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Original Article

Correlation between peritumoral fat space blur on preoperative abdominal enhanced CT and postoperative complications in colorectal cancer: a single-center retrospective study

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Abstract: Objective: To investigate the association between blurred peritumoral fat planes on preoperative contrast-enhanced abdominal CT and postoperative complications in colorectal cancer, and to evaluate its predictive value. Methods: This study was a single-center retrospective analysis that consecutively enrolled 135 patients with colorectal adenocarcinoma who underwent curative surgery at Anhui West Health Vocational College Affiliated Hospital between February 2019 and December 2024. Two radiologists, blinded to clinical outcomes, independently assessed the degree of peritumoral fat plane blurring on preoperative CT scans using a 0-3 grading scale. Clinicopathological, surgical, and postoperative complication data were collected. Univariate and multivariate logistic regression analyses were performed to evaluate the association between fat plane blurring and postoperative complications. The predictive performance was assessed using receiver operating characteristic (ROC) curve analysis, and subgroup analyses were conducted. Results: A total of 135 patients were included, with a mean age of 66.3±9.8 years, and 63.0% were male. The distribution of peritumoral fat plane blurring grades was as follows: grade 0 in 22 patients (16.3%), grade 1 in 14 (10.4%), grade 2 in 40 (29.6%), and grade 3 in 59 (43.7%). The overall postoperative complication rate was 61.5% (83/135), and the rate of severe complications (Clavien-Dindo grade ≥III) was 44.4% (60/135). The degree of fat plane blurring was significantly associated with both overall complications ($P<0.001$) and severe complications ($P<0.001$), demonstrating a clear dose-response relationship. Multivariate analysis identified the fat plane blurring grade as an independent predictor of postoperative complications (OR=2.59; 95% CI: 1.70-3.95; $P<0.001$). ROC curve analysis yielded an area under the curve (AUC) of 0.750 for predicting complications. Using a cutoff of grade ≥2, the sensitivity was 81.6% and the specificity was 75.8%. Subgroup analyses confirmed that this association remained consistent across different tumor locations and surgical approaches. Conclusions: Blurred peritumoral fat planes on preoperative CT are an independent predictor of postoperative complications in colorectal cancer, demonstrating moderate predictive performance. This imaging feature can serve as a practical tool for preoperative risk assessment, aiding in the identification of high-risk patients and guiding individualized perioperative management.

Keywords: Colorectal cancer, fat space blur, CT imaging, postoperative complications, predictive value

Introduction

Colorectal cancer (CRC) is one of the most common malignancies worldwide, with high incidence and mortality rates-over 1.9 million new cases and more than 930,000 deaths annually [1]. Surgical resection remains the primary treatment for localized CRC; however, postoperative complication rates remain high, ranging from 30% to 40%, significantly impairing patients' recovery, quality of life, and long-term prognosis [2]. Common postoperative complications include anastomotic leakage, intra-abdominal infection, bleeding, and bowel obstruction [3-6]. Among these, anastomotic leakage is one of the most severe, occurring in approximately 3-15% of cases and carrying a related mortality rate as high as 10-20%. Therefore, accurate preoperative identification of high-risk patients is of critical importance for

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optimizing surgical strategies, enhancing perioperative management, and improving clinical outcomes [7].

Currently, commonly used clinical risk assessment tools-such as the American Society of Anesthesiologists (ASA) physical status classification, the Charlson Comorbidity Index, or the POSSUM scoring system-primarily rely on patients' overall health status and comorbidities [8]. Although these tools offer some predictive value, they generally lack consideration of the local biological behavior of the tumor. In recent years, with the advancement of precision surgery concepts, researchers have increasingly recognized that the interaction between the tumor and its surrounding microenvironment plays a critical role in determining surgical complexity and tissue healing capacity [9-11]. In particular, local inflammatory responses not only promote tumor invasion and metastasis but can also compromise intestinal perfusion and impair wound healing, thereby substantially increasing the risk of postoperative complications [12].

Contrast-enhanced abdominal CT is the standard imaging modality for preoperative staging and surgical planning in colorectal cancer [13]. It not only assesses tumor invasion depth (T stage), lymph node status, and distant metastases but also provides valuable information about the tumor microenvironment. Among its findings, "peritumoral fat space blurring" - characterized by increased density, stranding, thickening, or loss of the normal fat planes adjacent to the tumor - is a common yet often overlooked imaging sign. Pathological studies have shown that this sign reflects tumor-induced local inflammatory infiltration, edema, and fibrotic reactions, representing a direct manifestation of tumor-host interactions. Previous research has demonstrated that peritumoral fat blurring is strongly associated with poor prognosis in various solid tumors, including gastric, pancreatic, and ovarian cancers, suggesting its potential role as an imaging biomarker reflecting both tumor aggressiveness and the host immune response.

