Radiotherapy and Oncology 221 (2026) 111604

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original Article

Anatomic distribution of postoperative recurrence and radiotherapy target volume optimization in rectal cancer: A large-scale real-world study

Yueying Zhang [a,1], Qingliang Lin [a,b,c,1], Hongbin Cai [a,b,c], Zhenxin Zhao [a], Zhaohan Zeng [a], Yaobin Lin [a,b,c,*], Jianwu Chen [a,b,c,*]

[a] Department of Radiation Oncology, Fujian Medical University Union Hospital, Clinical Research Center for Radiology and Radiotherapy of Fujian Province (Digestive, Haematological and Breast Malignancies), Fuzhou, Fujian, China
[b] Fujian Key Laboratory of Intelligent Imaging and Precision Radiotherapy for Tumours (Fujian Medical University), Fuzhou, Fujian, China
[c] Clinical Research Center for Radiology and Radiotherapy of Fujian Province (Digestive, Haematological and Breast Malignancies), Fuzhou, Fujian, China

ARTICLE INFO

Keywords:
Rectal cancer
Tumour height
Pattern of failure
Clinical target volume
Low anterior resection syndrome

ABSTRACT

Objective: To characterize the anatomic pattern of postoperative recurrence in rectal cancer and determine whether irradiation of the distal mesorectum is necessary during preoperative radiotherapy, thereby informing safe target-volume reduction.

Methods: We retrospectively analyzed 2,530 patients with rectal cancer who underwent total mesorectal excision (TME) at our institution between 2006 and 2024, with protocolized postoperative follow-up. Survival was evaluated using Kaplan–Meier methods, and independent predictors were identified with Cox proportional hazards models. Recurrence topography was visualized using a registration-based, voxel-wise probabilistic atlas. We quantified the vertical distance from the caudal edge of each recurrence to the coccygeal tip plane. In sphincter-preserved patients, bowel function was assessed with the Low Anterior Resection Syndrome (LARS) score.

Results: In the overall cohort, pelvic-floor recurrence occurred in 0.75%; no pelvic-floor recurrence was observed in the high rectal subgroup. Pelvic-floor recurrence was rare, and no statistically significant difference in survival outcomes was observed; however, this comparison was limited by the small number of events. Independent predictors of recurrence included family history of non-colorectal malignancy, poor differentiation, surgical approach, pT4 stage, pN positivity, and M1 disease. Compared with open surgery, laparoscopic surgery was associated with a lower risk of recurrence. After excluding pelvic-floor, anastomotic, and visceral recurrences, the most caudal in-field recurrence in mid/high rectal cancer remained above the coccygeal tip (mid rectum: 56.88 mm [45.21–68.56]; high rectum: 64.18 mm [45.35–83.01]). Long-term bowel function was favorable: 125 patients (88.65%) had LARS scores $\leq$ 20, 6 (4.26%) had scores of 21–29, and 10 (7.09%) had scores $\geq$ 30.

Conclusions: Pelvic-floor recurrence after rectal cancer surgery was rare in this cohort. The small number of events precluded a definitive survival analysis, and no statistically significant association with overall survival was detected (HR 0.986; 95% CI 0.139–7.018). In mid/high rectal cancer, the caudal boundary of in-field recurrence lies cranial to the coccygeal tip, suggesting limited benefit from routine distal mesorectal coverage. These anatomic recurrence data provide exploratory support for selective distal CTV de-escalation in mid/high rectal cancer, but prospective validation with treatment-plan-based dosimetric assessment is required before clinical implementation.

Introduction

With the standardized implementation of total mesorectal excision (TME) and neoadjuvant chemoradiotherapy, local control in rectal cancer has improved substantially. A large body of randomized trials and population-based studies has established that preoperative radiotherapy effectively reduces local recurrence and remains a cornerstone of multimodal treatment for locally advanced disease [1–3]. However,

* Corresponding authors at: Department of Radiation Oncology, Fujian Medical University Union Hospital, Fuzhou 350001, Fujian Province, China.
E-mail addresses: yaobinlin@aliyun.com (Y. Lin), chenjianwucn@aliyun.com (J. Chen).
[1] These authors contributed equally to this work and share first authorship.

https://doi.org/10.1016/j.radonc.2026.111604
Received 25 February 2026; Received in revised form 26 April 2026; Accepted 14 May 2026
Available online 23 May 2026
0167-8140/© 2026 Elsevier B.V. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

in the TME era, although radiotherapy retains clear value for local control, its incremental benefit for overall survival is modest, while long-term treatment-related functional impairment has become increasingly prominent [4,5]. This shift has fundamentally reframed clinical decision-making: rather than pursuing maximal local control at any cost, current practice must optimize the balance between oncologic safety and long-term quality of life [4].

In rectal cancer, the central goals of preoperative radiotherapy are tumour downstaging, higher rates of radical resection and sphincter preservation, and reduced risk of local failure [6,7]. As surgical quality and systemic therapy continue to improve, postoperative local recurrence rates have declined overall, and the absolute marginal benefit of radiotherapy in selected subgroups is narrowing [1,8,9]. At the same time, late pelvic radiation sequelae—particularly chronic bowel toxicity and quality-of-life deterioration—are increasingly recognized as major determinants of long-term outcomes [3,10]. Therefore, a critical question for precision radiotherapy is no longer whether to irradiate broadly, but how to reduce unnecessary radiation exposure without compromising oncologic safety.

Recent failure-pattern studies indicate that the anatomic distribution of postoperative recurrence is tightly linked to primary tumour height [11–13]. Retrospective analyses have shown that recurrence in pelvic-floor-related regions is uncommon, and is particularly rare in high rectal cancer [11]. This height-dependent pattern is anatomically plausible, aligning with segment-specific pelvic anatomy and lymphatic drainage [12], and suggests that the pelvic floor is not a dominant failure site in high rectal tumours [14]. Nevertheless, conventional irradiation of the entire mesorectal nodal drainage territory for all rectal cancers may not reflect the true spatial risk distribution of recurrence. A comparable de-intensification logic has already gained international consensus in nasopharyngeal carcinoma: the 2024 international guideline by Lin et al. emphasized risk-adapted selective coverage and dose optimization [15] and additional studies have demonstrated that systematic failure-pattern analysis with stepwise reduction of low-yield target volumes can lower normal-tissue dose while preserving local control [16]. By the same principle, preoperative radiotherapy for rectal cancer should not assign equal priority to all pelvic compartments, but should concentrate dose on anatomically high-risk regions. Reappraising target-volume boundaries on the basis of postoperative recurrence topography is therefore clinically justified and timely.

Against this background, we used a large real-world cohort to systematically map the anatomic distribution of postoperative recurrence in rectal cancer, with a specific focus on its association with tumour height. By directly comparing observed failure patterns with current target-volume coverage, we aimed to test the feasibility of reducing irradiation to low-yield regions without compromising prognosis. This study provides empirical support for moving rectal radiotherapy from an experience-based "one-template-fits-all" strategy toward failure pattern-informed, precision target delineation.

Methods

Study design and population

This was a single-center retrospective cohort study. We consecutively enrolled patients treated between 2006 and 2024 who underwent total mesorectal excision (TME) for rectal cancer and completed protocolized postoperative imaging follow-up at our institution. Protocolized follow-up included review of electronic medical records and telephone follow-up, together with regular postoperative clinical assessment and imaging surveillance, consisting of pelvic Magnetic Resonance Imaging (MRI) and/or contrast-enhanced Computed Tomography (CT), with Positron Emission Tomography-Computed Tomography (PET-CT) performed when clinically indicated. All cases were pathologically confirmed as rectal carcinoma. After excluding patients with concurrent non-rectal malignancies, we included 2,530 patients in the final analysis.

