

Clinical Determinants of Surgical Difficulty in Robotic Rectal Cancer Surgery: Toward Preoperative Risk Stratification

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Abstract

Purpose

Robotic-assisted rectal surgery (RRS) offers technical advantages within the narrow pelvis; however, surgical difficulty remains difficult to predict. This study aimed to identify clinical and tumor-related factors associated with increased surgical difficulty in RRS.

Methods

A retrospective analysis was conducted on 638 consecutive patients who underwent robotic total mesorectal excision for rectal neoplasms between May 2013 and December 2024 at a single tertiary center. Surgical difficulty was assessed using a Modified Escal Score incorporating console time, estimated blood loss, postoperative complications, and postoperative length of stay. Independent predictors of high surgical difficulty were evaluated using multivariable logistic regression analysis.

Results

Among 638 patients, 141 (22.1%) were classified as having high surgical difficulty. Multivariable analysis identified male sex (odds ratio (OR) 2.00, 95% confidence interval (CI) 1.28–3.12; $P = 0.0022$), higher body mass index (OR 1.10 per unit increase, 95% CI 1.04–1.17; $P = 0.0012$), neoadjuvant chemoradiotherapy (OR 1.85, 95% CI 1.11–3.08; $P = 0.0191$), and tumor location > 5 to ≤ 10 cm from the anal verge (OR 2.28, 95% CI 1.20–4.32; $P = 0.0119$) as independent predictors of increased surgical difficulty. High-difficulty cases showed significantly higher rates of anastomotic leakage and multiple stapler firings, whereas oncological surrogate outcomes remained comparable between groups.

Conclusion

Surgical difficulty in RRS is influenced by patient morphology, neoadjuvant treatment, and tumor location. Mid-rectal tumors may pose greater technical challenges than very low rectal tumors in robotic rectal surgery. These findings may assist preoperative risk stratification and operative planning.

Introduction

Colorectal cancer (CRC) remains a major contributor to global cancer-related morbidity and mortality. In 2022, CRC ranked as the third most commonly diagnosed malignancy and the second leading cause of cancer-related death worldwide [1]. Rectal cancer, accounting for approximately 30–40% of CRC cases, presents distinct clinical and technical challenges because of the confined pelvic anatomy and the need to preserve anorectal function whenever feasible [2].

The surgical management of rectal cancer was revolutionized by the introduction of total mesorectal excision (TME) by Bill Heald. This gold-standard technique emphasizes sharp dissection along the

embryological “holy plane,” enabling intact mesorectal excision to reduce local recurrence and improve oncological outcomes [3].

In recent years, robotic-assisted rectal surgery (RRS) has gained widespread adoption. By providing high-definition three-dimensional (3D) visualization, tremor filtration, and articulating instruments with enhanced dexterity, RRS may facilitate precise dissection within the confined pelvic cavity [4]. These technical advantages are intended to overcome some limitations of conventional laparoscopy, particularly in technically demanding cases.

Despite these advances, intraoperative difficulty remains variable and difficult to predict. Although pelvic anatomy and tumor characteristics are recognized determinants of difficulty in open and laparoscopic surgery, evidence regarding these factors in robotic surgery remains limited and inconsistent [5].

Therefore, this study aimed to identify the clinical and tumor-related determinants of surgical difficulty in RRS and to establish a framework for preoperative risk stratification and operative planning.

Materials and Methods

The study was approved by the Institutional Review Board of a tertiary referral center in Taiwan (KMUHIRB-E(II)-20250266). We retrospectively reviewed consecutive patients who underwent RRS using the da Vinci Si or Xi systems (Intuitive Surgical, Sunnyvale, CA, USA) at a single tertiary referral center between May 2013 and December 2024.

