the era of laparoscopic surgery or the prime time of Si® robotic system can be successfully and highly efficiently performed in all patients using Xi® robotic system, as demonstrated by the short operation time (median: 32 min) and minimal intra-operative blood loss (median: 14 mL), with low rate of technical complications (3.8%), acceptable surgical morbidity (14.4%) and mortality (1.9%) rate. Xi® robotic system seemed to overcome the drawbacks of Si® robotic system in the mobilization of colonic splenic flexure, especially the problem of inaccessibility of robotic dissectors to the distant colonic splenic flexure.

Through the correlation of intra-operative laparoscopy to the post-operative findings of the surgical specimens, we defined the following anatomic hallmarks for the colonic splenic flexure: (1) the transverse mesocolon distal to the inferior mesenteric vein adheres to the low border of pancreas by the avascular fibrous connective tissue, which has been inappropriately named as "mesenteric root" (Fig. 3); (2) the colonic splenic flexure abuts closely to spleen with an acute angle in 78.85% (n = 82/104), and the remaining patients whose colonic splenic flexure were quite pendular, and obtuse in angle; and (3) only a minority of patients presented with the Riolan branch (15.38%, n = 16/104) and even rarer (8.65%, n = 9/104) for the presence of the Moskowitz artery (Fig. 1).

Discussion

In the present study, we successfully developed and standardized the robotic complete mobilization of colonic splenic flexure using Xi® robotic system. The technique is feasible and less time consuming and does not involve use of a laparoscope, undocking the robot or a change in patient's position. Based on the present study, we standardized the following 8 steps for complete splenic flexure mobilization: (1) ligate and transect IMA (after visualizing autonomic nerves and left ureter); (2) mobilize the mesentery of left colon from retroperitoneum along the Gerota fascia; (3) identify, ligate, divide the IMV with the preservation of Riolan arc or Moskowitz artery, if present; (4) develop and keep the dissection plane over pancreas surface; (5) enter the lesser sac through ventral edge of pancreas; (6) divide left branch of MCA and advance the dissection along the mesenteric attachment of distal transverse colon toward the splenic hilum; (7) divide gastrocolic ligament and splenocolic attachments through the supracolonic or superior approach; and (8) divide the lateral attachments. During the whole procedure, we emphasized the stepwise approach, especially in patients with

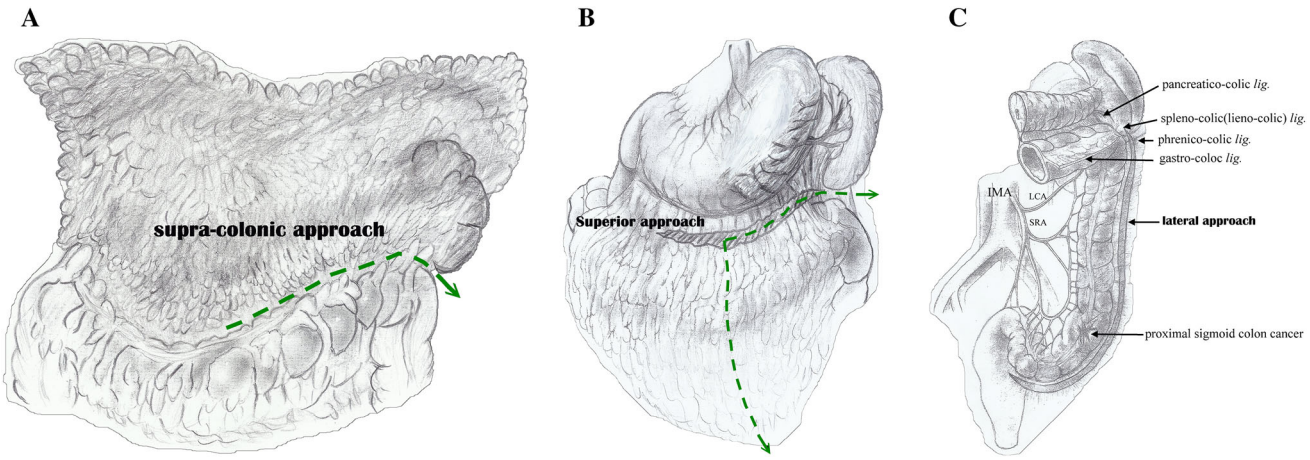

Fig. 2 Essential steps for the mobilization of colonic splenic flexure: **a** supracolonic approach; **b** superior approach; and **c** lateral approach