Tumour-height stratification

Tumour height was determined using the institutional database, which included the baseline MRI accession number, the full MRI report, the full endoscopy report, operative records, and diagnostic and staging information. When the tumour-height information from MRI, endoscopy, and postoperative records was concordant, the recorded value was used directly. In cases of discrepancy, the baseline pelvic MRI was reviewed and tumour height was reassessed according to the distance from the anal verge to the lower border of the tumour. Patients were then stratified into three predefined groups: low rectal cancer (<5 cm), mid-rectal cancer (5–9 cm), and high rectal cancer (≥ 10 cm).

Treatment and radiotherapy details

Neoadjuvant treatment was determined by a multidisciplinary team according to tumour stage, tumour height, patient condition, and institutional practice. Neoadjuvant radiotherapy was delivered according to contemporary guideline-recommended regimens, including long-course chemoradiotherapy, typically 50 – 50.4 Gy in 25 – 28 fractions with concurrent fluoropyrimidine-based chemotherapy, or short-course radiotherapy of 25 Gy in 5 fractions when clinically indicated. The pelvic clinical target volume generally included the primary tumour, mesorectum, presacral region, and relevant pelvic nodal drainage regions, with distal coverage defined according to institutional protocols and contemporary guidelines. Because this retrospective cohort spanned 2006 – 2024, radiotherapy techniques and target − delineation practices evolved over time. Individual dose distributions were not available for all patients; therefore, this study evaluated anatomical recurrence patterns rather than patient-level dose–recurrence relationships.

Definition of recurrence sites

Local recurrence was identified on the basis of postoperative pelvic MRI, CT, or PET-CT findings, with histopathological confirmation when available. When recurrence was suspected during follow-up, the corresponding imaging studies were re-reviewed and recurrent lesions were delineated for construction of the anatomical recurrence atlas. Lesions were subsequently classified according to predefined anatomical criteria as anastomotic, presacral, intrapelvic nodal, pelvic-floor, or intrapelvic organ recurrence. Anastomotic recurrence was defined as recurrence at the anastomotic site; presacral recurrence as recurrence in the presacral space; intrapelvic nodal recurrence as recurrence within pelvic nodal drainage regions; pelvic-floor recurrence as a lesion located at or below the coccygeal tip plane on axial imaging and involving the levator ani muscle, intersphincteric plane, or ischioanal fossa; and intrapelvic organ recurrence as recurrence involving pelvic organs such as the bladder, prostate, or vagina. Anastomotic recurrences extending into the pelvic floor were classified as anastomotic rather than pelvic-floor recurrence according to the predefined classification rules.

Recurrence mapping and atlas construction

For patients with locoregional recurrence, imaging at first recurrence was reviewed using pelvic MRI, CT, or PET − CT when clinically indicated. Recurrent lesions were delineated by radiation oncologists and reviewed by a senior radiation oncologist. Lesions were mapped onto a common pelvic reference image using anatomical landmarks, including the sacrum, coccyx, pubic symphysis, and pelvic sidewalls. A voxel − wise recurrence density atlas was generated by summing mapped recurrence regions, with warmer colours indicating higher recurrence density. The coccygeal tip plane was used as the anatomical reference for measuring the vertical distance from the caudal border of each recurrence to the coccygeal tip plane. For analyses focused on radiotherapy-modifiable in-field recurrence, anastomotic, pelvic-floor, and intrapelvic organ recurrences were excluded; therefore, the

distance analysis focused on presacral and pelvic nodal drainage recurrences.

Treatment characteristics and follow-up

We collected demographic characteristics, preoperative stage, neoadjuvant treatment, surgical approach, and pathological findings. Baseline stratification was primarily performed according to tumour height, and clinicopathological characteristics were compared between patients with and without locoregional recurrence. We defined time to recurrence as the interval from surgery to first documented recurrence. Overall survival (OS) was defined as the time from surgery to death from any cause. Patients who were still alive at the last follow-up were censored at that date.

Bowel-function assessment

We assessed bowel function using the Low Anterior Resection Syndrome (LARS) score. This five-item instrument quantified stool frequency, urgency, incontinence, and clustering. Total scores ranged from 0 to 42 and were categorized as no LARS (0–20), minor LARS (21–29), and major LARS (30–42). Among all sphincter-preserved patients who had completed at least 36 months of postoperative follow-up (n = 1737), we used simple random sampling to select 141 patients for LARS assessment. Patients with ongoing pelvic infection, permanent stoma without reversal, or active recurrent disease were excluded from the sampling frame. *Statistical analysis.*

We performed all statistical analyses using IBM SPSS Statistics, version 27.0 (IBM Corp., Armonk, NY, USA). For comparisons between recurrence and non-recurrence groups, we used the chi-square test for categorical variables and the Mann–Whitney *U* test for continuous variables. We estimated survival using the Kaplan–Meier method. We performed univariable and multivariable analyses using Cox proportional hazards models. Variables entered into the initial multivariable model were selected based on clinical relevance, prior literature, and potential confounding effects, regardless of their significance in univariable analysis, and backward stepwise (likelihood-ratio) selection was then applied to identify independent predictors [17–19]. A two-sided $p < 0.05$ was considered statistically significant.

Results

The median follow-up was 55 months. Among 2,530 patients, 138 developed locoregional recurrence (5.45%). Compared with patients without recurrence, those with recurrence were more frequently younger than 60 years (63.77% vs 55.02%), had higher carcinoembryonic antigen (CEA) levels (6.00 ng/mL vs 4.70 ng/mL) and CA19-9 levels (17.50 U/mL vs 12.67 U/mL), and had higher rates of lymphovascular invasion (12.32% vs 5.23%) and perineural invasion (21.01% vs 10.83%) (Table 1).

Kaplan–Meier analysis showed cumulative recurrence probabilities of 4.29% at 3 years and 5.89% at 5 years (Fig. 1A). The crude recurrence proportions by tumour height were 6.27% in low rectal cancer, 5.04% in mid-rectal cancer, and 4.25% in high rectal cancer (Table 2), whereas Kaplan–Meier curves showed no significant difference in cumulative recurrence probability among the three groups (Fig. 1B). The most frequent recurrence sites were the pelvic nodal drainage region (2.69%) and the anastomotic site (2.25%), while pelvic-floor recurrence was rare overall (0.75%). No pelvic-floor recurrence was observed in the high-rectal subgroup, and this pattern remained unchanged after stratification by radiotherapy status (Tables 3 and 4).

We further mapped recurrences in the presacral and pelvic nodal drainage regions (Fig. 2). The vertical distance from the caudal border of each lesion to the coccygeal tip plane is summarized in Table 5. In mid- and high-rectal cancer, these distances were 56.88 mm (45.21–68.56 mm) and 64.18 mm (45.35–83.01 mm), respectively.

Table 1
Baseline characteristics.

