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RESEARCH

Predictors of difficulty in robotic splenic flexure mobilization during rectal cancer surgery

Yusuke Yamaoka[1] · Akio Shiomi[1] · Hiroyasu Kagawa[1] · Hitoshi Hino[1] · Shoichi Manabe[1] · Yusuke Tanaka[1] · Shunsuke Kasai[1] · Tetsushi Ishiguro[1] · Akifumi Notsu[2]

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Abstract

Purpose In surgery for rectal cancer, splenic flexure mobilization is sometimes necessary to ensure a tension-free colorectal anastomosis with adequate blood supply. Splenic flexure mobilization is regarded as a challenging and risky maneuver, but there are no clear indicators of its difficulty in rectal cancer surgery. This study evaluated the impact of clinical and anatomical factors, including splenic flexure height measured qualitatively on the basis of vertebral level using computed tomography, on the difficulty of splenic flexure mobilization during rectal cancer surgery.

Methods The enrolled patients underwent robotic splenic flexure mobilization during rectal surgery for primary rectal cancer at Shizuoka Cancer Center in Japan between December 2011 and March 2022. All patients were scheduled to undergo splenic flexure mobilization preoperatively, and all procedures were carried out following a standardized approach. Linear regression analysis was conducted to determine the clinical and anatomical factors significantly influencing the operative time of the abdominal phase, which is defined as the duration from lymph node dissection around the inferior mesenteric artery to the mobilization of the sigmoid and descending colon, including the splenic flexure.

Results The median operative time for the abdominal phase was 88 min (range, 39–179 min). Univariate analysis revealed that the following variables were significantly correlated with a prolonged abdominal phase: higher body mass index, larger visceral fat area, and higher splenic flexure. In a multiple linear regression analysis, only higher splenic flexure remained significantly associated with a longer abdominal phase ($p < 0.01$).

Conclusions Splenic flexure height measured on the basis of vertebral level using computed tomography may be useful for predicting the difficulty of robotic splenic flexure mobilization in surgery for rectal cancer.

Keywords Splenic flexure mobilization · Robotic surgery · Surgical difficulty · Operative time

Introduction

In rectal cancer surgery, if the colon on the oral side of the tumor is characterized by multiple diverticula, wall thickening due to tumor stenosis, or microscopically impaired blood flow due to preoperative radiotherapy, splenic flexure mobilization (SFM) is required to ensure a tension-free colorectal anastomosis with adequate blood supply [1]. SFM is considered to be a challenging and risky maneuver because it extends the operative time by 20–70 min [1–3], and serious complications such as pancreatic or splenic injury can occur [4, 5]. Although the anatomical position of the splenic flexure is considered to be related to the difficulty of SFM [4, 6], the clinical and anatomical factors predicting this difficulty remain unclear. In part, this is because only a few studies have identified a practical and straightforward indicator of the anatomical position of the splenic flexure. Meecham et al. reported a simple and highly reproducible method for qualitatively assessing splenic flexure height based on vertebral level using computed tomography (CT) [7]. In this study, we examined how splenic flexure height, assessed using that method, along with other clinical and

✉ Yusuke Yamaoka
yamaoka.yusuke@gmail.com

[1] Division of Colon and Rectal Surgery, Shizuoka Cancer Center, 1007 Shimonagakubo, Nagaizumi-Cho, Sunto-Gun, Shizuoka 411-8777, Japan

[2] Clinical Research Center, Shizuoka Cancer Center, 1007 Shimonagakubo, Nagaizumi-Cho, Sunto-Gun, Shizuoka 411-8777, Japan

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anatomical factors, affected the difficulty of SFM in robotic rectal cancer surgery.