However, in the field of colorectal cancer, research on the association between peritumoral fat blurring and postoperative complications remains very limited and inconclusive. Some small-sample studies have suggested a potential link with anastomotic leakage, but these findings lack systematic validation and have not established whether this sign possesses independent predictive value. Moreover, existing studies have mostly employed a binary assessment (presence or absence of blurring), which fails to adequately capture the continuous nature and heterogeneity of this imaging feature. Given that peritumoral fat blurring essentially represents an imaging correlate of local inflammatory burden, its severity is likely to exhibit a dose-response relationship with the risk of postoperative complications.

Therefore, based on a single-center, large-sample retrospective cohort, this study employs a four-tier quantitative scoring system to perform a refined assessment of peritumoral fat blurring on preoperative contrast-enhanced CT, with the following aims: (1) To systematically investigate the association between the grade of fat blurring and both overall and severe postoperative complications in colorectal cancer; (2) To validate its value as an independent predictor and evaluate its discriminative performance; and (3) To test the robustness of this association across subgroups defined by tumor location and surgical approach through subgroup analyses. We hypothesize that peritumoral fat blurring is not only an imaging phenotype of local inflammation but also a simple, non-invasive, and routinely obtainable preoperative tool for risk stratification, thereby providing a basis for individualized perioperative interventions.

Materials and methods

Study design and patient selection

This was a single-center retrospective observational study conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). The study protocol was reviewed and approved by the Institutional Ethics Committee of Anhui West Health Vocational College Affiliated Hospital. Since the research utilized only previously collected, de-identified imaging and electronic medical record data from routine clinical practice and involved no additional interventions, the Ethics Committee granted a waiver of individual informed consent.