Variable	Recurrence (n = 138)	No recurrence (n = 2392)	*p*
Tumour location			
Low	64(46.38%)	957(40.01%)	0.289
Middle	63(45.65%)	1187(49.62%)	
High	11(7.97%)	248(10.37%)	
Sex			
Male	83(60.14%)	1554(64.97%)	0.249
Female	55(39.86%)	838(35.03%)	
Age			
<60	88(63.77%)	1316(55.02%)	0.044
≥60	50(36.23%)	1076(44.98%)	
Family history			
None	125(90.58%)	2238(93.76%)	0.101
History of CRC	4(2.90%)	74(3.10%)	
History of other cancers	9(6.52%)	75(3.14%)	
Smoking			
No	95(68.84%)	1585(66.26%)	0.533
Yes	43(32.16%)	807(33.74%)	
Drinking			
No	114(82.61%)	1904(79.60%)	0.392
Yes	24(17.39%)	488(20.40%)	
CEA (ng/mL)			
Median(range)	6.00(3.00–14.70)	4.70(2.40–11.35)	0.022
CA199 (U/mL)			
Median(range)	17.50 (8.70–41.00)	12.67 (7.00–24.30)	0.006
Pathological type			
Carcinoma,NOS	12(8.70%)	144(6.02%)	0.132
Adenocarcinoma	123(89.13%)	2224(92.98%)	
Signet-ring cell carcinoma	2(1.45%)	17(0.67%)	
Squamous cell carcinoma	1(0.72%)	3(0.12%)	
Neuroendocrine carcinoma	0(0.00%)	4(0.16%)	
Histologic differentiation			
Poorly differentiated	21(15.22%)	86(3.60%)	<0.001
Moderately differentiated	67(48.55%)	1260(52.68%)	
Well differentiated	0(0.0%)	21(0.88%)	
Not recorded	50(36.23%)	1025(42.85%)	
Neoadjuvant radiotherapy			
No	4(2.90%)	101(4.22%)	0.448
Yes	134(97.10%)	2291(95.78%)	
Neoadjuvant chemotherapy			
No	9(6.52%)	143(5.98%)	0.794
Yes	129(93.48%)	2249(94.02%)	
Neoadjuvant targeted therapy			
No	127(92.03%)	2248(93.98%)	0.353
Yes	11(7.97%)	144(6.02%)	
Surgical approach			
Open surgery	36(26.09%)	320(13.38%)	<0.001
Laparoscopic surgery	95(68.84%)	1979(82.73%)	
Transanal TME	7(5.07%)	93(3.89%)	
Lymph node dissection			
No	7(5.07%)	108(4.52%)	0.760
Yes	131(94.93%)	2284(95.48%)	
LVI			
No	121(87.68%)	2267(94.77%)	<0.001
Yes	17(12.32%)	125(5.23%)	
PNI			
No	109(78.99%)	2133(89.17%)	<0.001
Yes	29(21.01%)	259(10.83%)	
TRG			0.533
0	14(10.14%)	458(19.15%)	——
1	52(37.68%)	946(39.55%)	0.853
2	50(36.23%)	668(27.93%)	0.636
3	11(7.97%)	156(6.52%)	0.839
Not recorded	11(6.29%)	164(6.86%)	0.437
Postoperative T stage			
T0	16(11.59%)	531(22.20%)	<0.001
T1	4(2.90%)	138(5.77%)	
T2	20(14.49%)	538(22.49%)	
T3	81(58.70%)	1075(44.94%)	
T4	17(12.32%)	110(4.60%)	
Postoperative N stage			
N0	82(59.42%)	1928(80.94%)	<0.001

(*continued on next page*)

Table 1 (*continued*)

Variable	Recurrence (n = 138)	No recurrence (n = 2392)	*p*
N1	32(23.19%)	327(13.72%)	
N2	24(17.39%)	127(5.33%)	
Postoperative M stage			
M0	109(78.99%)	2101(87.83%)	0.002
M1	29(21.01%)	291(12.17%)	

Abbreviations: CI, confidence interval; HR, hazard ratio; CRC, colorectal cancer; NOS, not otherwise specified; LVI, Lymphovascular invasion; PNI, Perineural invasion; TRG, AJCC Tumour Regression Grade.

Univariable and multivariable Cox analyses (Fig. 3) showed that family history of non-colorectal malignancy ($p < 0.001$), poor differentiation ($p < 0.001$), surgical approach ($p = 0.002$), pT4 stage ($p = 0.037$), pN positivity ($p < 0.001$), and M1 disease ($p = 0.018$) were independently associated with locoregional recurrence. Compared with open surgery, laparoscopic surgery was associated with a lower risk of recurrence. Histologic subtype, lymphovascular invasion, and perineural invasion were not independently associated with postoperative recurrence (all $p > 0.05$).

Overall survival (OS) for all rectal cancer patients and by tumour-height subgroup is shown in Fig. 4A and 4B, respectively. Fig. 4C shows OS by recurrence status. Median OS was not reached in patients without recurrence, whereas it was approximately 56 months in patients with recurrence. The site-specific impact of recurrence on OS is shown in Fig. 5 and Table 6. Isolated pelvic-floor recurrence was rare, and no statistically significant association with OS was observed (Fig. 5D, p = 0.998; Table 6: HR, 0.986; 95% CI, 0.139–7.018; $p = 0.989$), although this analysis was limited by the very small number of events. In contrast, recurrence at other isolated sites and multi-site recurrence were associated with worse OS.

Among sphincter-preserved patients, long-term postoperative bowel function was generally favorable: 125 of 141 patients (88.65%) had LARS scores ≤ 20, 6 of 141 (4.26%) had scores of 21–29, and 10 of 141 (7.09%) had scores ≥ 30 (Table 7).

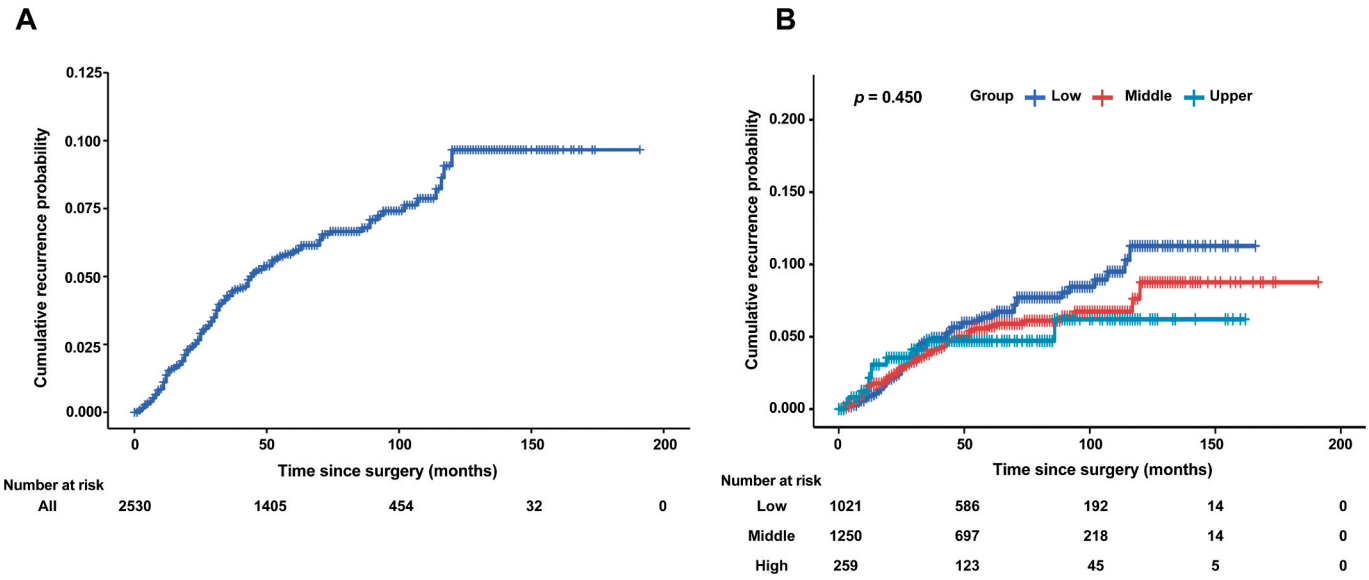


Fig. 1. Kaplan–Meier curves of cumulative locoregional recurrence probability after surgery. (A) Cumulative recurrence probability in the overall cohort. (B) Cumulative recurrence probability stratified by tumour height. Tumour height was defined according to the distance from the anal verge to the lower border of the tumour as low rectal cancer (<5 cm), mid-rectal cancer (5 – 9 cm), and high rectal cancer (≥10 cm). Numbers at risk are shown below the x-axis. The p value was calculated using the log-rank test.