To establish a homogeneous cohort of rectal neoplasms, patients with colonic tumors, synchronous lesions, high rectal tumors (> 15 cm from the anal verge), or non-neoplastic conditions were excluded. Intraoperatively inoperable cases and conversions to open surgery were also excluded because of their rarity and to maintain the focus on technical predictors of successful robotic completion. Of the 778 procedures performed during the study period, 638 RRS were included in the final analysis.

The majority of cases were histologically confirmed adenocarcinoma (95.1%). The remaining lesions consisted of adenomas, neuroendocrine neoplasms, gastrointestinal stromal tumors, and other rare rectal pathologies.

Surgical Procedure

Robotic-assisted TME was performed using either the da Vinci Si (n = 534) or Xi (n = 104) surgical systems. All procedures followed a standardized, single-docking technique previously established and validated by our surgical team [6, 7]. This consistent approach was maintained across both robotic platforms to ensure technical uniformity and minimize intraoperative variability. After initial laparoscopic exploration and adhesiolysis, the robotic cart was docked over the patient's left flank. A medial-to-lateral approach was used, beginning at the sacral promontory and extending toward the root of the inferior mesenteric artery (IMA).

Lymphadenectomy was routinely performed using a high-dissection, selective low-ligation technique [8, 9]. The IMA was ligated distal to the origin of the left colic artery, whereas division of the inferior mesenteric vein and splenic flexure mobilization were performed selectively when additional colonic length was required.

Reconstruction was determined by tumor location and distal margin status. Upper and mid-rectal tumors were generally treated with anterior resection or low anterior resection (LAR), usually with a double-stapling anastomosis. Low rectal tumors suitable for sphincter preservation underwent intersphincteric resection (ISR) with hand-sewn coloanal anastomosis, whereas abdominoperineal resection was reserved for cases in which sphincter preservation was not feasible. A diverting stoma was selectively constructed according to intraoperative findings and patient-related risk factors.

Console time was defined as the net duration from the completion of robotic docking to the undocking of the system, specifically representing the interval of active surgical manipulation via the robotic interface. To isolate the technical difficulty inherent to the robotic platform, procedures performed outside of the console phase—including initial laparoscopic exploration, adhesiolysis, extracorporeal bowel reconstruction, specimen extraction, stoma creation, and drain placement—were recorded separately and excluded from the console time analysis.

Definition of Surgical Difficulty

To objectively quantify the technical challenges inherent in robotic rectal surgery, we employed a Modified Escal Score, adapted from the difficulty grading system originally proposed by Escal *et al.* [5]. While the original Escal Score was developed for a heterogeneous mix of operative approaches (open, laparoscopic, and robotic), our version was refined to specifically reflect the nuances of a purely robotic cohort. Compared with the original Escal Score, conversion to open surgery and transanal dissection were omitted, and total operative duration was replaced by console time to better capture robotic-specific operative difficulty.

As summarized in Table 1, the Modified Escal Score comprises four clinical components, each weighted to reflect surgical complexity:

Table 1
Modified Escal score used for surgical difficulty assessment

Variable	Score
Console time > 180 min	3
Clavien–Dindo complication grade $\geq$ II	2
Estimated blood loss > 100 mL	2
Postoperative hospital stay > 7 days	1
Total possible score	8
The modified Escal score was calculated using four perioperative variables, with a total score ranging from 0 to 8. Higher scores indicated greater surgical difficulty, with a total score of ≥ 5 predefined as high surgical difficulty.	

1. Console time (> 180 minutes)
2. Postoperative morbidity (Clavien–Dindo classification $\geq$ II)
3. Estimated blood loss (> 100 mL)
4. Postoperative length of hospital stay (LOS) (> 7 days)

The cumulative score ranges from 0 to 8, with a score ≥ 5 predefined as high surgical difficulty.