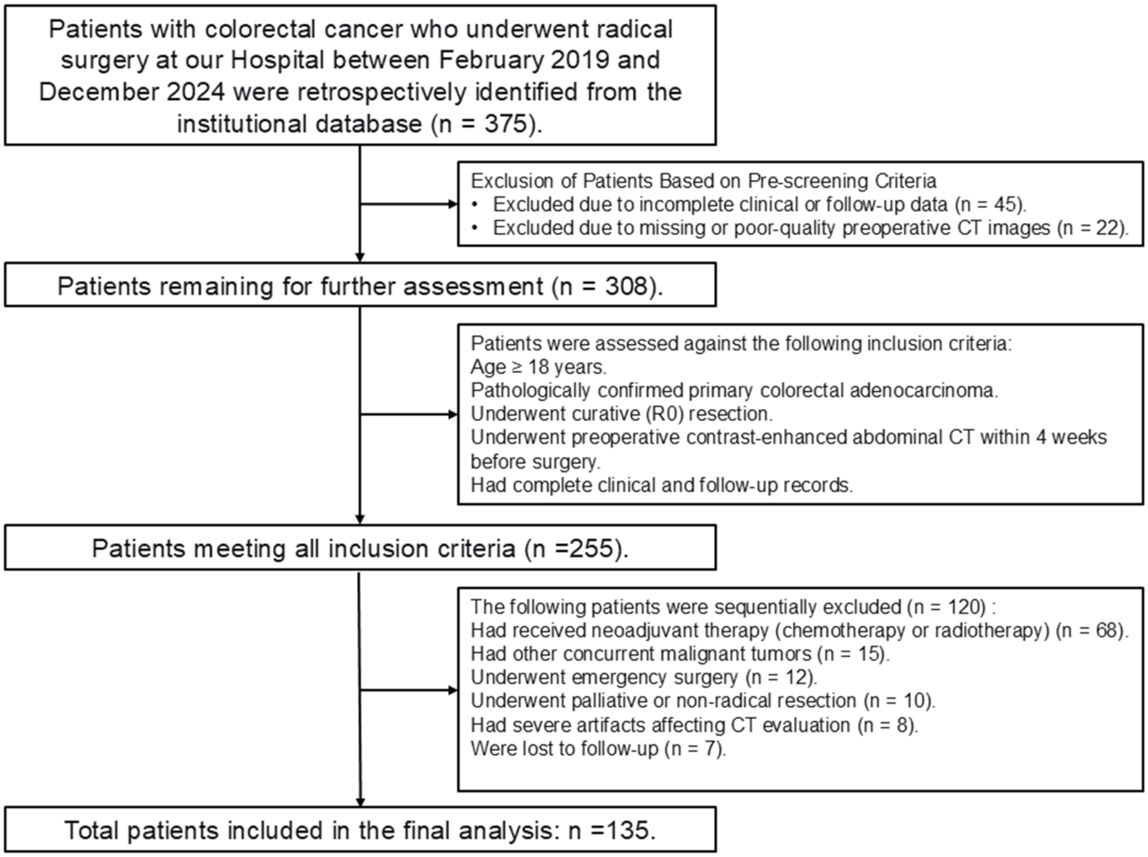

Figure 1. Study flowchart.

Consecutive patients who underwent curative (R0) surgery for primary colorectal adenocarcinoma at Anhui West Health Vocational College Affiliated Hospital between February 2019 and December 2024 were screened for eligibility.

Inclusion criteria were: (1) Age ≥18 years; (2) Pathological confirmation of colorectal adenocarcinoma; (3) Availability of a preoperative contrast-enhanced abdominal CT scan performed within four weeks before surgery; and (4) Complete clinical and follow-up data.

Exclusion criteria included: (1) Receipt of neoadjuvant therapy (chemotherapy or radiotherapy); (2) Presence of a concurrent malignancy; (3) Emergency surgery; (4) Palliative or non-curative resection (R1/R2); (5) Severe CT artifacts precluding image assessment; or (6) Loss to follow-up or incomplete clinical data.

A total of 135 patients meeting all criteria were included in the final analysis. Stringent data management protocols were implemented to protect patient confidentiality, including separation of identifiers and restricted access to anonymized datasets.

Sample size consideration

This study is an exploratory retrospective analysis, and the sample size was determined based on the total number of patients with complete data available during the study period. By consecutively enrolling all patients who met the inclusion and exclusion criteria between February 2019 and December 2024, a final cohort of 135 patients was included. This sample size satisfies the basic requirement for representativeness in retrospective observational studies and ensures adequate statistical power. The patient selection flowchart is shown in **Figure 1**. To ensure adequate statistical power for the primary outcome, we performed a post-hoc power calculation based on the observed odds ratio of 2.59 for the association between peritumoral fat plane blurring grade and overall postoperative complications, with a two-sided alpha of 0.05. Using the sample size of 135 patients and the distribution across grades, the achieved power exceeded 0.90, confirming that the study was sufficiently powered to detect the hypothesized association [14, 15].

Data collection

Through the hospital's electronic medical record system and imaging archive system, the following data were retrospectively extracted.

Baseline patient characteristics: Age, gender, Body Mass Index (BMI), American Society of Anesthesiologists (ASA) classification, comorbidities (such as diabetes, hypertension, coronary heart disease, etc.), smoking history, alcohol consumption history.

Laboratory tests: White blood cell count, neutrophil percentage, lymphocyte count, platelet count, hemoglobin, albumin, prealbumin, C-reactive protein (CRP), carcinoembryonic antigen (CEA), and carbohydrate antigen 199 (CA199) within one week before surgery. Neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) were calculated.

Tumor characteristics: Tumor location (rectum, left-sided colon, right-sided colon), postoperative pathological T stage (pT), pathological N stage (pN), degree of differentiation, maximum tumor diameter, vascular invasion, perineural invasion.

Surgical parameters: Surgical approach (open, laparoscopic, robotic-assisted), operative time, intraoperative blood loss, preventive stoma creation, conversion to open surgery.

Postoperative outcomes: All complications occurring within 30 days after surgery were recorded and classified according to the Clavien-Dindo grading system. The primary outcomes of this study were overall complications (Clavien-Dindo grade ≥I) and severe complications (Clavien-Dindo grade ≥III). Postoperative length of stay, reoperation, readmission within 30 days, and mortality within 30 days were also documented.

Follow-up: To assess medium to long-term outcomes, systematic postoperative follow-ups were conducted with patients. Through outpatient records, telephone interviews, and inpatient records, status information at the following time points was collected: 1 month, 3 months, 6 months, 18 months, and 24 months postoperatively. Follow-up content mainly included survival status, tumor recurrence or metastasis, and any long-term complications related to surgery or cancer.

