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ORIGINAL ARTICLE

Magnetic resonance-based pelvimetry and tumor volumetry can predict surgical difficulty and oncologic outcome in locally advanced mid–low rectal cancer

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Abstract

Purpose To investigate the impact of the pelvic dimensions and tumor volume on surgery in locally advanced rectal cancer.

Methods Patients who underwent open surgery after neoadjuvant long-course chemoradiation for primary rectal cancer were included. The predictive value of magnetic resonance-based pelvic measurements and tumor volume on the surgical difficulty and oncologic outcome were analyzed.

Results 125 patients were included. The independent risk factors related to the circumferential resection margin status were the pT stage [odds ratio (OR) 3.64, confidence interval (CI) 1.409–7.327] and tumor volume after neoadjuvant chemoradiotherapy (OR 1.59, CI 1.018–2.767). The operative time ($p = 0.014$, OR 1.453) and pelvic depth ($p = 0.023$, OR 1.116) were independent predictive factors for anastomotic leak. The median follow-up was 72 (2–113) months. Local recurrence was seen in 17 (14.1%) patients. Anastomotic leak (OR 1.799, CI 0.978–3.277), the circumferential resection margin status (OR 3.217, CI 1.262–7.870) and the relative tumor volume rate (OR 1.260, CI 1.004–1.912) were independent prognosticators of local recurrence. The 5-year overall survival was 66.7%. The circumferential resection margin status (hazard ratio: 4.739, CI 2.276–9.317), pN stage (OR 3.267, CI 1.195–8.930) and relative tumor volume rate (OR 2.628, CI 1.042–6.631) were independent prognostic factors for the overall survival.

Conclusions Relative dimensions of the tumor in the pelvis influence the local recurrence and overall survival rates. Magnetic resonance-based measurements can predict the difficulty of surgery and allow surgeons to consider the appropriate surgical approach.

Keywords Pelvimetry · Magnetic resonance · Rectal cancer · Survival · Local recurrence

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Introduction

Prognostic risk categorization of rectal cancer is mainly based on TNM staging. The penetration of the tumor through the bowel wall, as well as the presence of metastatic lymph nodes have been well-known determinants of oncologic results. However, information on the utility of clinical data on the pelvic dimensions and tumor volume has been very scarce, with conflicting findings reported in the literature [1, 2].

The quality of total mesorectal excision (TME) is directly associated with the rates of local recurrence and overall survival (OS) in rectal cancer [3–5]. The mesorectal integrity is influenced by many variables, including the stage of the disease, tumor dimensions, histopathologic features, circumferential resection margin (CRM) status and surgeon-, center- and patient-related factors [5, 6]. Several studies have demonstrated that surgical limitations related to difficult pelvic anatomy can compromise the quality of TME and result in higher rates of an involved CRM, surgical complications and local recurrence [5, 7, 8]. The surgical difficulty in radical rectal resection depends on the location and size of the tumor, as well as the accessibility to the tumor within the anatomic constraints of the bony pelvis. Easier dissection and a better quality of TME for a smaller tumor in a wider pelvis have been remarked by the majority of surgeons; however, objective evidence of the relationship between the pelvic anatomic measurements, tumor volume and outcome is lacking in the literature.

In this study, we assessed the impact of the tumor volume, pelvic dimensions and relative tumor/pelvis dimensions on the surgical and oncologic outcome in locally advanced mid–low rectal cancer.

Methods

The study was approved by the local ethics committee of Dokuz Eylul University Faculty of Medicine (Approval number: 381-GOA). An institutional board-approved prospective rectal cancer database was reviewed. Patients who received neoadjuvant long-course chemoradiotherapy (CRT) and underwent open TME for locally advanced (T3-4 or node positive) primary rectal cancer < 10 cm from the anal verge were included in the study. The tumor level was determined by rigid sigmoidoscopy according to the distance from the anal verge as follows: distal (0–5 cm) and middle (6–10 cm). Pelvimetric and volumetric measurements were obtained from magnetic resonance (MR) images by two radiologists blinded to the design of the study. The relationship between MR-based measurements and the surgical difficulty (operative time, blood loss, CRM status, anastomotic leak) and oncologic outcome (local recurrence and 5-year OS) were assessed.

Patients

Between October 2008 and February 2011, 267 patients with primary rectal cancer underwent radical resection with potential curative intent. The exclusion criteria were proximal tumors (> 10 cm) in 47 patients, incompletion of neoadjuvant treatment and/or protocol violation in 42 patients, laparoscopic surgery in 22 patients, synchronous distant/peritoneal metastasis in 21 patients, lack of proper MR imaging in 7 patients and poliposis coli syndrome in 3 patients.

All patients had colonoscopic biopsy-proven rectal cancer. Preoperative staging was performed with pelvic MR imaging and thoracoabdominal computed tomography (CT) before and after neoadjuvant therapy. Neoadjuvant long-course CRT consisted of 50.4-Gy irradiation and concomitant 225 mg/m^2/day 5-fluorouracil infusion. The schedule of treatment and imaging was a strict inclusion criterion: neoadjuvant CRT had to be started within 1 week after the first MR scan was obtained; the second MR scan had to be performed at week 7 after completing neoadjuvant CRT, with TME performed at week 8. Patients who did not meet this schedule were excluded.