Perioperative Variables and Outcomes

Clinicopathological and perioperative data were retrospectively retrieved from a prospectively maintained database. Tumor size was defined as the maximal diameter on the most recent preoperative computed tomography (CT) scan; in patients receiving neoadjuvant concurrent chemoradiotherapy (CCRT), post-CCRT measurements were used to reflect tumor status at the time of surgery. An unplanned stoma was defined as a diverting stoma created intraoperatively due to unexpected technical difficulty or postoperatively for anastomotic insufficiency, excluding those planned preoperatively. Postoperative complications within 30 days were graded according to the Clavien–Dindo classification, with Grade $\geq$ II defined as complications requiring at least pharmacological, surgical, endoscopic, or radiological intervention.

Statistical Analysis

Statistical analyses were performed using JMP Pro version 17 (SAS Institute Inc., Cary, NC, USA). Categorical variables were presented as frequencies with percentages and compared using the chi-square test. Continuous variables were expressed as mean $\pm$ standard deviation and analyzed using Student's t-test. To identify independent factors associated with high surgical difficulty, multivariable logistic regression analysis was performed, with results reported as odds ratios (ORs) and 95% confidence intervals (CIs). The predictive performance of the model was evaluated using the area under

the receiver operating characteristic curve (AUC). All statistical tests were two-sided, and a P-value < 0.05 was considered statistically significant.

Results

Of the 638 consecutive RRS analyzed, 141 cases (22.1%) were classified as high surgical difficulty and 497 (77.9%) as low difficulty based on the Modified Escal Score. The high-difficulty cohort demonstrated significantly worse perioperative performance across all four components of the composite score, including prolonged console time, increased blood loss, higher postoperative morbidity, and longer hospital stay (all $P < 0.001$).

Baseline characteristics are summarized in Table 2. Compared with the low-difficulty group, patients in the high-difficulty group were more frequently male, had a higher Body Mass Index (BMI), and were more likely to have received neoadjuvant CCRT (all $P < 0.001$). Tumor location was also associated with surgical difficulty, with a lower proportion of upper rectal tumors (> 10 cm from the anal verge) observed in the high-difficulty cohort ($P = 0.005$).

Table 2
Baseline characteristics according to surgical difficulty group

Variable	Total (n = 638)	Low difficulty (n = 497)	High difficulty (n = 141)	P
Age, years	61.1 (12.1)	61.3 (11.9)	60.4 (13.0)	0.46
Male sex, n (%)	363 (56.9)	262 (52.7)	101 (71.6)	< 0.0001*
BMI, kg/m²	24.3 (3.4)	24.0 (3.3)	25.3 (3.5)	< 0.0001*
Previous abdominal surgery, n (%)	119 (18.7)	95 (19.1)	24 (17.0)	0.57
ASA score ≥ 3, n (%)	241 (37.8)	186 (37.4)	55 (39.0)	0.73
Neoadjuvant CCRT, n (%)	446 (69.9)	331 (66.6)	115 (81.6)	0.0006*
Distance from anal verge, n (%)				
≤5 cm	277 (44.0)	211 (43.2)	66 (46.8)	0.0054*
>5 to ≤ 10 cm	216 (34.3)	158 (32.4)	58 (41.1)	
>10 cm	136 (21.6)	119 (24.4)	17 (12.1)	
Tumor size ≥ 3 cm, n (%)	205 (32.1)	160 (32.2)	45 (31.9)	0.95
T3–T4 stage, n (%)	245 (38.4)	188 (37.8)	57 (40.4)	0.58
N positive, n (%)	166 (26.0)	131 (26.4)	35 (24.8)	0.71
M positive, n (%)	69 (10.8)	52 (10.5)	17 (12.1)	0.59
Poorly differentiated histology, n (%)	22 (3.4)	16 (3.2)	6 (4.3)	0.55
CEA > 5 ng/mL, n (%)	99 (15.5)	73 (14.7)	26 (18.4)	0.28
Procedure, n (%)				
AR	23 (3.6)	22 (4.4)	1 (0.7)	0.16
LAR	430 (67.4)	336 (67.6)	94 (66.7)	
ISR	175 (27.4)	131 (26.4)	44 (31.2)	
APR	10 (1.6)	8 (1.6)	2 (1.4)	
Values are presented as mean (SD) or number (%). *P < 0.05 was considered statistically significant. ASA, American Society of Anesthesiologists; BMI, body mass index; CCRT, concurrent chemoradiotherapy; CEA, carcinoembryonic antigen; AR, anterior resection; LAR, low anterior resection; ISR, intersphincteric resection; APR, abdominoperineal resection; HS, hand-sewn; DS, double stapling; CAA, coloanal anastomosis.				