Materials and methods

Patient selection

This study included patients undergoing robotic SFM as part of rectal surgery for primary rectal cancer at Shizuoka Cancer Center in Japan between December 2011 and March 2022. Every operation was performed by one of three expert surgeons, and all patients were scheduled to undergo SFM preoperatively. The exclusion criteria were preoperative CT not performed at our institution, lack of data on operative time details, double cancer, paraaortic lymph node dissection, and a history of upper abdominal surgeries such as esophagectomy, gastrectomy, or pancreatectomy. Robotic surgery was indicated for patients with rectal adenocarcinoma at clinical stages 0–IV, while the indication for SFM in surgery for rectal cancer was intersphincteric resection, preoperative chemoradiotherapy, multiple sigmoid diverticulum, or obstructive colitis. Patient characteristics, as well as surgical and pathological findings, were prospectively recorded in a database. Patients were staged according to the tumor node metastasis (TNM) classification [8]. The grades of postoperative complications were evaluated on the basis of the Clavien–Dindo classification [9]. The operative time was measured from the initial skin incision to final skin closure and included the console time, defined as the period during which the surgeon performs the procedure using the robotic system, and is divided into the abdominal and pelvic phases. The operative time for the abdominal phase was defined as the interval from the initial mesenteric incision during the medial approach to the completion of mobilization of the sigmoid and descending colon, including the duration required for lymph node dissection around the inferior mesenteric artery and mobilization of the splenic flexure, while the operative time for the pelvic phase was defined as the duration required for rectal mobilization [10]. Both times were prospectively recorded intraoperatively. The primary outcome of this study was the operative time of the abdominal phase. The incidences of complications related to SFM, such as pancreatic or splenic injury, were also evaluated. The institutional review board of Shizuoka Cancer Center Hospital granted approval for data collection and analysis (institutional code J2022-58–2022-1–3).

Measurement of splenic flexure height on CT

Splenic flexure height was measured on the basis of vertebral level using CT, as previously reported [7, 8]. Dedicated software was utilized to analyze axial and coronal images with a slice thickness of 5 mm (SYNAPSE version 4.1; Fujifilm Medical Systems, and FUJIFILM Corporation, Tokyo, Japan). CT scanning was conducted in the supine position during deep inspiration. On an axial image, the splenic flexure was identified as the highest and most lateral portion of the transverse colon in relation to the splenic hilum. The vertebral level corresponding to the splenic flexure was identified on a coronal image. Each vertebra was segmented into three distinct sections: the higher half of the body, lower half of the body, and intervertebral disc (Fig. 1). The height of each vertebra was assigned an ordinal value ranging from 1 (higher half of the ninth thoracic vertebra) to 17 (lower half of the second lumbar vertebra) (Fig. 2). Figure 3 shows an example: white arrows indicate the splenic flexure in the axial and coronal views, and the vertebral level corresponding to the splenic flexure was 13 (superior half of the first lumbar vertebra). All measurements were conducted by a single observer (Y.Y.), who was unaware of the surgical outcomes at the time of measurement. To evaluate interobserver variability, a second observer (T.I.) independently performed the same measurements for all patients. Data on each splenic flexure height and the time taken to measure it were compared between observers.

Visceral fat area measurement

VFA was assessed using cross-sectional CT scans taken at the umbilical level and analyzed with specialized software (SYNAPSE VINCENT, version 4.6; Fujifilm Medical Systems, FUJIFILM Corporation). Visceral adipose tissue was distinguished by setting the attenuation range between −50 and −200 Hounsfield units. The software automatically identified the visceral fat region through contour tracing and calculated the VFA.

Surgical technique

All surgeries were conducted using either the da Vinci Si or da Vinci Xi platform (Intuitive Surgical, Sunnyvale, CA); da Vinci Si was used from 2011 to 2018, and da Vinci Xi has been used since 2017. For each platform, trocar placement in the abdominal phase is shown in Fig. 4. All procedures