MR imaging, pelvic measurements and tumor volumetry

Pelvic MR examinations were performed using a Philips Gyroscan NT15 Intera 1.5 T scanner (Philips Medical Systems, Boston MA, USA). Sagittal and axial T2-weighted sequences were downloaded onto a digital workstation (Philips Medical Systems), and the pelvic dimensions and tumor volume were measured using hand-drawn irregular 'regions of interest' for every section, as described by Curvo-Semedo et al. [9]. All measurements were made by the two blinded radiologists (FO, FDE), and pelvimetric measurements were repeated if the difference between the assessments of the two radiologists exceeded 10%.

Six pelvic diameters were measured (Fig. 1). The tumor volume was calculated before (V_1) and after (V_2) neoadjuvant CRT. The pelvic cavity index (PCI) was calculated by the formula [pelvic inlet (a) × interspinous distance/pelvic depth (b)]. The tumor volume regression rate (TVVR) was expressed as $[(V_1 - V_2) \times 100/V_1]$, and the relative tumor volume rate (RTVR) was expressed as $[(V_2/\text{PCI}) \times 100]$.

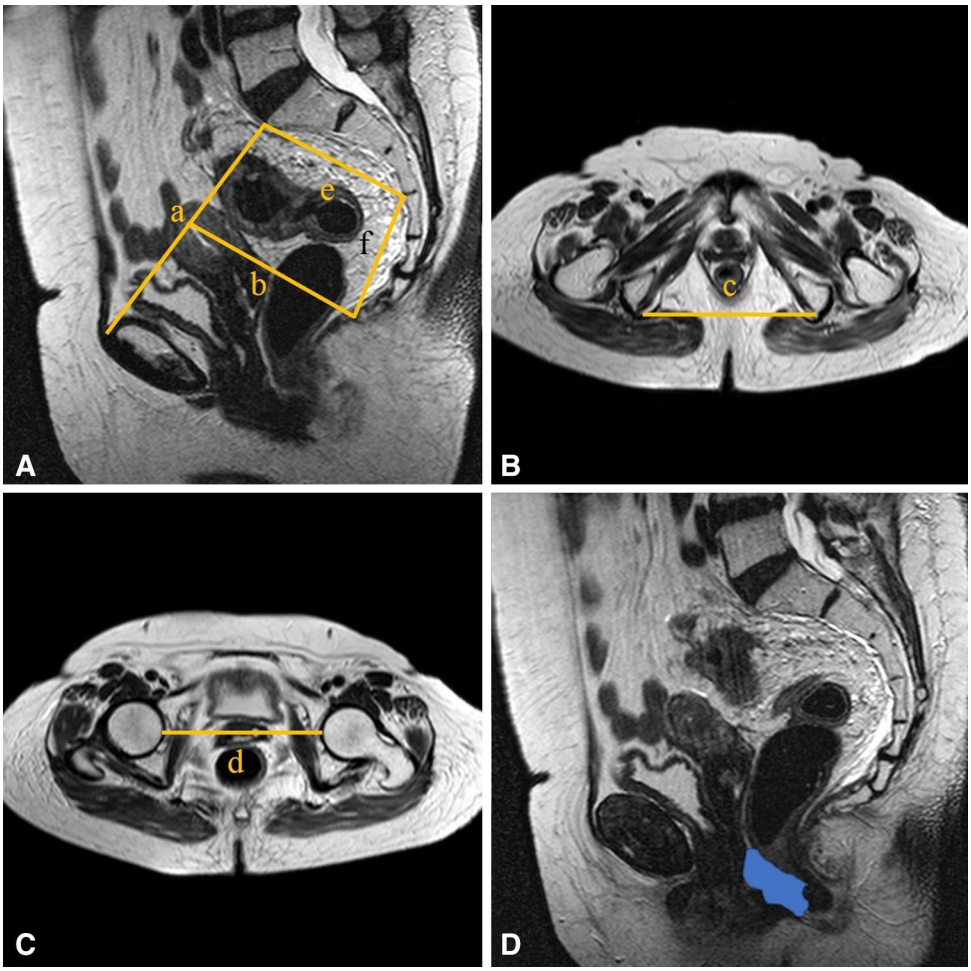

Fig. 1 Pelvic dimensions and volumetric measurements estimated by MR-based pelvimetry. **A** Pelvic inlet (a): distance between promontory and superior edge of symphysis pubis. Pelvic depth (b): distance between the center of inlet and coccyx. (e): Distance between sacral promontory and interdiscal space of S3–S4. (f): Distance between S3 and coccyx. **B** Intertuberous distance (c): distance between tuberosities of the ischium. **C** Interacetabular distance (d): distance between medial aspects of the femur heads. **D** Manual tracing of free-hand region of interests in one sectional area for calculation of tumor volume

Surgical technique

Radical open resection regarding TME principals was carried out by one of the three senior colorectal surgeons. Sphincter-preserving surgery was performed if a distal margin of 1 cm could be achieved, otherwise abdominoperineal resection was carried out. Double-stapled colorectal anastomosis was performed in all sphincter-preserving procedures. Diverting ileostomy was performed routinely. The duration between skin incision and closure was recorded as the operative time. Clinically or radiologically detected gastrointestinal extralumination or a pelvic abscess in the proximity of the anastomosis was considered indicative of an anastomotic leak [10].