Variable	Total (n = 638)	Low difficulty (n = 497)	High difficulty (n = 141)	P
Anastomosis, n (%)				
HS	6 (0.9)	5 (1.0)	1 (0.7)	0.60
DS	447 (70.1)	354 (71.2)	93 (66.0)	
CAA	175 (27.4)	130 (26.2)	45 (31.9)	
Values are presented as mean (SD) or number (%). *P < 0.05 was considered statistically significant. ASA, American Society of Anesthesiologists; BMI, body mass index; CCRT, concurrent chemoradiotherapy; CEA, carcinoembryonic antigen; AR, anterior resection; LAR, low anterior resection; ISR, intersphincteric resection; APR, abdominoperineal resection; HS, hand-sewn; DS, double stapling; CAA, coloanal anastomosis.				

In contrast, age, previous abdominal surgery, American Society of Anesthesiologists (ASA) score, tumor size, and clinical T or N stage did not differ significantly between groups. The distribution of surgical procedures was likewise comparable, with LAR and ISR remaining the predominant procedures in both cohorts ($P = 0.16$).

Multivariable logistic regression analysis was performed to identify independent predictors of high surgical difficulty (Table 3). Anastomotic technique was excluded from the final model because of collinearity with the surgical procedure performed.

Table 3
Multivariable logistic regression analysis of factors associated with high surgical difficulty

Variable	OR	95% CI	P
Age	0.99	0.97–1.01	0.47
Male sex	2.00	1.28–3.12	0.0022*
BMI	1.10	1.04–1.17	0.0012*
CEA > 5 ng/mL	1.39	0.80–2.44	0.24
Previous abdominal surgery	1.12	0.66–1.90	0.68
ASA score ≥ 3	1.17	0.63–1.85	0.78
Neoadjuvant CCRT	1.85	1.11–3.08	0.0191*
Distance from anal verge			
>10 cm (reference)	–	–	–
>5 to ≤ 10 cm	2.28	1.20–4.32	0.0119*
≤5 cm	1.66	0.79–3.49	0.18
Tumor size ≥ 3 cm	1.11	0.70–1.75	0.67
T3–T4 stage	1.14	0.72–1.80	0.58
N positive	0.93	0.57–1.52	0.78
M positive	1.00	0.52–1.94	0.98
Poorly differentiated histology	1.19	0.43–3.27	0.73
Procedure			0.28
AR	0.37	0.04–3.27	0.37
LAR (reference)	–	–	–
ISR	1.09	0.60–1.99	0.77
APR	0.37	0.04–3.42	0.39
*P < 0.05 was considered statistically significant. OR, odds ratio; CI, confidence interval; BMI, body mass index; CEA, carcinoembryonic antigen; ASA, American Society of Anesthesiologists; CCRT, concurrent chemoradiotherapy; AR, anterior resection; LAR, low anterior resection; ISR, intersphincteric resection; APR, abdominoperineal resection.			

Male sex independently doubled the risk of high surgical difficulty (OR 2.00, 95% CI 1.28–3.12; $P = 0.002$). Higher BMI was also associated with increased difficulty, with each unit increase conferring a 10% increase in risk (OR 1.10, 95% CI 1.04–1.17; $P = 0.001$). Neoadjuvant CCRT remained an independent predictor (OR 1.85, 95% CI 1.11–3.08; $P = 0.019$).