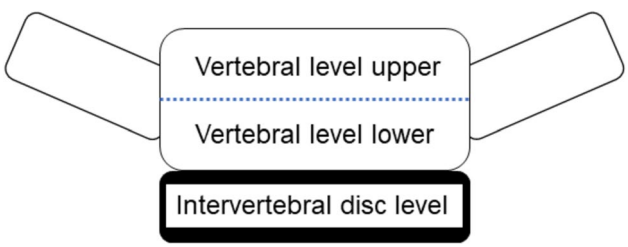

Fig. 1 Division of each vertebra

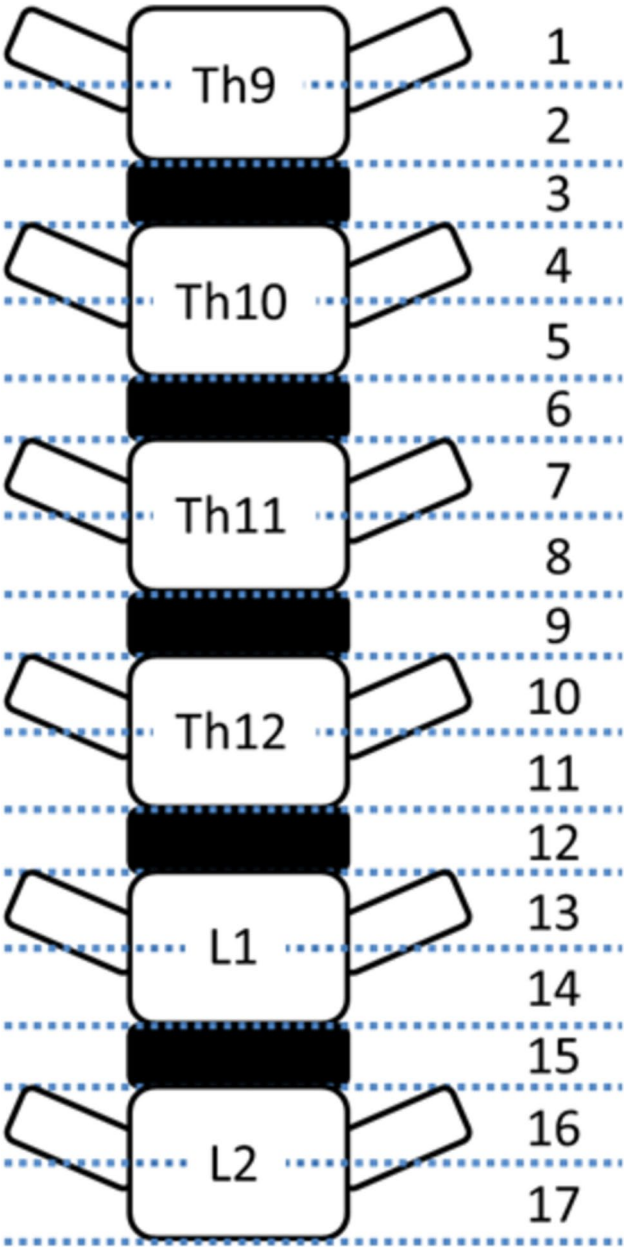

Fig. 2 Definition of vertebral levels

were carried out following a systematic and standardized approach. The patient was placed in a right-sided Trendelenburg position. The inferior mesenteric artery was ligated using the medial approach. In principle, D3 lymph node dissection was conducted for clinical T2–4 or clinical N1–2 tumors, whereas D2 lymph node dissection was applied to clinical T1 N0 tumors [11]. The left colic artery was not preserved in patients undergoing SFM. The inferior mesenteric vein was ligated at the lower edge of the pancreas, then dissection between the transverse mesocolon and pancreas was performed, and the omental bursa was opened. The descending and sigmoid segments of the colon were mobilized laterally. Before the cranial approach, the patient was repositioned in a right-sided anti-Trendelenburg position. The greater omentum was transected, and the omental bursa was opened cranially. The splenic flexure was completely taken down after transection of the mesenteric attachment of the transverse colon and the pancreaticocolic, splenocolic, and phrenicocolic ligaments.

Statistical analysis

Categorical variables are expressed as counts and percentages, whereas continuous variables are reported as medians with ranges. Univariate and multivariate analyses were conducted using a multiple linear regression model to determine factors associated with the operative time of the abdominal phase. To completely eliminate potential bias attributable to differences between da Vinci platforms, the aforementioned multivariate analysis was restricted to cases undergoing surgeries using the da Vinci Xi platform.