Pathologic examinations and local recurrence

All specimens were examined in our institution by a pathologist blinded to the study (OS). Mesorectum integrity was determined as described by Quirke [5]: complete TME, nearly-complete TME and incomplete TME. Viable tumor cells within 1 mm of the resection plane were deemed to indicate a positive CRM. Tumor staging was recorded according to 7th TNM. Any anastomotic, pelvic or perineal recurrence was accepted as local recurrence. Recurrent disease was verified either radiologically with positron emission tomography/CT or histopathologically.

Statistical analyses

Statistical analyses were performed using the SPSS software program, ver. 20.0, for Windows. Continuous variables were expressed as means ± standard deviation and categorical variables as the frequency and percentages. Linear regression was performed to determine variables associated with the operative time and blood loss. Associations between categorical variables were tested with the Chi-square test. Associations between continuous variables were tested by an independent samples *t*-test.

Multivariate analyses of factors associated with the CRM status and local recurrence were assessed by logistic regression. The OS rates were calculated using the Kaplan–Meier estimator, and the log-rank test was used to identify differences among the survival curves. Cox's proportional hazard

model was used in univariate and multivariate analyses to assess the survival. p values < 0.05 were defined as statistically significant.

Results

Of 267 patients, 125 met the inclusion criteria. 71 (56.8%) patients were male. The median age was 59 (19–83) years. The tumor site was the low rectum in 76 (60.8%) patients. Sphincter-preserving surgery was performed in 91 (72.8%) patients. The demographic and clinical characteristics of the patients are summarized in Table 1.

Surgical outcome

The mean operative time was 133.6 ± 28.1 min. Male gender ($p = 0.045$), a deeper pelvis (b) ($p = 0.019$) and a smaller PCI ($p < 0.001$) were associated with longer operative times in a multivariate analysis. The mean intraoperative blood loss was 219.9 ± 162.2 ml. Pelvic inlet (a) ($p = 0.004$) and TVRR ($p = 0.011$) were independent risk factors for blood loss (Table 2).

Clear CRM was achieved in 87.2% of the patients. Patients with a higher body mass index (BMI; $p = 0.004$), advanced T stage ($p = 0.012$), narrower interacetabular distance (d) ($p = 0.002$), larger V_1 ($p = 0.017$) and V_2 ($p = 0.001$), lower TVRR ($p = 0.009$) and higher RTVR ($p = 0.003$) were more likely to have involved CRM than others. The independent risk factors associated with an involved CRM were pT stage [odds ratio (OR) 3.64, confidence interval (CI) 1.409–7.327] and V_2 (OR 1.59, CI 1.018–2.767) (Table 3). The cut-off value for V_2 to predict CRM involvement was 67.4 [area under the curve (AUC) 0.794] (Fig. 2).

Among 91 (72.8%) patients who underwent sphincter-preserving surgery, 9 (9.8%) had anastomotic leak. Four of those were managed with conservative approach, and the other five required relaparotomy (one died due to septic shock). The operative time ($p = 0.032$), blood loss ($p = 0.016$), pelvic depth ($p = 0.039$), distance between the sacral promontory and the interdiscal space of S3–S4 (e) ($p = 0.049$) and V_2 ($p = 0.030$) were significantly associated with anastomotic leak, while the operative time ($p = 0.014$, OR 1.453) and pelvic depth ($p = 0.023$, OR 1.116) were independent risk factors.

Perioperative mortality was seen in 5 (4%) patients: 2 pulmonary infection, 1 stroke, 1 urinary sepsis and 1 anastomotic leak.

Oncologic outcomes

The median follow-up was 72 (2–113) months. Local recurrence was seen in 17 (14.1%) patients. The median interval between surgery and local recurrence was 13 (5–29) months. Four (50%) out of 8 patients with anastomotic leak had local recurrence ($p = 0.009$). The local recurrence rate was significantly higher in patients with involved CRM than in those without it (8.6 vs. 53.3%, $p < 0.001$). The operative

Table 1 Demographic, surgical, and pathologic characteristics and pelvimetric measurements of the patients

Characteristic	$n = 125$
Age (mean ± SD, year)	59.1 ± 11.2
Sex	
Male	71 (56.8%)
Female	54 (43.2%)
BMI (mean ± SD, kg/m^2)	26.4 ± 3.9
Tumor level	
6–10 cm	49 (39.2%)
≤ 5 cm	76 (60.8%)
Surgical procedure	
SPS	91 (72.8%)
APR	34 (27.2%)
Blood loss (mean ± SD, ml)	219.9 ± 162.2
Operative time (mean ± SD, min)	133.6 ± 28.1
ypTN	
0	22 (17.6%)
1	5 (4%)
2	33 (26.4%)
3	55 (44%)
4	10 (8%)
Harvested lymph nodes (mean ± SD)	12.3 ± 8.4
Quality of TME	
Good/Intermediate	106 (84.8%)
Poor	19 (15.2%)
Involved CRM	16 (12.8%)
a (mean ± SD, mm)	116.8 ± 11.7
b (mean ± SD, mm)	105.9 ± 12.6
c (mean ± SD, mm)	88.3 ± 13.9
d (mean ± SD, mm)	124 ± 11.5
e (mean ± SD, mm)	76.5 ± 6.8
f (mean ± SD, mm)	61.8 ± 10.2
PCI (mean ± SD)	98.8 ± 31.9
V_1 (mean, range, mm^3)	312.6 (11.06–1074.2)
V_2 (mean, range, mm^3)	88.9 (0–724.7)
TVRR (mean ± SD)	73.7 ± 18.9
RTVR (mean ± SD)	96.2 ± 81.2