Table 2
Analysis of Recurrence Patterns.

Primary tumour level (cm)	Number of patients	Number of recurrences	Location of recurrent tumour				
			Anastomosis	Presacral	Pelvic lymph nodes	Pelvic floor	Intrapelvic organs
<5	1021	64	27	8	33	13	7
5 – 9	1250	63	25	15	28	6	17
≥10	259	11	5	2	7	0	2

Abbreviations: Recurrence sites were not mutually exclusive because some patients had multi-site recurrence.

Table 3
Recurrence Patterns in the Radiotherapy Group.

Primary tumour level (cm)	Number of patients	Number of recurrences	Location of recurrent tumour				
			Anastomosis	Presacral	Pelvic lymph nodes	Pelvic floor	Intrapelvic organs
<5	1017	64	27	8	33	13	7
5 – 9	1211	60	24	15	25	6	17
≥10	197	10	5	2	6	0	2

Abbreviations: Recurrence sites were not mutually exclusive because some patients had multi-site recurrence.

Table 4
Recurrence Patterns in the Non-Radiotherapy Group.

Primary tumour level (cm)	Number of patients	Number of recurrences	Location of recurrent tumour				
			Anastomosis	Presacral	Pelvic lymph nodes	Pelvic floor	Intrapelvic organs
<5	4	0	0	0	0	0	0
5 – 9	39	3	1	0	3	0	0
≥10	62	1	0	0	1	0	0

Abbreviations: Recurrence sites were not mutually exclusive because some patients had multi-site recurrence.

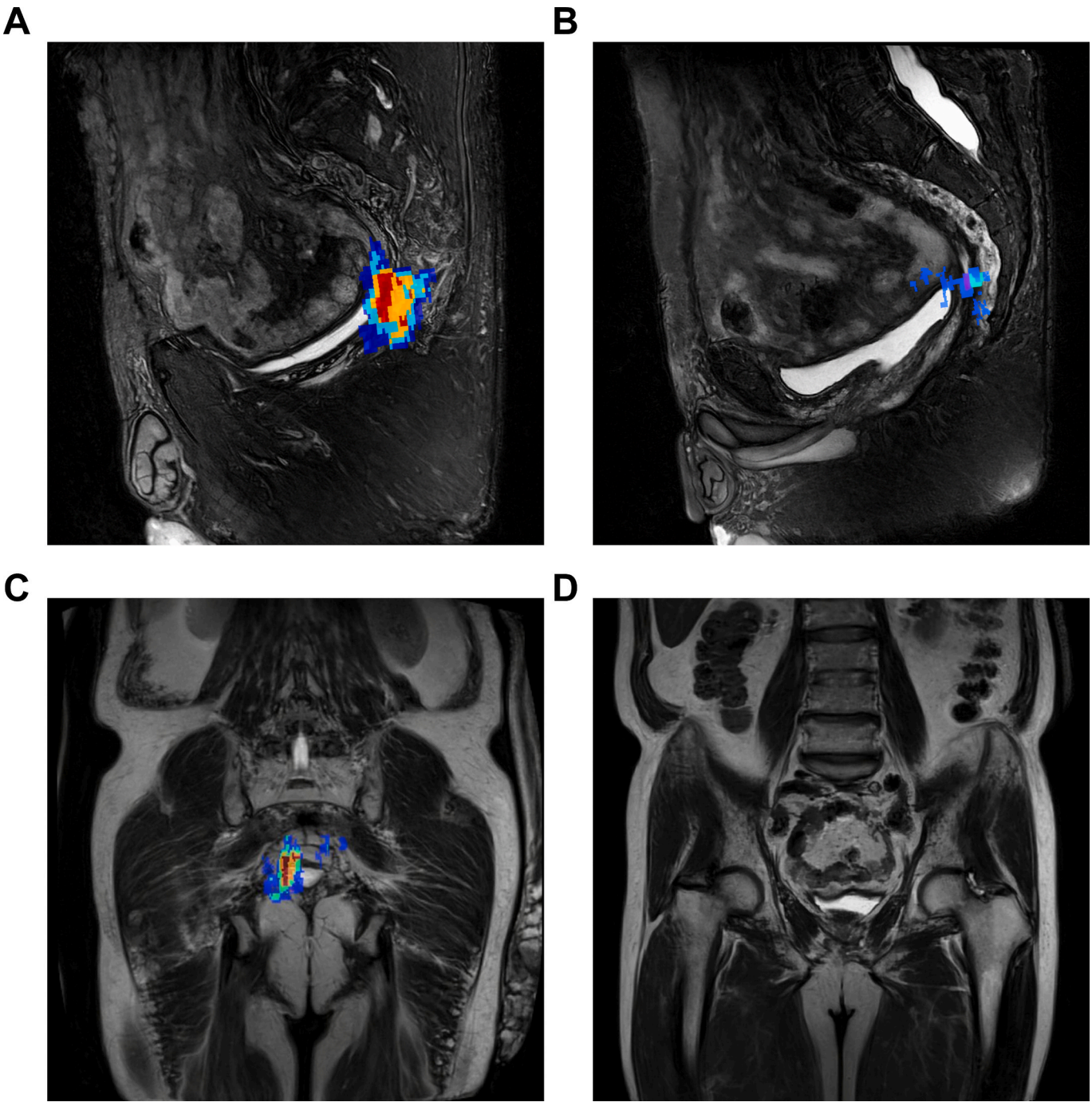


Fig. 2. Voxel-wise visualization of the anatomic distribution of postoperative recurrent lesions. (A) Sagittal view at the slice with the highest recurrence density. (B) Sagittal view at the coccygeal tip plane. (C) Coronal view at the slice with the highest recurrence density. (D) Coronal view at the coccygeal tip plane. The recurrence atlas was generated using a registration-based, voxel-wise mapping approach. The heatmap represents the spatial density of recurrent lesions, with warmer colours indicating higher recurrence density. This analysis included presacral and pelvic nodal drainage recurrences, after excluding anastomotic, pelvic-floor, and intrapelvic organ recurrences. The coccygeal tip plane was used as the anatomical reference for measuring the vertical distance from the caudal border of each recurrent lesion.

Table 5
Vertical Distance Between Recurrent Lesions and the Coccygeal Tip.

Variable	Average (95% CI)	Median (P_{25}, P_{75}, P_{90})
Tumour location		
Low	51.04(41.20–60.88)	48.13(13.81, 84.55, 110.45)
Middle	56.88(45.21–68.56)	41.19(18.42, 90.00, 123.25)
High	64.18(45.35–83.01)	69.10(31.49, 85.05, 120.25)
Middle + High	58.59(48.79–68.38)	57.52(20.23, 88.67, 118.25)

Abbreviations: CI, confidence interval; P, percentile.