To assess interobserver variation, the splenic flexure height based on vertebral level was measured by two colorectal surgeons (Y.Y. and T.I.). Interobserver agreement was assessed using Spearman's correlation coefficient. All statistical analyses were conducted with the statistical program R version 4.2.2 (http://www.r-project.org/), under the advice of a statistician (A.N.). Two-sided *p*-values less than 0.05 were regarded as statistically significant.

Results

Patient characteristics

Table 1 summarizes the clinical characteristics of the study patients. Eighty-nine patients were enrolled. The median age was 65 years (range, 31–89 years), and 62 patients (70%) were male. The median body mass index (BMI) was 22.6 kg/m^2 (range, 16.6–33.8 kg/m^2), and the median VFA was 87.8 cm^2 (range, 7.5–326.9 cm^2). Seventy-eight patients (12%) underwent D3 lymph node dissection. The proportions of surgeries performed using the da Vinci Xi and Si platforms were 65% and 35%, respectively. Surgeons X, Y, and Z performed 25, 30, and 34 surgeries, respectively. The median vertebral level of the splenic flexure was 10 (range, 1–17). By sex, the median vertebral levels of the splenic flexure in men and women were 9 (range, 3–14) and 11 (1–17), respectively.

Surgical outcomes

Surgical results are presented in Table 2. The median duration of the abdominal phase was 88 min (range, 39–179 min). No patients underwent conversion to open or laparoscopic

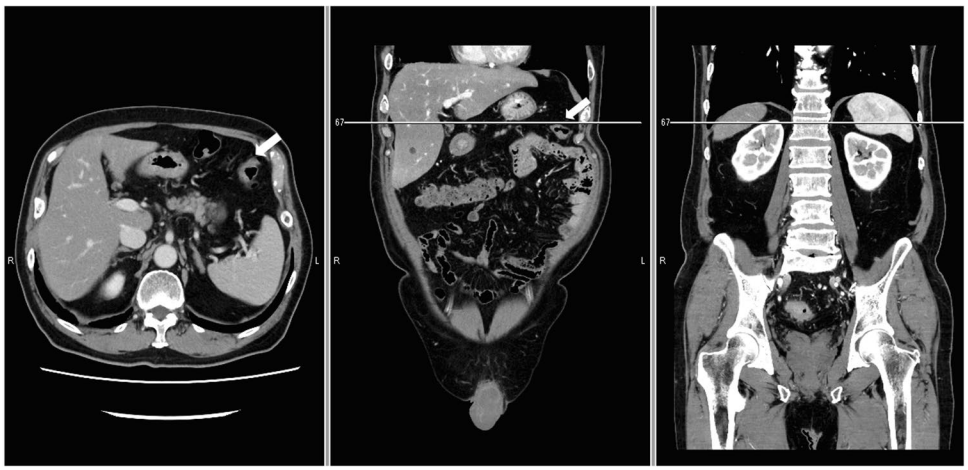

Fig. 3 An example of the splenic flexure height measurement based on vertebral level. The white arrows indicate the splenic flexure in axial and coronal views, and the vertebral level corresponding to the splenic flexure was 13 (superior half of the first lumbar vertebra)

Fig. 4 Trocar placement in the abdominal phase using the da Vinci Si and da Vinci Xi platforms. R1, R2, R3, R3, robotic arms 1, 2, 3, 4

surgery. There were no cases with intraoperative pancreatic, splenic, or intestinal injury and none with postoperative pancreatic fistula or splenic hemorrhage.

Factors influencing the operative time of the abdominal phase

Table 3 summarizes the relationship between clinical factors and the operative time of the abdominal phase. Univariate analysis indicated that a higher BMI, larger VFA, and higher splenic flexure were significantly correlated with a longer operative time for the abdominal phase. Multivariate analysis identified higher splenic flexure as the only factor that remained significantly associated with a prolonged operative time ($p < 0.01$). Table 4 presents the results of the aforementioned analysis, restricted to cases performed using the da Vinci Xi platform. In both univariate and multivariate analyses, a larger VFA and higher splenic flexure were independently associated with a prolonged operative time for the abdominal phase.