BMI body mass index, *SPS* sphincter-preserving surgery, *APR* abdominoperineal resection, *ypTN* pathologic TN stage in irradiated tumor, *TME* total mesorectal excision, *CRM* circumferential resection margin, *a* pelvic inlet, *b* pelvic depth, *c* intertuberous distance, *d* interacetabular distance, *e* distance between sacral promontorium and interdiscal space of S3–S4, *f* distance between S3 and coccyx, *PCI* pelvic cavity index, V_1 tumor volume before neoadjuvant therapy, V_2 tumor volume after neoadjuvant therapy, *TVRR* tumor volume regression rate, *RTVR* relative tumor volume rate, *SD* standard deviation

Table 2 Linear regression analysis of factors associated with operative time and intraoperative blood loss

	Operative time				Intraoperative blood loss			
	Univariate		Multivariate		Univariate		Multivariate	
	β	*p*	*β*	*p*	*β*	*p*	*β*	*p*
Sex	0.361	**< 0.001**	**0.190**	**0.045**	0.165	0.072		
Age	− 0.40	0.660			0.119	0.194		
BMI	0.021	0.817			0.082	0.374		
Tumor level	0.162	0.071			− 0.001	0.994		
T stage	− 0.62	0.491			0.109	0.237		
Surgeon	0.196	0.081			0.132	0.311		
a	− 0.357	**< 0.001**			− 0.246	**0.007**	**− 2.263**	**0.004**
b	0.269	**0.002**	**0.220**	**0.019**	0.255	**0.005**		
c	− 0.383	**< 0.001**			− 0.117	0.204		
d	− 0.057	0.526			− 0.114	0.216		
e	− 0.022	0.804			− 0.011	0.901		
f	0.107	0.235			− 0.064	0.487		
PCI	− 1.546	**< 0.001**	**− 0.404**	**< 0.001**	− 0.047	0.612		
V_1	0.023	0.797			− 0.028	0.760		
V_2	0.033	0.714			0.105	0.257		
TVRR	0.019	0.830			− 0.115	0.214		
RTVR	− 0.044	< 0.001			0.190	0.038	0.231	**0.011**

a pelvic inlet, *b* pelvic depth, *c* intertuberous distance, *d* interacetabular distance, *e* distance between sacral promontorium and interdiscal space of S3–S4, *f* distance between S3 and coccyx, *PCI* pelvic cavity index, V_1 tumor volume before neoadjuvant therapy, V_2 tumor volume after neoadjuvant therapy, *TVRR* tumor volume regression rate, *RTVR* relative tumor volume rate