Discussion

Current target-volume delineation for rectal cancer radiotherapy still relies heavily on an empirical, one-size-fits-all paradigm and does not adequately account for anatomy driven by tumour height [20]. In routine practice, pelvic clinical target volumes (CTVs) often include the distal mesorectal/pelvic-floor region regardless of whether the primary tumour is high or low. At the same time, studies by Nuyttens [21] and Taylor [22] demonstrated substantial inter-institutional and inter-physician variability in coverage of pelvic drainage regions and distal borders, underscoring both the experience dependence and limited reproducibility of conventional target design. Against this background, previous studies and guidelines have already suggested that high rectal cancer ($\geq$ 10 cm from the anal verge) carries a lower risk of pelvic local recurrence and tends to drain cranially rather than caudally [12,20,23]. Some guidelines therefore allow selective omission of routine neoadjuvant radiotherapy [24,25]. Nevertheless, the specific necessity of routine pelvic-floor coverage remains insufficiently evidenced. To address this gap, our large real-world cohort evaluated target optimization from the perspective of "radiotherapy-modifiable failure patterns". Specifically, when defining the distal boundary of mesorectal irradiation, we included only presacral and pelvic nodal drainage recurrences, while separately identifying anastomotic, pelvic-floor, and intrapelvic organ recurrences—events more likely to be influenced by surgical factors or non-CTV anatomic extension pathways and therefore less directly controllable by standard preoperative radiation fields. This framework helps move practice from empirical full-field coverage toward stratified target delineation grounded in failure topography and biological/technical intervenability.

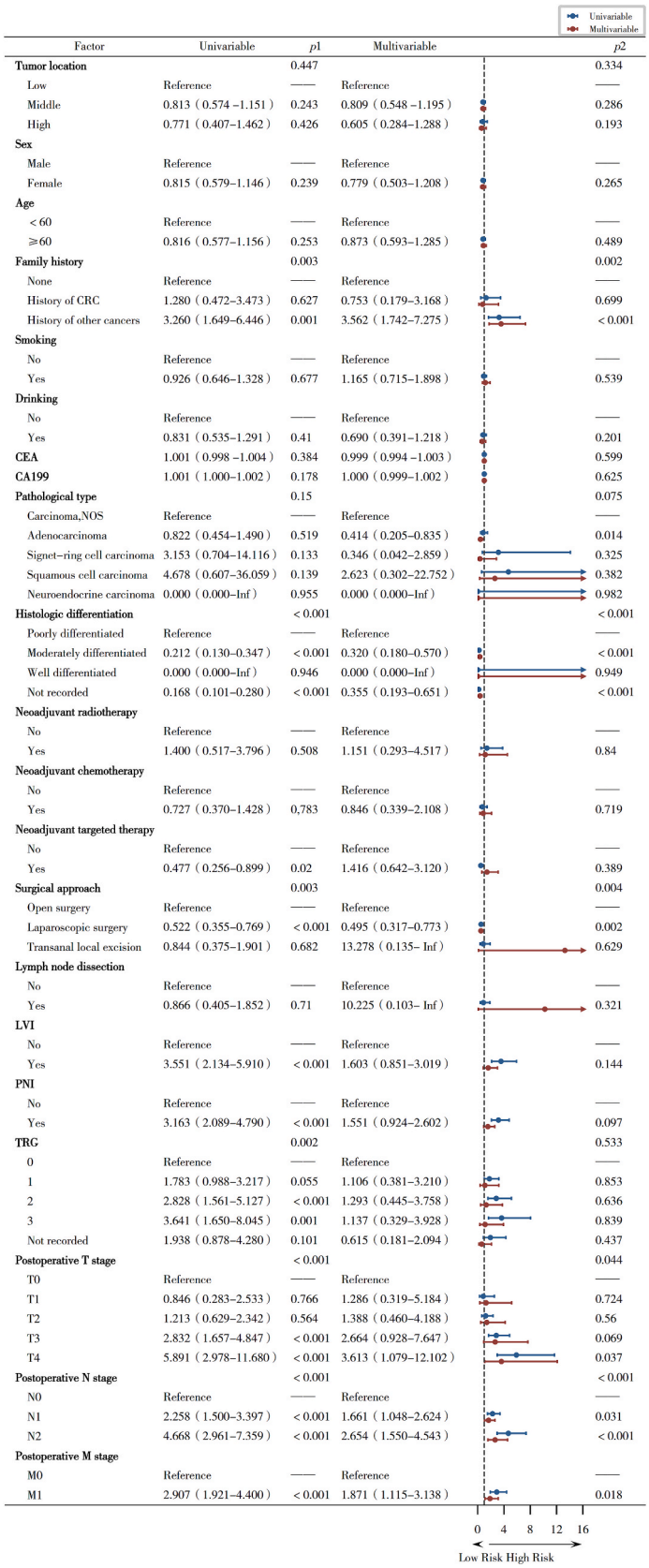
The retrospective analysis by Syk [11] reported that pelvic-floor recurrence was rare in mid/high rectal cancer (tumour lower edge $>$ 5 cm from the anal verge), and accordingly proposed moderate reduction of distal prophylactic fields in selected patients, including potential omission of routine coverage of the anal sphincter complex and adjacent tissues. In a large Chinese cohort, Ma [26] further supported this approach at the outcome level: among radically resected high rectal cancers, propensity-score-matched analyses showed similar 5-year local recurrence-free survival between radiotherapy and no-radiotherapy groups (96.50% vs 94.70%, $p = 0.364$), with no clear local-control gain even in high-risk subsets. Consistent with these data, pelvic-floor recurrence in our cohort was uncommon overall (0.75%), and no pelvic-floor recurrence was observed in the high-rectal subgroup, indicating that the pelvic floor is unlikely to represent a dominant local failure compartment in high rectal cancer. Moreover, no statistically significant association between isolated pelvic-floor recurrence and OS was observed, but the small number of events precludes a definitive conclusion.

Building on these observations, our study adds quantitative anatomic evidence: in mid- and high-rectal cancers, the caudal edge of recurrence clusters lay well above the coccygeal tip, with lower bounds of the 95% confidence intervals at 45.21 mm and 45.35 mm, respectively. Under a "safe lower-bound by high-coverage principle" (a high-coverage threshold plus a safety margin of $\geq$ 3 cm distal to the primary tumour edge), an exploratory cranial shift of the distal mesorectal boundary becomes technically plausible. For mid/high rectal cancers, provided that coverage extends at least 3 cm beyond the tumour's distal edge, the distal boundary may be shifted upward to approximately 4.5 cm above the coccygeal tip. By contrast, for low rectal cancer, a $\pm$ 3 cm expansion around the tumour generally already encompasses the full mesorectal compartment; therefore, target adjustment is not currently recommended. This step advances the field from a qualitative question ("whether de-intensification is possible") to an operational one ("how to de-intensify safely"), providing practical support for risk-adapted small-volume strategies. However, oncologic safety and functional benefit must still be confirmed in prospective, multicenter validation studies.

In the era of survivorship care, local control is not the sole endpoint; functional toxicity carries independent and substantial clinical weight. A systematic review and *meta*-analysis by Liang et al. [27] showed that preoperative radiotherapy significantly worsened postoperative bowel function: versus no radiotherapy, the risk of overall LARS increased about 3.6-fold (odds ratio [OR] = 3.59), and major LARS about 3.3-fold (OR = 3.28), both statistically significant. This evidence supports the mechanistic-clinical link between pelvic irradiation—particularly when the pelvic floor and distal mesorectum are included—and persistent bowel dysfunction. In line with prior literature, follow-up in our sphincter-preserved cohort also identified a non-negligible proportion of moderate-to-severe bowel dysfunction, suggesting that irradiation of distal mesorectal/pelvic-floor structures may impose lasting functional burden. Therefore, when recurrence probability in a given region is extremely low, routine irradiation of that region is more likely to create an asymmetric risk structure of low absolute oncologic benefit versus durable toxicity [28]. Integrating local failure patterns, long-term survival, and functional outcomes within one risk–benefit framework is thus essential for rational evaluation of small-volume strategies.