Using tumors located > 10 cm from the anal verge as the reference group, mid-rectal tumors (> 5 to ≤ 10 cm) were associated with a significantly higher risk of high surgical difficulty (OR 2.28, 95% CI 1.20–4.32; $P = 0.012$), whereas low rectal tumors (≤ 5 cm) were not independently associated with increased difficulty (OR 1.66, 95% CI 0.79–3.49; $P = 0.18$). A direct comparison between mid- and low-rectal tumors likewise showed no significant difference in surgical difficulty (OR 1.37; $P = 0.28$). No significant associations were observed for age, carcinoembryonic antigen level, previous abdominal surgery, ASA score, tumor size, clinical stage, or surgical procedure.

As shown in Table 4, patients in the high-difficulty group experienced significantly worse intraoperative and postoperative outcomes. High-difficulty procedures were associated with a greater likelihood of requiring ≥ 3 linear stapler firings during rectal transection (8.9% vs. 2.6%, $P = 0.005$), as well as longer operative duration, greater blood loss, higher transfusion rates, and prolonged hospitalization (all $P < 0.001$).

Table 4
Surgical and pathological outcomes according to surgical difficulty group

Outcome	Total	Low difficulty	High difficulty	P
Linear stapler firings ≥ 3, n (%)	17 (3.8)	9 (2.6)	8 (8.9)	0.0052*
Console time, min	181.0 (48.3)	166.7 (36.0)	230.8 (52.6)	< 0.0001*
Operation time, min	308.3 (82.0)	288.1 (61.2)	378.7 (103.1)	< 0.0001*
Anastomotic leakage, n (%)	36 (5.6)	13 (2.6)	23 (16.3)	< 0.0001*
Unplanned stoma, n (%)	34 (5.3)	13 (2.6)	21 (14.9)	< 0.0001*
Blood loss, mL	106.6 (114.5)	77.5 (81.2)	210.6 (150.3)	< 0.0001*
Blood transfusion, n (%)	12 (1.9)	5 (1.0)	7 (5.0)	0.0023*
Postoperative LOS, days	7.7 (4.4)	7.2 (2.8)	9.6 (7.6)	0.0005*
Lymph nodes retrieved	14.3 (8.9)	14.5 (8.5)	13.4 (10.3)	0.24
DRM < 1 cm, n (%)	144 (22.6)	113 (22.7)	31 (22.0)	0.85
CRM positive, n (%)	4 (0.6)	3 (0.6)	1 (0.7)	0.89
Values are presented as mean (SD) or number (%). * $P < 0.05$ was considered statistically significant. LOS, length of stay; DRM, distal resection margin; CRM, circumferential resection margin.				

Clinically, high-difficulty cases demonstrated significantly higher rates of anastomotic leakage (16.3% vs. 2.6%, $P < 0.001$) and unplanned stoma formation (14.9% vs. 2.6%, $P < 0.001$).

In contrast, surrogate markers of oncologic quality, including lymph node harvest, distal resection margin status, and circumferential resection margin positivity, were comparable between groups. Long-term

oncologic outcomes were not evaluated.

To explore whether the determinants of surgical difficulty varied by tumor location, subgroup multivariable analyses were performed according to tumor distance from the anal verge (Table 5). In low rectal tumors (≤ 5 cm), ASA score ≥ 3 was the only independent predictor of high surgical difficulty (*OR* 1.96, 95% *CI* 1.01–3.79; *P* = 0.046).