Bold values indicate better results than other filtering methods

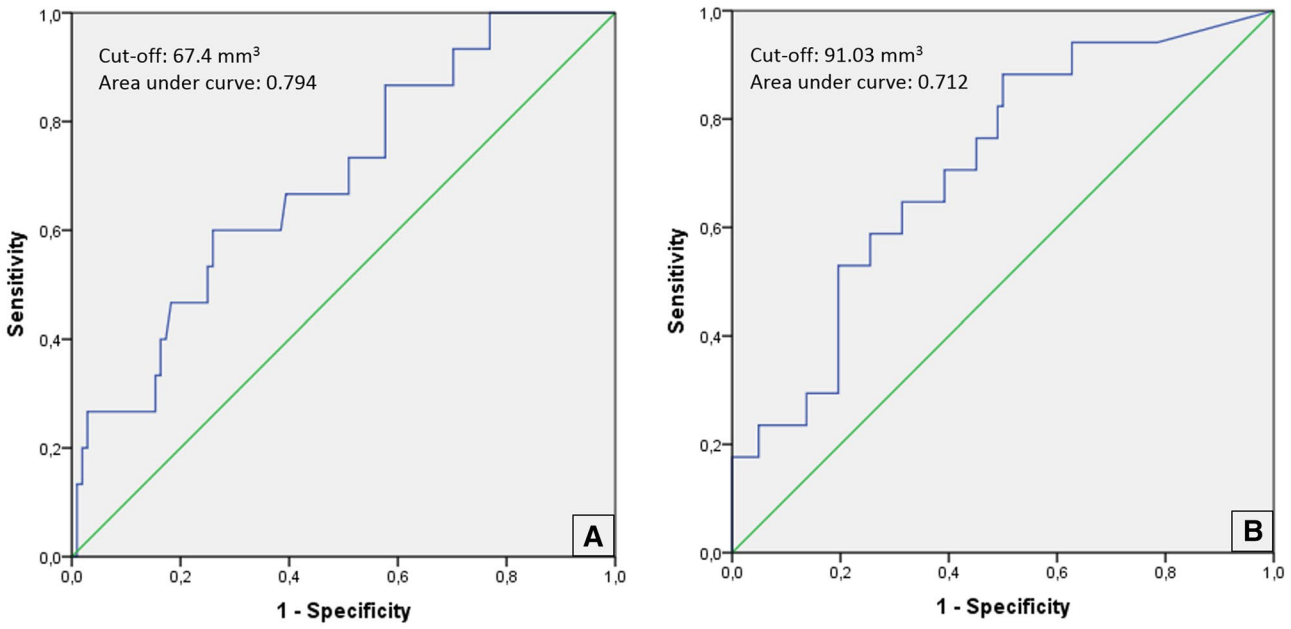

Fig. 2 ROC curves and cut-off values of independent prognostic pelvimetric factors. **a** Predictivity of volume after neoadjuvant chemotherapy (V_2) for involved circumferential resection margin. **b** Predictivity of relative tumor volume rate for local recurrence

Table 3 Factors associated with circumferential resection margin status

CRM status	Clear ($n=109$)	Involved ($n=16$)	p	Multivariate analysis (OR 95% CI)
Age (mean ± SD, year)			0.417	
Sex			0.557	
Female	46	9 (14.8%)		
Male	63	8 (11.3%)		
BMI			**0.004**	
Tumor level	23.7 ± 2.2	26.8 ± 4.1	0.073	
6–10 cm	46	3 (6.1%)		
≤ 5 cm	63	13 (17.1%)		
Surgical procedure			0.111	
SPS	82	9 (9.9%)		
APR	27	7 (20.6%)		
T stage			**0.012**	**3.64** (1.409–7.327)
pT 0–2	57	3 (5%)		
pT 3–4	52	13 (20%)		
a (mean ± SD, mm)	116.7 ± 11.8	117.6 ± 11.6	0.774	
b (mean ± SD, mm)	105.8 ± 12.6	106.3 ± 12.8	0.891	
c (mean ± SD, mm)	88.7 ± 14.4	86.4 ± 10.7	0.560	
d (mean ± SD, mm)	125.3 ± 10.8	115.3 ± 12.8	**0.002**	
e (mean ± SD, mm)	76.2 ± 6.8	77.8 ± 6.6	0.396	
f (mean ± SD, mm)	61.8 ± 10.4	61.6 ± 9.3	0.939	
PCI (mean ± SD)	99.6 ± 33.3	93.6 ± 19.9	0.503	
V_1 (mean ± SD, mm^3)	297.1 ± 155.3	420.7 ± 331	**0.017**	
V_2 (mean ± SD, mm^3)	76.1 ± 54.1	178.4 ± 96.9	**0.001**	**1.59** (1.018–2.767)
TVRR (mean ± SD)	75.4 ± 18.5	61.8 ± 18.4	**0.009**	
RTVR (mean ± SD)	82.9 ± 65.7	187.9 ± 130.3	0.003	

OR odds ratio, *CI* confidence interval, *SD* standard deviation, *TME* total mesorectal excision, *CRM* circumferential radial margin, *a* pelvic inlet, *b* pelvic depth, *c* intertuberous distance, *d* interacetabular distance, *e* distance between sacral promontorium and interdiscal space of S3–S4, *f* distance between S3 and coccyx, *PCI* pelvic cavity index, V_1 tumor volume before neoadjuvant therapy, V_2 tumor volume after neoadjuvant therapy, *TVRR* tumor volume regression rate, *RTVR* relative tumor volume rate

time ($p=0.012$), quality of TME ($p=0.001$), pT stage ($p=0.039$), pelvic depth (b) ($p=0.001$), intertuberous distance (c) ($p=0.027$), V_2 ($p=0.004$), TVRR ($p=0.001$) and RTVR ($p<0.001$) were other significant factors associated with local recurrence. A multivariate analysis revealed that anastomotic leak (OR 1.799, CI 0.978–3.277), CRM status (OR 3.217, CI 1.262–7.870) and RTVR (OR 1.260, CI 1.004–1.912) were independent prognostic factors of local recurrence (Table 4). The cut-off value for RTVR to predict local recurrence was 91.03 (AUC 0.712) (Fig. 2).

The 5-year OS was 66.7%. The quality of TME ($p<0.001$), CRM status ($p<0.001$), pT stage ($p=0.002$), pN stage ($p=0.001$), pathologic complete response ($p=0.034$), perineural invasion ($p=0.002$), adjuvant chemotherapy ($p=0.001$), pelvic depth (b) ($p=0.042$), PCI ($p=0.018$) and RTVR ($p=0.009$) were associated with the 5-year OS in the Kaplan–Meier analysis. The following factors were independent prognostic factors according to the multivariate analysis: CRM status (hazard ratio: 4.739, CI 2.276–9.317), pN stage (OR 3.267, CI 1.195–8.930) and RTVR (OR 2.628, CI 1.042–6.631) (Table 5).