Importantly, target reduction is not a blanket policy and should be individualized through strict risk stratification. Our multivariable analysis showed that recurrence risk was significantly shaped by family history of malignancy, aggressive pathological features, and surgical approach. Notably, laparoscopic surgery was associated with a lower recurrence risk than open surgery, although this association should be interpreted cautiously because surgical approach may partly reflect patient selection, tumour complexity, and temporal improvements in surgical practice. Several clinicopathological variables included in the multivariable model have previously been reported to be associated with recurrence and prognosis in rectal cancer; therefore, these factors were considered candidate covariates even when they did not reach statistical significance in univariable analysis [29,30]. Earlier rectal cancer studies identified perineural invasion (PNI) as an independent predictor of local recurrence, indicating that tumour biology can materially alter local-failure probability [30]. Accordingly, CTV optimization should be conditional: in patients with clearly mid/high tumours, no imaging evidence of pelvic-floor involvement, no high-risk pathology, and planned minimally invasive surgery, the incremental benefit of distal mesorectal irradiation may be limited; in contrast, for patients harboring recurrence risk factors, oncologic safety of target reduction should be evaluated cautiously in multidisciplinary discussion, even when tumour location is relatively high.

Several limitations should be acknowledged. First, the retrospective design was vulnerable to selection bias and residual confounding, limiting causal inference. Second, the number of pelvic-floor recurrence events was small; while this likely reflects true low risk, underestimation due to sample size, follow-up duration, or surveillance sensitivity cannot be excluded. Third, neoadjuvant treatment exposure was heterogeneous, and lower recurrence rates may have been partly attributable to radiotherapy effects rather than anatomy alone. Fourth, recurrence localization relied on routine imaging and chart documentation, which may introduce measurement and classification error across readers and time points. Fifth, functional endpoints such as LARS are influenced by multiple factors (surgical technique, anastomotic height, postoperative complications), and the independent effect of target-volume reduction could not be isolated precisely. Therefore, the proposed CTV lower-



Factor	Univariable	p1	Multivariable	p2
Tumor location		0.447		0.334
Low	Reference	——	Reference	——
Middle	0.813 (0.574 –1.151)	0.243	0.809 (0.548 –1.195)	0.286
High	0.771 (0.407–1.462)	0.426	0.605 (0.284–1.288)	0.193
Sex				
Male	Reference	——	Reference	——
Female	0.815 (0.579–1.146)	0.239	0.779 (0.503–1.208)	0.265
Age				
< 60	Reference	——	Reference	——
≥60	0.816 (0.577–1.156)	0.253	0.873 (0.593–1.285)	0.489
Family history		0.003		0.002
None	Reference	——	Reference	——
History of CRC	1.280 (0.472–3.473)	0.627	0.753 (0.179–3.168)	0.699
History of other cancers	3.260 (1.649–6.446)	0.001	3.562 (1.742–7.275)	< 0.001
Smoking				
No	Reference	——	Reference	——
Yes	0.926 (0.646–1.328)	0.677	1.165 (0.715–1.898)	0.539
Drinking				
No	Reference	——	Reference	——
Yes	0.831 (0.535–1.291)	0.41	0.690 (0.391–1.218)	0.201
CEA	1.001 (0.998 –1.004)	0.384	0.999 (0.994 –1.003)	0.599
CA199	1.001 (1.000–1.002)	0.178	1.000 (0.999–1.002)	0.625
Pathological type		0.15		0.075
Carcinoma,NOS	Reference	——	Reference	——
Adenocarcinoma	0.822 (0.454–1.490)	0.519	0.414 (0.205–0.835)	0.014
Signet–ring cell carcinoma	3.153 (0.704–14.116)	0.133	0.346 (0.042–2.859)	0.325
Squamous cell carcinoma	4.678 (0.607–36.059)	0.139	2.623 (0.302–22.752)	0.382
Neuroendocrine carcinoma	0.000 (0.000–Inf)	0.955	0.000 (0.000–Inf)	0.982
Histologic differentiation		< 0.001		< 0.001
Poorly differentiated	Reference	——	Reference	——
Moderately differentiated	0.212 (0.130–0.347)	< 0.001	0.320 (0.180–0.570)	< 0.001
Well differentiated	0.000 (0.000–Inf)	0.946	0.000 (0.000–Inf)	0.949
Not recorded	0.168 (0.101–0.280)	< 0.001	0.355 (0.193–0.651)	< 0.001
Neoadjuvant radiotherapy				
No	Reference	——	Reference	——
Yes	1.400 (0.517–3.796)	0.508	1.151 (0.293–4.517)	0.84
Neoadjuvant chemotherapy				
No	Reference	——	Reference	——
Yes	0.727 (0.370–1.428)	0,783	0.846 (0.339–2.108)	0.719
Neoadjuvant targeted therapy				
No	Reference	——	Reference	——
Yes	0.477 (0.256–0.899)	0.02	1.416 (0.642–3.120)	0.389
Surgical approach		0.003		0.004
Open surgery	Reference	——	Reference	——
Laparoscopic surgery	0.522 (0.355–0.769)	< 0.001	0.495 (0.317–0.773)	0.002
Transanal local excision	0.844 (0.375–1.901)	0.682	13.278 (0.135– Inf)	0.629
Lymph node dissection				
No	Reference	——	Reference	——
Yes	0.866 (0.405–1.852)	0.71	10.225 (0.103– Inf)	0.321
LVI				
No	Reference	——	Reference	——
Yes	3.551 (2.134–5.910)	< 0.001	1.603 (0.851–3.019)	0.144
PNI				
No	Reference	——	Reference	——
Yes	3.163 (2.089–4.790)	< 0.001	1.551 (0.924–2.602)	0.097
TRG		0.002		0.533
0	Reference	——	Reference	——
1	1.783 (0.988–3.217)	0.055	1.106 (0.381–3.210)	0.853
2	2.828 (1.561–5.127)	< 0.001	1.293 (0.445–3.758)	0.636
3	3.641 (1.650–8.045)	0.001	1.137 (0.329–3.928)	0.839
Not recorded	1.938 (0.878–4.280)	0.101	0.615 (0.181–2.094)	0.437
Postoperative T stage		< 0.001		0.044
T0	Reference	——	Reference	——
T1	0.846 (0.283–2.533)	0.766	1.286 (0.319–5.184)	0.724
T2	1.213 (0.629–2.342)	0.564	1.388 (0.460–4.188)	0.56
T3	2.832 (1.657–4.847)	< 0.001	2.664 (0.928–7.647)	0.069
T4	5.891 (2.978–11.680)	< 0.001	3.613 (1.079–12.102)	0.037
Postoperative N stage		< 0.001		< 0.001
N0	Reference	——	Reference	——
N1	2.258 (1.500–3.397)	< 0.001	1.661 (1.048–2.624)	0.031
N2	4.668 (2.961–7.359)	< 0.001	2.654 (1.550–4.543)	< 0.001
Postoperative M stage				
M0	Reference	——	Reference	——
M1	2.907 (1.921–4.400)	< 0.001	1.871 (1.115–3.138)	0.018

Fig. 3. Forest plot of univariable and multivariable Cox regression analyses for locoregional recurrence. Hazard ratios (HRs) and 95% confidence intervals (CIs) are shown. Variables entered into the multivariable model were selected based on clinical relevance, prior evidence, and potential confounding effects, followed by backward stepwise selection. HRs greater than 1 indicate a higher risk of locoregional recurrence, whereas HRs less than 1 indicate a lower risk. The vertical reference line represents HR = 1. P values are shown for univariable and multivariable analyses, respectively. Variables with sparse events or unstable estimates should be interpreted cautiously.