Table 1 Clinical characteristics of the study patients ($n = 89$)

Characteristics	Values
Age, years (median [range])	65 (31–89)
Sex	
Male	62 (70)
Female	27 (30)
ASA score	
I	25 (28)
II	61 (69)
III	3 (3)
Body mass index, kg/m^2 (median [range])	22.6 (16.6–33.8)
Visceral fat area, cm^2 (median [range])	87.8 (7.5–326.9)
Distance from tumor to anal verge, cm (median [range])	4.0 (0.5–20)
Preoperative chemoradiotherapy	15 (17)
c(yc) T	
1	11 (12)
2	13 (15)
3	48 (54)
4	17 (19)
c(yc) N	
0	39 (44)
1	29 (33)
2	21 (24)
c(yc) stage	
I	20 (22)
II	18 (20)
III	45 (51)
IV	6 (7)
Operative procedure	
Anterior resection	33 (37)
Intersphincteric resection	56 (63)
Central lymph node dissection	
D2	11 (12)
D3	78 (88)
Lateral lymph node dissection	51 (57)
da Vinci platform	
Xi	58 (65)
Si	31 (35)
Surgeon	
X	25 (28)
Y	30 (34)
Z	34 (38)
Vertebral level of splenic flexure (median [range])	10 (1–17)

Values in parentheses represent percentages unless otherwise noted

ASA, American Society of Anesthesiologists

Interobserver variation

As shown in Table 5, Spearman's correlation coefficient for interobserver variation in assessing the vertebral level of the splenic flexure on CT was 0.86, indicating high reproducibility and strong agreement between the two observers ($p < 0.01$). The median measurement times for splenic flexure height were 46 s (range, 33–115 s) for Y.Y. and 43 s (range, 20–127 s) for K.T., with no significant difference between the two observers.

Discussion

Thus far, there have been no useful indicators of SFM difficulty in rectal cancer surgery. In this study, we analyzed the operative time for the abdominal phase, which was defined as the interval from the initial mesenteric incision during the medial approach to the completion of mobilization of the sigmoid and descending colon, including the duration required for lymph node dissection around the inferior mesenteric artery and mobilization of the splenic flexure. This duration was evaluated because it was prospectively recorded intraoperatively, and overall operative time is commonly used to evaluate surgical difficulty [10]. Additional potential indicators of SFM difficulty include the incidence of intraoperative injuries to the pancreas, spleen, or intestines; the occurrence of postoperative pancreatic fistula or splenic hemorrhage; and the rate of conversion to open surgery. The incidence of pancreatic, splenic, and intestinal injuries during laparoscopic or robotic SFM has been reported to be low, with each occurring in less than 1% of cases [5, 12, 13]. Furthermore, in the present study, there were no intraoperative injuries to the pancreas, spleen, or intestines; no cases of postoperative pancreatic fistula or splenic hemorrhage; and no patients required conversion to open or laparoscopic surgery. Therefore, we considered that it was appropriate to evaluate robotic SFM difficulty in rectal cancer surgery using the operative time of the abdominal phase. Although this duration included the interval of lymph node dissection, we considered that multivariate analysis minimized the influence of the extent of lymph node dissection. Among the variables analyzed, multivariate analysis identified a higher splenic flexure as the only factor significantly correlated with a prolonged operative time of the abdominal phase; therefore, splenic flexure height measured on the basis of vertebral level using CT was useful for predicting the difficulty of robotic SFM. Patients with a high splenic flexure are likely to have strong adhesions involving the greater omentum around the splenic flexure, and the splenic flexure tends to be close to the spleen or pancreas, both factors that might increase surgical difficulty. Therefore, in such patients, it may be better to increase the angle of the right-sided anti-Trendelenburg position, or to use a medial approach to fully dissect between the transverse mesocolon and the pancreas and to fully mobilize the descending colon via a lateral approach before transecting the mesenteric attachment of

Table 2 Surgical outcomes of the study patients ($n = 89$)