Discussion

Adequate TME is a prerequisite for achieving success in the management of rectal cancer. Some patient- and/or tumor-related factors that cannot be altered by technology or managed with mastery of the learning curve have been proposed to be responsible for surgical failure. A high BMI, distal tumor, advanced T stage, neoadjuvant radiotherapy and history of abdominal surgery are well-known factors associated with difficulties and postoperative complications of TME [11–13]. However, objective data assessing the relationship between the pelvic anatomy and operative results are very limited and inconsistent.

In this study, we evaluated the influence of the anatomy and tumor volume on the surgical and oncologic outcomes

Table 4 Factors associated with local recurrence

Local recurrence	– ($n=103$)	+ ($n=17$)	p	Multivariate analysis (OR 95% CI)
Age (mean ± SD, year)	58.5 ± 11.7	62.8 ± 7.1	0.147	
Sex			0.789	
Female	46	7 (13.2%)		
Male	57	10 (14.9%)		
BMI	26.5 ± 3.9	25.6 ± 4.4	0.396	
Tumor level			0.724	
6–10 cm	41	6 (12.8%)		
≤ 5 cm	61	11 (15.1%)		
Operative time (mean ± SD, min)	129.7 ± 23.9	157.1 ± 39	**0.012**	
Blood loss (mean ± SD, ml)	212.7 ± 155.1	263.8 ± 199.2	0.230	
Surgical procedure			0.635	
SPS	73	13 (15.1%)		
APR	30	4 (11.8%)		
Surgeon			0.153	
#1	36	7 (18.4%)		
#2	21	2 (9%)		
#3	35	8 (18.6%)		
Anastomotic leak			**0.009**	**1.799** (0.978–3.277)
(−)	69	9 (11.5%)		
(+)	4	4 (50.0%)		
Quality of TME			**0.001**	
Good/Intermediate	90	11 (10.9%)		
Poor	13	6 (31.6%)		
CRM			< **0.001**	**3.217** (1.262–7.870)
(−)	96	9 (8.6%)		
(+)	7	8 (53.3%)		
T stage			**0.039**	
pT 0–2	52	4 (7.1%)		
pT 3–4	51	13 (20.3%)		
N stage			0.077	
pN (–)	81	10 (11%)		
pN (+)	22	7 (24.1%)		
pCR			0.152	
(–)	82	16 (16.3)		
(+)	21	1 (4.5%)		
Lymphatic invasion			0.905	
(–)	59	10 (14.5%)		
(+)	44	7 (13.7%)		
Venous invasion			0.864	
(–)	83	14 (14.4%)		
(+)	20	3 (13%)		
Perineural invasion			0.403	
(–)	82	12 (12.8%)		
(+)	21	5 (19.2%)		
Adjuvant chemotherapy			0.076	
(–)	81	10 (11%)		
(+)	22	7 (24.1%)		
a (mean ± SD, mm)	117.7 ± 12.1	111.7 ± 7.3	0.050	
b (mean ± SD, mm)	104.4 ± 12.2	115.1 ± 11.4	**0.001**	
c (mean ± SD, mm)	89.5 ± 14.1	81.4 ± 10.4	**0.027**	

Table 4 (continued)

Local recurrence	– ($n=103$)	+ ($n=17$)	p	Multivariate analysis (OR 95% CI)
d (mean ± SD, mm)	124.8 ± 11.2	119.4 ± 12.7	0.078	
e (mean ± SD, mm)	76.1 ± 6.7	78.7 ± 7.6	0.142	
f (mean ± SD, mm)	61.2 ± 10.4	65.7 ± 8.5	0.091	
PCI (mean ± SD)	101.7 ± 33.4	81.4 ± 10.1	**0.015**	
V_1 (mean ± SD, mm^3)	291.1 ± 147.5	509.4 ± 312.4	0.535	
V_2 (mean ± SD, mm^3)	77.3 ± 90.7	163.9 ± 201.8	**0.004**	
TVRR (mean ± SD)	76.6 ± 16.6	61.2 ± 18.5	**0.001**	
RTVR (mean ± SD)	77.8 ± 86.3	206.6 ± 254.4	< 0.001	1.260 (1.004–1.912)

OR odds ratio, *CI* confidence interval, *SD* standard deviation, *TME* total mesorectal excision, *CRM* circumferential radial margin, *a* pelvic inlet, *b* pelvic depth, *c* intertuberous distance, *d* interacetabular distance, *e* distance between sacral promontorium and interdiscal space of S3–S4, *f* distance between S3 and coccyx, *PCI* pelvic cavity index, V_1 tumor volume before neoadjuvant therapy, V_2 tumor volume after neoadjuvant therapy, *TVRR* tumor volume regression rate, *RTVR* relative tumor volume rate

of open TME. We analyzed not only the pelvic dimensions but the tumor volume and tumor/pelvis volume relativity. Our results indicated that the pelvic anatomy, tumor volume and tumor/pelvis relationship influence the surgical difficulty and rates of local recurrence and survival.