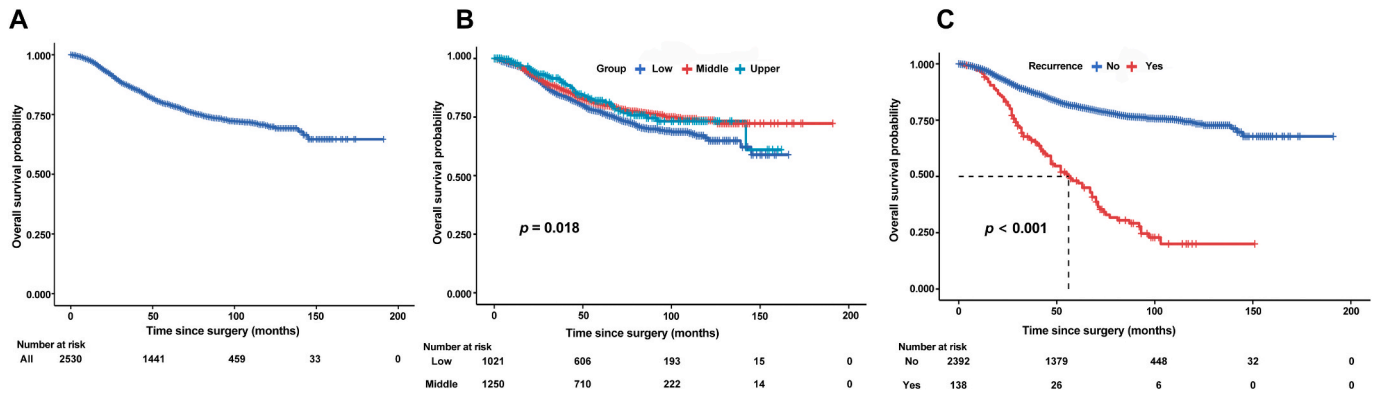


Fig. 4. Kaplan–Meier curves of overall survival after surgery. (A) Overall survival in the entire rectal cancer cohort. (B) Overall survival stratified by tumour height, defined as low rectal cancer (<5 cm), mid-rectal cancer (5 – 9 cm), and high rectal cancer (≥10 cm). (C) Overall survival according to locoregional recurrence status. Numbers at risk are shown below the x-axis. The p value was calculated using the log-rank test. OS, overall survival.

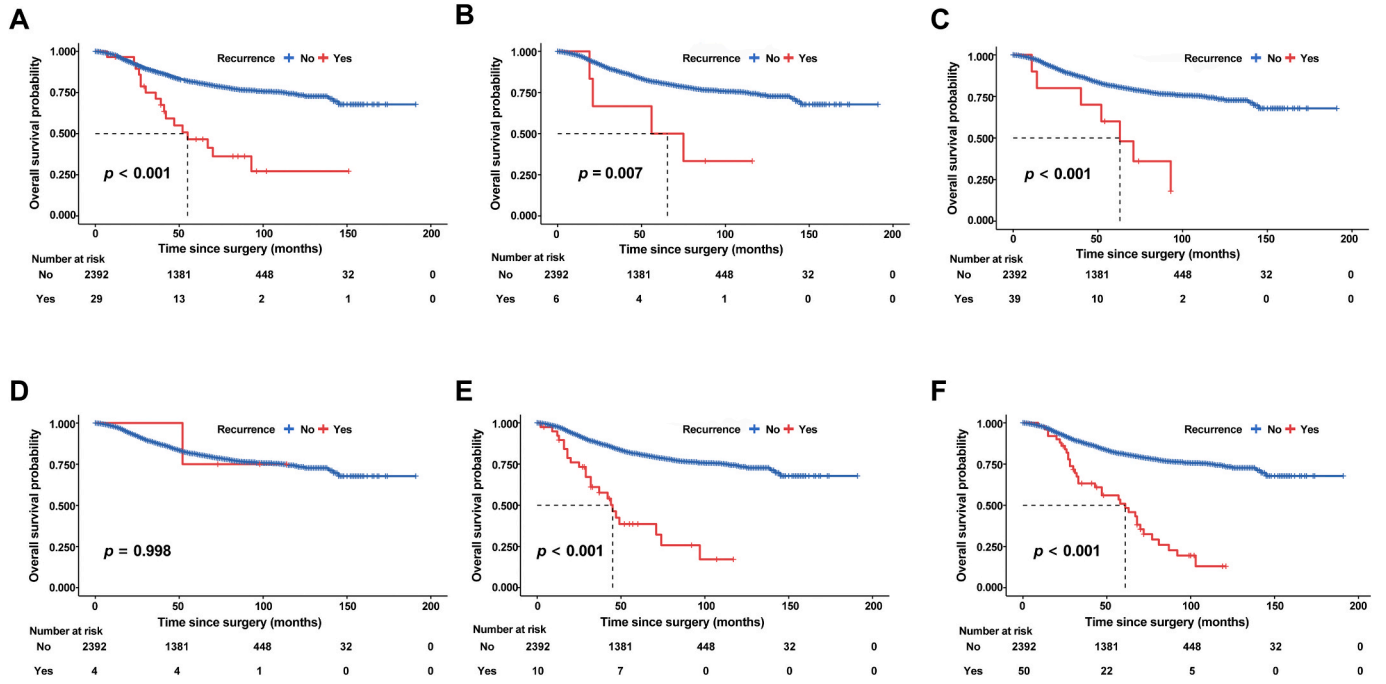


Fig. 5. Overall survival according to isolated recurrence site. Kaplan–Meier curves comparing patients with isolated site-specific recurrence with patients without recurrence: (A) isolated anastomotic recurrence; (B) isolated presacral recurrence; (C) isolated intrapelvic nodal recurrence; (D) isolated pelvic-floor recurrence; (E) isolated intrapelvic organ recurrence; and (F) multi-site recurrence. Patients with other isolated recurrence patterns were not included in each site-specific comparison. Numbers at risk are shown below the x-axis. The p values were calculated using the log-rank test. OS, overall survival.

Table 6
Impact of Recurrence Site on Overall Survival.

Variable	Univariable Cox Analysis HR (95% CI)	*p*
Local recurrence sites		<0.001
No recurrence	Reference	——
Isolated anastomotic recurrence	3.472(2.139–5.638)	<0.001
Isolated presacral recurrence	3.538(1.322–9.468)	0.012
Isolated intrapelvic nodal recurrence	4.687(3.079–7.135)	<0.001
Isolated pelvic-floor recurrence	0.986(0.139–7.018)	0.989
Isolated intrapelvic organ recurrence	3.874(1.836–8.175)	<0.001
Multi-site recurrence	4.268(3.024–6.023)	<0.001

Abbreviations: CI, confidence interval; HR, hazard ratio;

bound optimization should be viewed as exploratory and requires confirmation in larger, multicenter prospective studies.

Table 7
Distribution of Long-Term Postoperative Bowel Function in Sphincter-Preserved Patients.