Outcomes	Values
Total operative time, min (median (range))	359 (170–599)
Operative time of the abdominal phase, min (median (range))	88 (39–179)
Blood loss, mL (median (range))	15 (0–1010)
Transfusion	0
Conversion to open or laparoscopic surgery	0
Postoperative complications[a]	
Intra-abdominal or intraluminal bleeding	2 (2.2)
Anastomotic leakage	2 (2.2)
Intraabdominal abscess	1 (1.1)
Bowel obstruction	3 (3.3)
Urinary tract infection	3 (3.3)
Enterocolitis	2 (2.2)
Pneumonia	1 (1.1)
Wound infection	3 (3.3)
Complications related to splenic flexure mobilization	
Intraoperative pancreatic injury	0
Splenic injury	0
Intestinal injury	0
Postoperative pancreatic fistula	0
Splenic hemorrhage	0
Time to soft diet, days [median (range)]	3 (3–11)
Postoperative hospital stay, days [median (range)]	7 (6–32)

Values in parentheses represent percentages unless otherwise noted

[a]Grade II or III in the Clavien–Dindo classification

Table 3 Clinical factors associated with the operative time of the abdominal phase

		Univariate analysis			Multivariate analysis		
Variable		β	95%CI	p	β	95%CI	p
Age		− 0.31	− 0.88 to 0.26	0.29	− 0.22	− 0.78 to 0.34	0.44
Sex (male vs female)		11.3	− 0.85 to 23.46	0.07	3.2	− 8.59 to 14.98	0.59
Body mass index		2.85	1.21 to 4.48	< 0.01	− 0.07	− 2.33 to 2.18	0.95
Visceral fat area		0.19	0.08 to 0.29	< 0.01	0.11	− 0.02 to 0.24	0.09
Vertebral level of splenic flexure		− 4.3	− 5.86 to − 2.73	< 0.01	− 3.27	− 5.16 to − 1.37	< 0.01
Central lymph node dissection (D2 vs D3)		− 4.29	− 21.57 to 12.98	0.62	− 2.9	− 18.55 to 12.74	0.71
da Vinci system (Xi vs Si)		5.68	− 6.21 to 17.57	0.35	1.13	− 13.63 to 15.88	0.88
Surgeon	Y vs X	− 3.41	− 17.67 to 10.86	0.64	− 4.86	− 22.34 to 12.62	0.58
	Z vs X	10.14	− 3.74 to 24.01	0.15	1.47	− 12.19 to 15.13	0.83

CI, confidence interval

the transverse colon and the pancreaticocolic, splenocolic, and phrenicocolic ligaments. This is the first study to evaluate the difficulty of robotic SFM, and the largest to evaluate the difficulty of SFM overall. Another strength of this study was that all robotic SFM procedures at our institution are standardized. Furthermore, the study excluded patients with double cancer, such as simultaneous transverse or descending colon cancer and splenic flexure colon cancer, which can affect the difficulty of SFM.

Brookes et al. reported that the mean vertebral levels of the splenic flexure in men and women were 8.88 (range, 1–17) and 11.36 (4–16), respectively [14], which is similar to our findings of 9 and 11, respectively. In the current study, there was excellent interobserver agreement regarding the measurement of the splenic flexure height based on vertebral level using CT, and it took less than 1 min to determine each height. Therefore, using this approach to measure the splenic flexure height is highly feasible and reproducible in

Table 4 Clinical factors associated with the operative time of the abdominal phase in cases undergoing surgeries using the da Vinci Xi platform

Variable		Univariate analysis			Multivariate analysis		
		β	95%CI	*p*	*β*	95%CI	*p*
Age		− 0.22	− 0.95 to 0.51	0.55	− 0.12	− 0.80 to 0.56	0.72
Sex (male vs female)		12.96	− 2.33 to 28.26	0.10	11.10	− 2.77 to 24.96	0.11
Body mass index		1.96	− 0.28 to 4.21	0.09	− 1.52	− 4.14 to 1.10	0.25
Visceral fat area		0.20	0.07 to 0.35	< 0.01	0.19	0.03 to 0.36	0.02
Vertebral level of splenic flexure		− 4.49	− 6.57 to − 2.41	< 0.01	− 4.33	− 6.59 to − 2.06	< 0.01
Central lymph node dissection (D2 vs D3)		− 5.07	− 26.64 to 16.51	0.64	− 11.94	− 30.77 to 6.89	0.21
Surgeon	Y vs X	15.54	− 10.13 to 41.21	0.23	13.17	− 9.40 to 35.75	0.25
	Z vs X	8.99	− 6.65 to 24.64	0.25	− 2.43	− 17.42 to 12.57	0.75