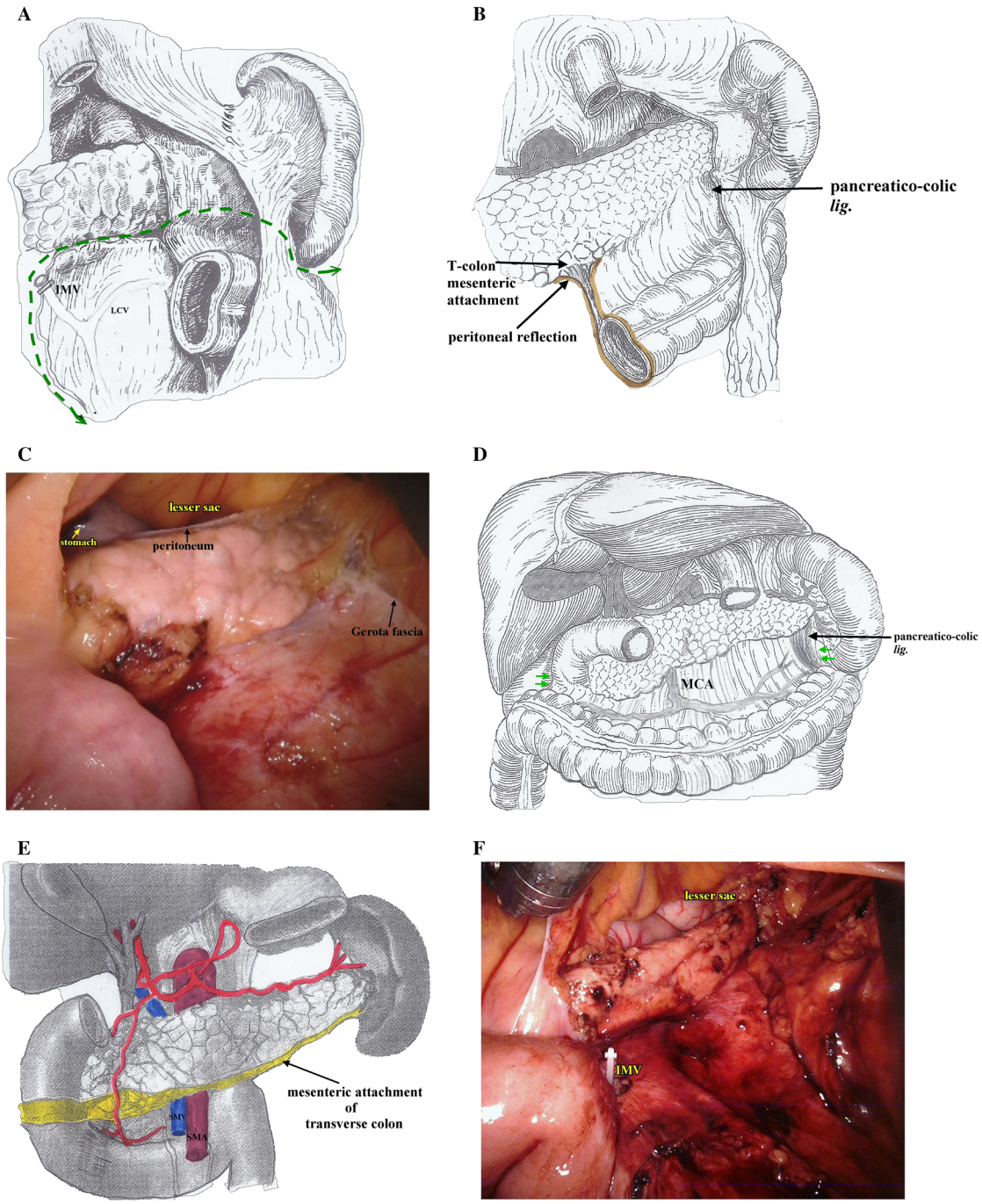

Fig. 3 **a** Medial-to-lateral mobilization of the mesentery of colonic splenic flexure commenced from the initial ligation and transection of inferior mesenteric vein, followed by dissection along the ventral surface of pancreas and Toldt's fascia plane; **b** the transverse mesocolon adheres to the low border of pancreas by the avascular fibrous connective tissue, which was inappropriately named as "mesenteric root"; **c** the lesser sac was entered by cutting the visceral peritoneum over the upper edge of the pancreas surface; **d**, **e**, **f** show the span of the left-half mesenteric attachment of transverse colon distal to IMV