Table 5
Multivariable logistic regression analysis stratified by tumor distance from the anal verge

Variable	≤ 5 cm			> 5 to ≤ 10 cm			> 10 cm		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
Age	0.98	0.95–1.00	0.07	1.02	0.98–1.06	0.27	0.99	0.94–1.04	0.76
Male sex	1.85	0.97–3.53	0.06	3.18	1.42–7.10	0.0048*	1.36	0.36–5.08	0.65
BMI	1.07	0.98–1.17	0.12	1.18	1.06–1.30	0.0015*	1.10	0.91–1.34	0.32
Previous abdominal surgery	0.49	0.19–1.26	0.14	1.79	0.69–4.62	0.23	3.52	1.05–11.75	0.0411*
Neoadjuvant CCRT	1.72	0.73–4.02	0.21	1.61	0.73–3.53	0.24	5.11	1.29–20.23	0.0200*
ASA score ≥ 3	1.96	1.01–3.79	0.0459*	0.68	0.31–1.51	0.35	0.72	0.21–2.51	0.61
Tumor size ≥ 3 cm	0.82	0.40–1.66	0.58	0.91	0.42–1.97	0.82	5.93	1.43–24.63	0.0142*
T3–T4 stage	1.62	0.81–3.25	0.18	0.91	0.43–1.90	0.80	0.77	0.21–2.78	0.69
N positive	1.03	0.48–2.22	0.93	1.02	0.47–2.23	0.96	0.35	0.08–1.45	0.15
M positive	1.60	0.66–3.89	0.30	0.64	0.15–2.67	0.54	0.47	0.06–3.38	0.45
CEA > 5 ng/mL	1.17	0.51–2.66	0.71	1.83	0.64–5.22	0.26	1.77	0.40–7.73	0.45
* <i>P</i> < 0.05 was considered statistically significant. BMI, body mass index; ASA, American Society of Anesthesiologists; CCRT, concurrent chemoradiotherapy; CEA, carcinoembryonic antigen; CI, confidence interval; OR, odds ratio.									

In mid-rectal tumors (> 5 to ≤ 10 cm), male sex and BMI emerged as the dominant predictors. Male patients had more than a three-fold increased risk of high surgical difficulty (*OR* 3.18, 95% *CI* 1.42–7.10;

$P = 0.005$), while each unit increase in BMI was associated with an 18% increase in risk ($OR\ 1.18$, 95% $CI\ 1.06–1.30$; $P = 0.002$).

In upper rectal tumors ($> 10\text{ cm}$), neoadjuvant CCRT ($OR\ 5.11$, 95% $CI\ 1.29–20.23$; $P = 0.02$), previous abdominal surgery ($OR\ 3.52$, 95% $CI\ 1.05–11.75$; $P = 0.04$), and tumor size $\geq 3\text{ cm}$ ($OR\ 5.93$, 95% $CI\ 1.43–24.63$; $P = 0.014$) were independently associated with high surgical difficulty.

These findings suggest that the determinants of surgical difficulty vary according to tumor location, with anatomical factors predominating in mid-rectal tumors and treatment- or tumor-related factors playing a greater role in upper rectal tumors.

Discussion

This retrospective study, encompassing 638 patients, delineated several independent clinicopathological predictors of increased technical difficulty in RRS: male sex, higher BMI, mid-rectal tumor location, and prior neoadjuvant CCRT. Conversely, variables such as age, serum carcinoembryonic antigen levels, a history of prior abdominal surgery, clinical tumor stage, and the specific surgical procedure did not emerge as significant contributors to operative difficulty within this cohort.

Despite advances in minimally invasive techniques, predicting surgical difficulty in rectal cancer surgery remains challenging. In laparoscopic TME, factors such as male sex, obesity, and low tumor location have been associated with increased operative complexity, although reported predictors remain heterogeneous across studies [10, 11]. While robotic-assisted surgery was introduced to overcome some technical limitations of laparoscopy, current evidence suggests that patient- and tumor-related factors, particularly high BMI, male sex, and tumor height, continue to influence operative difficulty, especially during deep pelvic transection and double-stapling anastomosis [12–14].