CI, confidence interval

Table 5 Interobserver variation in the measurement of the splenic flexure height based on vertebral level using computed tomography

	First observer (Y.Y.)	Second observer (T.I.)	r^a	*p*
Vertebral level of splenic flexure	10 (1–17)	11 (1–17)	0.86	< 0.01

Data shown as median (range)

[a]Spearman's correlation coefficient

clinical practice. Kawai et al. classified the splenic flexure on the basis of three-dimensional CT analysis by identifying the locations of the ligament of Treitz, the left renal hilum, and the splenic hilum, and clarified factors influencing the time spent for laparoscopic SFM in 34 patients [15]. They reported that SFM took longer in patients in the lateral group than in those in the caudal or cranial groups. Further research may be needed to evaluate whether their method or ours is more suitable for predicting the difficulty of SFM.

Robotic surgery offers multiple benefits, such as freely movable multi-jointed forceps, motion scaling, tremor reduction, and a stable camera that provides high-resolution three-dimensional imaging. These advantages help address the inherent challenges of traditional laparoscopic surgery, which include the use of straight, rigid instruments, restricted range of motion, an unstable two-dimensional imaging system, and ergonomic difficulties in rectal cancer procedures due to the narrow and anatomically complex pelvic cavity [10]. However, the optimal surgical approach for rectal cancer remains debatable. Three major randomized controlled trials—the ROLLAR, COLRAR, and REAL trials [16–18]—have evaluated the differences between robotic and laparoscopic surgery for rectal cancer. While the ROLLAR and COLRAR trials did not establish the superiority of robotic surgery over laparoscopic surgery in terms of their primary endpoints—conversion rate to open surgery and total mesorectal excision quality—the REAL trial found that robotic surgery was associated with significantly lower rates of circumferential resection margin positivity and postoperative complications, which were secondary endpoints of the study. Our previous studies have demonstrated the superiority of robotic surgery over open and laparoscopic approaches for rectal cancer, considering surgical, functional, and oncological outcomes [19–25]. As a result, robotic surgery is the preferred method for rectal cancer treatment at our institution. Moreover, the use of robotic surgery for rectal cancer is rapidly increasing [26, 27]. Given this trend, it is crucial to identify the factors influencing the complexity of robotic SFM.

This study has several limitations. First, it was a retrospective analysis performed at a single institution. To confirm the usefulness of measuring splenic flexure height based on vertebral level using CT, a prospective study is required. Second, operations in this study were performed by three different surgeons. However, all three surgeons were experts in colorectal cancer surgery, and multivariate analysis showed that the operative time of the abdominal phase did not differ significantly between surgeons. Third, the anatomical position of the splenic flexure was not evaluated from a medial–lateral or ventral–dorsal perspective due to the lack of a simple, objective, and reproducible indicator to perform these assessments. Fourth, information regarding the type of vascular closure device employed, the role or level of experience of surgical assistants, the presence of intra-abdominal adhesions, and the existence of accessory middle colic arteries was not available.

In conclusion, our findings suggest that, in multivariate analysis, a higher splenic flexure was the only factor significantly correlated with a longer operative time during the abdominal phase. Splenic flexure height measured on the basis of vertebral level using CT was useful for predicting the difficulty of robotic SFM.

Author contribution Yusuke Yamaoka drafted the paper and designed this study. Yusuke Yamaoka, Akio Shiomi, Hiroyasu Kagawa, Hitoshi Hino, Shoichi Manabe, Yusuke Tanaka, Shunsuke Kasai, and Tetsushi Ishiguro obtained and analyzed data. Akifumi Notsu supervised statistical analyses.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethical approval This study was approved by the Institutional Review Board of Shizuoka Cancer Center Hospital (institutional code J2022-58–2022-1–3).

Competing interests The authors declare no competing interests.

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