extreme habitus and high colonic splenic flexure, whose splenic flexures are hard to reach by the robotic dissectors. In difficult cases, entering the lesser sac through the ventral edge of pancreas is an essential step, which provided subsequent proper traction and countertraction of distal transverse colon from the patient-side assistant to keep the operation field always within the reach of robotic arms.

Table 1 Patients undergoing complete mobilization of colonic splenic flexure using da Vinci Xi® robotic system

	n = 104	Percentage (%)
Successful rate	104	100
Operation type		
Total mesorectal excision	80	76.9
With CCRT	64	
Without CCRT	16	
Anterior Resection	10	9.7
Left hemicolectomy	14	13.4
Age (years, mean ± SD)	60.4 ± 9.8	–
Gender		
Male	64	61.5
Female	40	38.5
BMI (weight/height^2, kg/m^2)	26.4 ± 2.8	–
ASA class		–
I	28	26.9
II	52	50.0
III	24	23.1
TNM stage		
0	16	15.4
I	15	14.4
II	30	28.8
III	33	31.7
IV	10	9.7
Operation time (min), median (range)	32 (22–64)	
Blood loss (mL), median (range)	14 (10–54)	
Technical complication	4	3.8
Mesenteric bleeding	1	
Colon thermal injury	1	
Stomach thermal injury	1	
Spleen minor tearing	1	
Surgical morbidity	15	14.4
Anastomotic leakage	4	
Wound infection	5	
Post-operative ileus	3	
Urinary tract infection	2	
Cerebrovascular accident	1	
30-day mortality	2	1.9
Disability		
Stoma creation	66	63.5
Hospitalization (days), median (range)	12 (10–28)	
Re-admission	4	3.8

The present study has better clarified the relevant anatomic concept for the efficient complete mobilization of colonic splenic flexure. Complete mobilization of colonic splenic flexure involves the takedown of the "root region" of distal transverse colon. The term "mesenteric root" was coined by Treves, which corresponds to the attachment of superior mesenteric artery to the aorta [20]. In this context, the anatomic structure of so-called "mesenteric root" should be a part of mesentery with feeding and drainage vessels inside. However, based on the meticulous robotic dissection for the present 104 patients, we found that the left half of the mesentery of transverse colon hung on the low border of the pancreas through avascular fibrous tissues. Moreover, Matsuda et al. [9] has pointed out that the mesentery of the transverse and descending colon is anatomically and embryologically a continuous sheet, which rotates and partially fuses to each other during development. Therefore, the term "mesenteric root" of the distal transverse colon is misnamed; the so-called mesenteric root of distal transverse colon is actually neither mesentery nor root in structure. Remarkably, the mesocolon of distal transverse colon goes transversally from the right angle in front of the pancreas and then, at the aortic level, turns down in the direction of the IMA; the parts of so-called mesenteric root of transverse colon are in fact adherences that we can sharply cut without bleeding.

On the other hand, this observational study showed that the Moskowitz artery (8.65%) and Riolan arc (15.38%) are found in a small yet significant part of the population. The proximity of such meandering vessels to the ventral surface of the pancreas might cause intra-operative bleeding and increase the risk of a colorectal anastomotic leak. Awareness and respect of these inconstant arteries through the 3D high-definition robotic images could be essential for accurate and safe surgery in this area.