A pivotal implication of these findings is that the intrinsic mechanical constraints of the bony pelvis remain a formidable determinant of surgical complexity, even in the robotic era. Despite the high-definition 3D visualization and articulating instrumentation offered by robotic systems, the technical limitations imposed by a narrow pelvic cavity are not entirely circumvented. Previous morphometric analyses using magnetic resonance imaging (MRI)- and CT-based pelvimetry have established that pelvic dimensions—including the pelvic outlet, interspinous and intertuberous distances, sacral configuration, and the mesorectal area—are critically associated with operative difficulty during rectal cancer resection [14–18]. Anatomically, male patients typically possess more restrictive pelvic dimensions compared to females, characterized by a narrower pelvic outlet and a deeper, funnel-shaped cavity. This inherent morphological disadvantage likely explains why male sex remained a potent independent predictor of high surgical difficulty in our multivariable analysis [16, 18].

Higher BMI was identified as a robust independent predictor of surgical difficulty in our multivariable analysis, with each unit increase corresponding to a 10% elevation in the risk of high difficulty. Our findings were consistent with previous studies. Obesity and visceral adiposity may reduce the effective

pelvic working space, increase mesorectal bulk and obscure dissection planes during TME [14, 16, 19, 20]. This mechanism is particularly relevant in the narrow male pelvis, where an enlarged mesorectum may further compromise visualization and instrument maneuverability.

In our subgroup analysis, the impact of BMI was particularly striking for mid-rectal tumors, where the risk of high difficulty increased by 18% per unit of BMI. This suggests that the presence of excessive fatty tissue, coupled with the narrowing bony pelvis in the mid-rectum, creates a cumulative technical challenge that complicates stable traction and optimal exposure.

Preoperative CCRT was identified as an independent predictor of high surgical difficulty. Radiation-induced tissue edema, pelvic fibrosis, and obliteration of embryological dissection planes may increase the technical demands of pelvic dissection and the risk of autonomic nerve injury [16, 21]. Notably, the impact of CCRT was most pronounced in upper rectal tumors, where the risk of high surgical difficulty increased more than five-fold. This finding suggests that radiation-related fibrosis may substantially increase the complexity of upper pelvic dissection and IMA skeletonization despite the technical advantages of robotic systems.

The relationship between tumor distance from the anal verge and surgical difficulty yielded a somewhat counterintuitive finding. Our data indicates that the most technically demanding cases were not necessarily very low rectal tumors, but rather those located in the mid-to-low transition zone, specifically 5–10 cm from the anal verge. In the multivariable model, mid-rectal location was the strongest predictor among tumor-related factors, whereas low rectal tumors did not reach statistical significance after adjustment for confounders.

These findings challenge the conventional assumption that surgical difficulty increases linearly as the tumor location becomes more distal. While conventional wisdom in the era of manual laparoscopy suggests that technical challenge increases as the tumor approaches the pelvic floor, this "mid-pelvic hurdle" likely reflects the interplay between anatomical constraints and technological compensation. In the deep pelvis (≤ 5 cm), where space is most restricted, the robotic system's high-definition 3D visualization and wristed instrumentation allow for meticulous dissection and stable retraction that effectively "neutralize" the anatomical constraints of a narrow male pelvis or high BMI.

In contrast, the mid-rectal zone (> 5 to ≤ 10 cm) represents a critical "transition and tapering" area. In this region, surgeons must navigate the narrowing funnel of the bony pelvis to achieve a secure rectal transection and construct a double-stapled anastomosis. The mechanical interference between robotic arms and the constrained space is often most pronounced here, particularly when attempting to achieve an optimal stapling angle. Such anatomical confinement frequently leads to difficult stapler positioning and multiple linear stapler reloads. Indeed, our results showed that high-difficulty cases were significantly more likely to require ≥ 3 stapler firings. This technical struggle is clinically consequential, as multiple firings have been consistently associated with an increased risk of anastomotic insufficiency [22, 23]. The markedly higher rate of anastomotic leakage observed in our high-difficulty group

underscores the importance of recognizing the mid-pelvis as a substantial mechanical challenge that persists in the robotic era.