When deciding on neoadjuvant treatment for rectal cancer, the accurate prediction of the CRM status and involved lymph nodes as well as distant metastasis are essential. Guidelines recommend thoracoabdominal CT for systemic screening and MR or endorectal ultrasound for local staging of the tumor [14]. Recently, there has been a trend toward using CT alone for initial staging, as CT is more widely available and enables screening of the thorax, liver, peritoneum and pelvis all at once for a lower cost than CT with MR imaging [15]. However, the predictive value of CT for involved CRM is decreased in low-lying tumors. MR imaging is more accurate than CT for detecting subcentimetric lymph nodes and mesorectal fascia status in distal tumors [16]. The reproducibility and a better understanding of the levators are other advantages associated with MR imaging [17]. A recent study including 559 patients assessed the quality of CT and MR imaging for the preoperative staging of rectal cancer and concluded that MR imaging was underutilized, CT reporting of the mesorectal fascia status was low, and the accuracy of T and N staging were similar. This study included patients from several institutions in a wide region of Ontario and highlighted the importance of standardized technics and reporting of imaging modalities. At our institution, we have a colorectal team including a radiologist specializing in rectal cancer with the ability to perform MR routinely with standardized techniques and reporting. Our study includes mid–low-rectal tumors. We, therefore, preferred to use MR imaging for local staging and pelvimetric/volumetric measurements.

A reliable indicator of the difficulty of pelvic dissection may help deciding the surgical procedure (open, laparoscopic, robotic or transanal) as well as stoma and/or anastomosis formation, and (neo-)adjuvant therapies. Surgical difficulty was demonstrated by the operative time, intraoperative blood loss, CRM involvement and rate of anastomotic leak in our study. The surgery was performed by one of three senior colorectal surgeons. Surgical difficulty may depend on the surgeons' skills, but this was not a significant factor in our series. All of the surgeons had similar results regarding the operative time, blood loss and rates of local recurrence and 5-year OS. The definition of operative time was a limitation, as the pure pelvic dissection time was lacking in our records, and abdominoperineal resections were included in the study. In their study including 79 laparoscopic low anterior resections, Akiyoshi et al. [18] represented surgical difficulty as the pelvic dissection time and showed that pelvic outlet as well as the BMI, tumor distance from anal verge and tumor depth were independent predictive factors of the operative time. They did not find any association between the pelvic measurements and postoperative complications [18]. In our study, the pelvic depth and operative time were independent risk factors for anastomotic leak. Another study focusing on pelvic dimensions by Killeen et al. [19] showed that a less acutely curved sacrum and wider pelvic outlet were associated with a longer operative time. In contrast, Ogiso et al. [20] suggested no correlation between the pelvic dimensions and operative time in 50 patients who underwent laparoscopic TME. The tumor size, BMI and tumor location were also independent predictors of the operative time in their study. In our study, male gender, a deeper pelvis and a smaller peritoneal cavity independently predicted a longer operative time. The pelvic inlet and relative tumor/pelvis volume were independently correlated with the intraoperative blood loss. In contrast with the findings of other studies, the BMI was not significantly associated with surgical difficulty, probably because our series consisted of open TME procedures.

Table 5 Factors associated with 5-year overall survival

Variables	*n*	5-year OS (%)	*p*	Multivariate analysis (HR 95% CI)
Age				
≤ 65	86	67.4	0.783	
> 65	34	64.7		
Sex			0.353	
Female	53	71.7		
Male	67	62.7		
Tumor level			0.398	
6–10 cm	47	61.7		
≤ 5 cm	73	69.9		
Surgical procedure			0.262	
SPS	86	73.5		
APR	34	64		
Surgeon			0.750	
#1	43	69.8		
#2	23	65.2		
#3	54	64.8		
Anastomotic leak			0.074	
(−)	73	67.1		
(+)	13	46.2		
Quality of TME			**< 0.001**	
Good/Intermediate	101	74.3		
Poor	19	26.3		
CRM			**< 0.001**	**4.739** (2.276–9.317)
(−)	105	71.4		
(+)	15	33.3		
T stage			**0.002**	
pT 0–2	56	80.4		
pT 3–4	64	54.7		
N stage			**0.001**	**3.267** (1.195–8.930)
pN (−)	91	74.7		
pN (+)	29	41.4		
pCR			**0.034**	
(+)	22	86.4		
(−)	98	62.2		
Lymphatic invasion			0.395	
(−)	69	69.6		
(+)	51	62.7		
Venous invasion			0.371	
(−)	97	73.9		
(+)	23	64.9		
Perineural invasion			**0.002**	
(−)	94	73.4		
(+)	26	42.3		
Adjuvant chemotherapy			**0.001**	
(−)	81	74.7%		
(+)	22	41.4%		
a (mm)			0.456	
< 116	55	63.6		
≥ 116	65	69.2		
b (mm)			**0.042**	

Table 5 (continued)

Variables	*n*	5-year OS (%)	*p*	Multivariate analysis (HR 95% CI)
< 107	60	75		
≥ 107	60	58.3		
c (mm)			0.349	
< 88	62	62.9		
≥ 88	58	70.7		
d (mm)			0.868	
< 127	63	66.7		
≥ 127	57	66.7		
e (mm)			0.250	
< 77	63	71.4		
≥ 77	57	61.4		
f (mm)			0.098	
< 60	62	74.2		
≥ 60	58	58.6		
PCI			**0.018**	
< 91	55	56.4		
≥ 91	65	75.4		
V_1 (mm^3)			0.287	
< 292	63	61.9		
≥ 292	57	71.9		
V_2 (mm^3)				
< 69	62	74.2	0.079	
≥ 69	58	58.6		
TVRR			0.076	
< 74	58	58.6		
≥ 74	62	74.2		
RTVR			**0.009**	**2.628** (1.042–6.631)
< 70	61	77		
≥ 70	58	55.2		