In conclusion, the art of surgery is a never-ending learning process, with the surgeons incorporating new concepts and techniques to standard procedures in a consistent fashion. With the advances in understanding of the mesenteric structures of colonic splenic flexure and the maximized maneuverability of the robotic arms in Xi® robotic system, the surgical technique of complete mobilization of colonic splenic flexure can currently be efficiently performed and standardized. Standardization of the surgical technique is the essential step toward the futuristic robotic systems with artificial general intelligence.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Marsden MR, Conti JA, Zeidan S et al (2012) The selective use of splenic flexure mobilization is safe in both laparoscopic and open anterior resections. Colorectal Dis 14:1255–1261
2. Brennan DJ, Moynagh M, Brannigan AE et al (2007) Routine mobilization of the splenic flexure is not necessary during anterior resection for rectal cancer. Dis Colon Rectum 50:302–307
3. Jamali FR, Soweid AM, Dimassi H et al (2008) Evaluating the degree of difficulty of laparoscopic colorectal surgery. Arch Surg 143:762–767
4. Akiyoshi T, Kuroyanagi H, Oya M et al (2010) Factors affecting difficulty of laparoscopic surgery for left-sided colon cancer. Surg Endosc 24:2749–2754
5. Liang JT, Lee PH (2005) Laparoscopic medial-to-lateral approach for the curative left hemicolectomy. Dis Colon Rectum 48:2142–2143
6. Okuda J, Yamamoto M, Tanaka K et al (2016) Laparoscopic resection of transverse colon cancer at splenic flexure: technical aspects and results. Updates Surg 68:71–75
7. Benseler V, Hornung M, Iesalnieks I et al (2012) Different approaches for complete mobilization of the splenic flexure during laparoscopic rectal cancer resection. Int J Colorectal Dis 27:1521–1529
8. Matsuda T et al (2015) A 3-step method for laparoscopic mobilization of the splenic flexure. Ann Surg Oncol 22(Suppl 3):S335. https://doi.org/10.1245/s10434-015-4637-6
9. Matsuda T et al (2017) Anatomical and embryological perspectives in laparoscopic complete mesocoloic excision of splenic flexure cancers. Surg Endosc. https://doi.org/10.1007/s00464-017-5792-6
10. Koh DC, Tsang CB, Kim SH (2011) A new application of the four-arm standard da Vinci surgical system: totally robotic-assisted left-sided colon or rectal resection. Surg Endosc 25:1945–1952
11. Liang JT (2014) Surgical technique of robotic D3 lymph node dissection around the inferior mesenteric artery with preservation of the left colic artery and autonomic nerves for the treatment of distal rectal cancer. Surg Endosc 28:1727–1733
12. Bae SU, Baek SJ, Hur H et al (2015) Robotic left colon cancer resection: a dual docking technique that maximizes splenic flexure mobilization. Surg Endosc 29:1303–1309
13. Isik O, Benlice C, Gorgun E (2017) A novel approach for robotic mobilization of the splenic flexure. Tech Coloproctol 21:53–57
14. Ahmed J, Kuzu MA, Figueiredo N et al (2016) Three-step standardized approach for complete mobilization of the splenic flexure during robotic rectal cancer surgery. Colorectal Dis 18:O171–O174
15. Morelli L, Guadagni S, Di Franco G et al (2015) Use of the new Da Vinci Xi during robotic rectal resection for cancer: technical considerations and early experience. Int J Colorectal Dis 30:1281–1283
16. Lange JF, Komen N, Akkerman G, Nout E, Horstmanshoff H, Schlesinger F, Bonjer J, Kleinrensink GJ (2007) Riolan's arch: confusing, misnomer, and obsolete A literature survey of the connection(s) between the superior and inferior mesenteric arteries. Am J Surg 193:742–748
17. Garcia-Granero A, Sánchez-Guillén L, Carreño O et al (2017) Importance of the Moskowitz artery in the laparoscopic medial approach to splenic flexure mobilization: a cadaveric study. Tech Coloproctol 21:567–572
18. van Gulik TM, Schoots I (2005) Anastomosis of Riolan revisited: the meandering mesenteric artery. Arch Surg 140:1225–1229
19. Toh JWT, Matthews R, Kim SH (2018) Arc of riolan-preserving splenic flexure takedown during anterior resection: potentially critical to prevent acute anastomotic ischemia. Dis Colon Rectum 61:411–414
20. Coffey JC, O'Leary DP (2016) The mesentery: structure, function, and role in disease. Lancet Gastroenterol Hepatol 1:238–247