Moreover, pelvimetry-based studies of the double-stapling technique have shown that pelvic inlet, interspinous/intertuberous distances, and tumor height are related to the technical difficulty of rectal transection and the number of stapler cartridges required [12, 13]. This concept may also explain why ISR did not demonstrate greater overall surgical difficulty compared with LAR in our cohort, despite requiring deeper distal pelvic dissection. With LAR serving as the reference, ISR showed a comparable difficulty level ($OR\ 1.09$; $P = 0.77$), suggesting that surgical difficulty reflects a composite of distinct technical challenges rather than distal tumor location alone. While ISR requires meticulous dissection within the deep pelvis, it may simultaneously avoid some of the key mechanical constraints encountered during low pelvic stapling and double-stapled anastomosis in LAR, particularly in patients with bulky mid-rectal tumors or a narrow pelvis. These insights support the future integration of pelvimetric and body-composition parameters into predictive models to better anticipate operative complexity and optimize patient outcomes [14–17, 20].

The impact of tumor size appeared to be context-dependent. Although tumors ≥ 3 cm were not predictive in the overall cohort, they were independently associated with increased difficulty in tumors located > 10 cm from the anal verge. Consistent with this finding, larger tumors were more common in the upper rectal group than in the mid- or low-rectal groups (44.1% vs. 28.7% and 28.5%, respectively; $P = 0.003$). In mid- to low-rectal cancers, the constraints of the bony pelvis and the demands of deep TME may overshadow the effect of tumor volume. In contrast, within the less confined upper rectum, larger tumors may directly impair mobilization and exposure. Previous studies have likewise suggested that the influence of tumor size on surgical difficulty varies according to tumor location, pelvic anatomy, and the outcome measure examined [24, 25].

Finally, our multivariable model demonstrated a moderate discriminative ability with an AUC of 0.693. While providing a reasonable framework for preoperative risk assessment, this level of performance suggests that clinicopathological variables alone are insufficient to capture the full spectrum of operative complexity. The integration of dynamic, imaging-based anatomical parameters—such as MRI or CT pelvimetry—may be essential to enhance the predictive accuracy and clinical utility of future difficulty models in robotic rectal surgery [26, 27].

Conclusion and Future Perspectives

In conclusion, male sex, higher BMI, tumor location 5–10 cm from the anal verge, and neoadjuvant CCRT were independent predictors of increased surgical difficulty in robotic rectal surgery. These findings suggest that, despite the technical advantages of robotic platforms, pelvic anatomy, mesorectal adiposity, and treatment-related fibrosis remain important determinants of operative complexity.

Although limited by its retrospective single-center design and focus on short-term outcomes, this study provides clinically relevant information for preoperative risk stratification and operative planning,

particularly during the early phase of the robotic learning curve. Future integration of imaging-based pelvimetry and artificial intelligence-assisted anatomical assessment may further improve the prediction of surgical difficulty and support individualized treatment strategies for rectal cancer.

Declarations

Previous Presentation

This work has not been previously presented at any scientific meeting or congress.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval

The study was approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E(II)-20250266).

Consent to Participate

The institutional review board waived the requirement for informed consent due to the retrospective nature of the study.

Consent to Publish

Not applicable.

Declarations of generative AI use

Generative AI was used solely for language editing and manuscript preparation. The authors take full responsibility for the content of the manuscript.

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Author Contribution

T.C.Y. contributed to the study conceptualization, data curation, formal analysis, methodology, visualization, and drafted the manuscript. W.C.S., T.K.C., I.C.L., F.S.C., P.J.C., C.C.L., Y.C.C., and C.C.C. contributed to data collection, investigation, and validation of clinical data. H.L.T. contributed to methodology development, supervision, and critical revision of the manuscript. C.W.H. and J.Y.W. contributed equally to conceptualization, supervision, project administration, and manuscript review and editing. All authors reviewed and approved the final manuscript.

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Data Availability Statement

The data underlying this article will be shared on reasonable request to the corresponding authors.

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