LARS category	Score range	n	Percentage (%)
Total	—	141	100.00
No LARS	0–20	125	88.65
Minor LARS	21–29	6	4.26
Major LARS	30–42	10	7.09

Abbreviations: LARS, Low Anterior Resection Syndrome.

In summary, pelvic-floor recurrence after rectal cancer treatment appears to be rare, and the absolute benefit of routinely covering the entire mesorectal compartment may be limited. With robust coverage of critical high-risk regions, an exploratory cranial shift of the distal mesorectal boundary in mid/high rectal cancer may preserve local control and long-term survival while reducing chronic functional toxicity and

improving quality of life.

CRediT authorship contribution statement

Yueying Zhang: Writing – original draft, Methodology, Formal analysis. **Qingliang Lin:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Hongbin Cai:** Methodology, Conceptualization. **Zhenxin Zhao:** Project administration, Investigation, Conceptualization. **Zhaohan Zeng:** Project administration, Investigation. **Yaobin Lin:** Methodology, Funding acquisition, Conceptualization. **Jianwu Chen:** Supervision.

Funding

This study was supported by the Fujian Key Laboratory of Intelligent Imaging and Precision Radiotherapy for Tumours; the Startup Fund for Scientific Research, Fujian Medical University (grant number: 2024QH1016); and the Talent Startup Fund Project of Fujian Medical University Union Hospital (grant number: 2025XH019).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Ethics statement

Ethical approval for this retrospective study was obtained from the Ethics Committee of Fujian Medical University Union Hospital (No. 2026KY164). The requirement for informed consent was waived by the ethics committee due to the retrospective design and the use of anonymized clinical data.

Data availability

Data will be made available on request.

References

[1] van Gijn W, et al. Preoperative radiotherapy combined with total mesorectal excision for resectable rectal cancer: 12-year follow-up of the multicentre, randomised controlled TME trial. Lancet Oncol 2011;12:575–82.
[2] Kitaguchi D, et al. Preoperative risk analysis for postoperative recurrence in locally advanced rectal cancer following chemoradiotherapy. Anticancer Res 2025;45:5147–57.
[3] Abraha I, et al. Preoperative radiotherapy and curative surgery for the management of localised rectal carcinoma. Cochrane Database Syst Rev 2018;10.
[4] Peeters KCMJ, et al. Late side effects of short-course preoperative radiotherapy combined with total mesorectal excision for rectal cancer: increased bowel dysfunction in irradiated patients–a dutch colorectal cancer group study. J Clin Oncol 2005;23:6199–206.
[5] Sipaviciute A, Sileika E, Burneckis A, Dulskas A. Late gastrointestinal toxicity after radiotherapy for rectal cancer: a systematic review. Int J Colorectal Dis 2020;35:977–83.
[6] Yu Z, et al. Radiotherapy in the preoperative neoadjuvant treatment of locally advanced rectal cancer. Front Oncol 2023;13.
[7] Feeney G, et al. Neoadjuvant radiotherapy for rectal cancer management. World J Gastroenterol 2019;25:4850–69.
[8] Jankowski M, et al. Clinical reality and treatment for local recurrence of rectal cancer: a single-center retrospective study. Medicina 2021;57:286.
[9] Chen J, Ye Q, Huang F. Determining the survival benefit of postoperative radiotherapy in patients with pT1-3N1M0 rectal cancer undergoing total mesorectal excision: a retrospective analysis. BMC Gastroenterol 2023;23:83.
[10] Dalsania RM, Shah KP, Stotsky-Himelfarb E, Hoffe S, Willingham FF. Management of long-term toxicity from pelvic radiation therapy. Am Soc Clin Oncol Educ Book 2021;147–157.
[11] Syk E, Torkzad MR, Blomqvist L, Nilsson PJ, Glimelius B. Local recurrence in rectal cancer: anatomic localization and effect on radiation target. Int J Radiat Oncol Biol Phys 2008;72:658–64.
[12] Rosén R, Thorlacius H, Rönnow C-F. Is tumour location a dominant risk factor of recurrence in early rectal cancer? Surg Endosc 2025;39:1056–66.
[13] Masaki T, et al. Site-specific risk factors for local recurrence after rectal cancer surgery. Surg Oncol 2021;37:101540.
[14] Enríquez-Navascués JM, et al. Patterns of local recurrence in rectal cancer after a multidisciplinary approach. World J Gastroenterol 2011;17:1674–84.
[15] Lin S, et al. International consensus guideline on delineation of the clinical target volumes at different dose levels for nasopharyngeal carcinoma (2024 version). Int J Radiat Oncol Biol Phys 2025;123:415–31.
[16] Billan S, Bakouche V, Borzov E, Gil Z, Abdah-Bortnyak R. Long-term outcomes in patients with nasopharyngeal carcinoma treated with reduced-volume conformal radiotherapy: a retrospective cohort study. J Med Imaging Radiat Oncol 2018. https://doi.org/10.1111/1754-9485.12722.
[17] Mickey RM, Greenland S. The impact of confounder selection criteria on effect estimation. Am J Epidemiol 1989;129:125–37.
[18] Bursac Z, Gauss CH, Williams DK, Hosmer DW. Purposeful selection of variables in logistic regression. Source Code Biol Med 2008;3:17.
[19] Efthimiou O, et al. Developing clinical prediction models: a step-by-step guide. BMJ 2024;386:e078276.
[20] Valentini V, et al. International consensus guidelines on clinical target volume delineation in rectal cancer. Radiother Oncol 2016;120:195–201.
[21] Joost J. Nuyttens, John M. Robertson, Di Yan, Alvaro Martinez. The variability of the clinical target volume for rectal cancer due to internal organ motion during adjuvant treatment. International J Radiat Oncol Biol Phys, 53, 497–503 (2002).
[22] Taylor A, Rockall AG, Reznek RH, Powell MEB. Mapping pelvic lymph nodes: guidelines for delineation in intensity-modulated radiotherapy. Int J Radiat Oncol Biol Phys 2005;63:1604–12.
[23] Lai I, et al. The risk factors of local recurrence and distant metastasis on pT1/T2N0 mid-low rectal cancer after total mesorectal excision. World J Surg Oncol 2021;19:116.
[24] Schrag D, et al. Preoperative treatment of locally advanced rectal cancer. N Engl J Med 2023;389:322–34.
[25] Wo JY, et al. Radiation therapy for rectal cancer: executive summary of an ASTRO clinical practice guideline. Pract Radiat Oncol 2021;11:13–25.
[26] Ma Z, et al. Is radiotherapy necessary for upper rectal cancer underwent curative resection? A retrospective study of 363 patients. Radiat Oncol 2024;19:8.
[27] Liang Z, et al. Effects of preoperative radiotherapy on long-term bowel function in patients with rectal cancer treated with anterior resection: a systematic review and meta-analysis. Technol Cancer Res Treat 2022;21:15330338221105156.
[28] Malik YG, Benth JŠ, Hamre HM, Færden AE, Schultz JK. Effect of radiotherapy on long-term quality of life in recurrence-free rectal cancer survivors (LaTE study): nationwide inverse probability of treatment-weighted registry-based cohort study and survey. BJS Open 2024;8:zrae091.
[29] Doroudian S, Osterman E, Glimelius B. Risk factors for recurrence after surgery for rectal cancer in a modern Nationwide Population-Based Cohort. Ann Surg Oncol 2024;31:5570–84.
[30] Peng J, et al. Perineural invasion in pT3N0 rectal cancer. Cancer 2011;117:1415–21.