OR odds ratio, *CI* confidence interval, *SD* standard deviation, *TME* total mesorectal excision, *CRM* circumferential radial margin, *a* pelvic inlet, *b* pelvic depth, *c* intertuberous distance, *d* interacetabular distance, *e* distance between sacral promontorium and interdiscal space of S3–S4, *f* distance between S3 and coccyx, *PCI* pelvic cavity index, V_1 tumor volume before neoadjuvant therapy, V_2 tumor volume after neoadjuvant therapy, *TVRR* tumor volume regression rate, *RTVR* relative tumor volume rate

In patients who received long-course neoadjuvant CRT, the CRM status is an indicator of adequate surgery and the major prognostic factor for local recurrence [3, 7]. Previous studies reported that a narrow pelvis is associated with poor operative outcomes, including an increased rate of anastomotic leak and an involved CRM [4, 12, 21]. In 2004, Boyle et al. showed the significance of preoperative MR imaging on predicting CRM positivity in female patients [12]. In their study of 126 patients, they concluded that preoperative MR imaging can be used to estimate surgical resectability and help proper patient selection for neoadjuvant CRT. In contrast, Salerno et al. stated that the only predictive factor for CRM positivity was the tumor height; however, MR-pelvimetry and CRM positivity had no significant relationship. In their cohort of 186 patients, 18.8% of those who received neoadjuvant long-course CRT had rectal cancer [11]. In our series patients were homogenous regarding neoadjuvant treatment. In distal tumors, the rate of involved CRM was higher than in mid-rectal tumors (6.1 vs. 17%), but the difference was not statistically significant, presumably due to a type-2 error (false negative). The initial tumor volume, tumor response to neoadjuvant treatment and relative tumor/pelvis volume relationship were significantly associated with the CRM status. The pT stage and tumor volume after neoadjuvant CRT were independent risk factors.

The tumor volumetry and tumor volume regression measured by MR imaging have been proposed to be correlated with the pathologic tumor response to neoadjuvant CRT and the survival in several studies [21–26]; however, the results are conflicting. Most of those studies include both colon and

rectal tumors, and the analyses were performed with regard to either pelvic diameters or tumor size [1, 26, 27]. Nougaret et al. [26] showed that a TVRR of at least 70% was associated with a better disease-free survival in 51 patients with mostly low-lying tumors. In another study, Ferko et al. [28] assessed the association between the pelvimetry parameter A5 (the angle between the longitudinal axis of the symphysis, and the lines between the symphysis and the promontory) and the quality of TME. They concluded that pelvic measurements can be useful for determining the risk of poor mesorectum integrity and aid in the consideration of adopting a transanal approach. In a study performed by Yeo et al., 430 patients with locally advanced rectal cancer underwent pre-CRT and post-CRT MR-pelvimetry. The tumor volume regression rate was found to be an independent prognostic factor for both disease-free survival and OS [22]. In contrast to other studies, we evaluated the relationship between the size of the tumor and the size of the pelvis. The relative tumor volume regression rate was an independent predicator of local recurrence and the 5-year OS in our series.

A few studies have focused on laparoscopic or robotic resections that were suggested to overcome anatomic challenges. In our study, we did not include laparoscopic procedures, since the number was too small to perform an analysis. In a study of 74 laparoscopic procedures, Kim et al. [29] evaluated the anatomical difficulty with pelvic dissection time and found that a long sacrum, shallow sacral angle, narrow pelvis and large tumor were associated with prolonged dissection. They categorized the patients into three groups according to the MR pelvimetric measurements: easy group, moderate group and difficult group. The intraoperative complication rate was significantly higher in the difficult group than in the other groups. In 2013, the same group published the results of robotic resections, indicating that a high BMI, neoadjuvant CRT and lower tumor location were significantly associated with a longer operative time, while the pelvimetric parameters were not [28]. They concluded that the outcome of robotic surgery was not influenced by pelvic anatomy. In addition to these reports, the drawbacks of laparoscopic TME in a narrow pelvis have been demonstrated in several studies [19, 30–32]. Transanal TME is a promising technique for high-risk distal tumors regarding CRM positivity. A recent meta-analysis of 209 transanal and 257 laparoscopic TME procedures in mid- and low-rectal cancer concluded that a transanal approach is superior to laparoscopy in terms of the CRM involvement, quality of TME and operative time [33]. Randomized studies are needed to identify the most favorable technique for managing difficult TME.

The tumor size, pelvic dimensions and tumor/pelvis relationship predict the surgical difficulty, local recurrence and survival in locally advanced mid- and low-rectal cancer. MR-based measurements may aid in the planning of rectal surgery, contribute to the TME quality and positively influence surgeons' intuitive choices in high-risk patients. Based on the preoperative MR-pelvimetry, alternative approaches, such as robotic or transanal TME, may be considered.

Compliance with ethical standards

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

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