Data quality control

All collected data were independently entered and cross-verified by two personnel. Any discrepancies were resolved by reviewing the original medical records. Key variables - such as complication grading and pathological staging were independently extracted by two researchers, with disagreements adjudicated by a third senior clinician.

Imaging assessment

Two radiologists with more than 10 years of experience in abdominal imaging independently and retrospectively evaluated stored preoperative contrast-enhanced abdominal CT images, blinded to patients' clinical outcomes. The evaluation included the grade of peritumoral fat plane blurring, maximum tumor diameter, lymph node metastasis status, and other relevant features.

Peritumoral fat plane blurring was graded using a four-tier scoring system.

Grade 0: No blurring; homogeneous fat attenuation, clear fat plane.

Grade 1: Mild blurring; subtle, fine linear stranding involving <25% of the tumor circumference, preserved fat plane.

Grade 2: Moderate blurring; definite coarse strand-like opacities involving 25-75% of the circumference, partially obscured fat plane.

Grade 3: Severe blurring; dense, confluent opacities involving >75% of the circumference, complete loss of fat plane, possibly with mass-like effect.

To assess inter-rater reliability, both radiologists independently scored the fat blurring grade for all patients. Interobserver agreement was quantified using the weighted kappa coefficient (κ).

Statistical analysis

All statistical analyses were performed using R software (version 4.2.0) and SPSS (version 26.0). Continuous variables were presented as mean ± standard deviation or median (interquartile range [IQR]), as appropriate, while categorical variables were reported as frequencies (percentages).

Group comparisons: For continuous variables, Student's t-test, one-way ANOVA, or the Mann-Whitney U test was used, depending on data distribution and variance homogeneity. For categorical variables, the chi-square (χ^2) test or Fisher's exact test was applied.

Correlation analysis: Pearson or Spearman correlation coefficients were used to assess associations between variables, based on their distributional properties.

Regression analysis: Univariate logistic regression was first conducted to screen potential predictors; variables with P<0.10 were entered into the multivariate logistic regression model. A stepwise selection procedure (forward likelihood ratio method) was employed, with entry and removal criteria set at P<0.05 and P>0.10, respectively, to identify independent predictors. Results were reported as odds ratios (ORs) with 95% confidence intervals (CIs).

Predictive performance evaluation: The predictive ability of the peritumoral fat blurring grade for postoperative complications was assessed using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC), along with sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), was calculated.

Subgroup analyses: Stratified analyses were performed according to tumor location (rectum, left-sided colon, right-sided colon) and surgical approach (open, laparoscopic, robot-assisted) to evaluate the robustness of the association between fat blurring grade and complications across different clinical contexts.

Survival analysis: Based on scheduled follow-up data, overall survival curves were estimated using the Kaplan-Meier method and compared across fat blurring grade groups via the log-rank test. Survival time was defined as the interval from the date of surgery to either death from any cause or the date of last follow-up.

Results

Patient characteristics and inter-rater reliability

This study included a total of 135 patients with colorectal adenocarcinoma who underwent curative surgery at Anhui West Health Vocational College Affiliated Hospital between February 2019 and December 2024. All patients had preoperative contrast-enhanced abdominal CT scans evaluated independently by two radiologists for the degree of peritumoral fat plane blurring. Based on the assessment results, patients were categorized into four subgroups: Grade 0 (no blurring) in 22 patients (16.3%), Grade 1 (mild blurring) in 14 patients (10.4%), Grade 2 (moderate blurring) in 40 patients (29.6%), and Grade 3 (severe blurring) in 59 patients (43.7%). The baseline clinical and pathological characteristics of patients in each group are summarized in **Table 1**.

The overall cohort had a mean age of 66.3±9.8 years, comprising 85 males (63.0%) and 50 females (37.0%). Comparisons between groups showed no statistically significant differences in age, gender, Body Mass Index (BMI), American Society of Anesthesiologists (ASA) classification, comorbidities (diabetes, hypertension, coronary heart disease), or most preoperative laboratory parameters (such as white blood cell count, lymphocyte count, platelet count, hemoglobin, neutrophil-to-lymphocyte ratio [NLR], platelet-to-lymphocyte ratio [PLR], C-reactive protein [CRP], carcinoembryonic antigen [CEA], and carbohydrate antigen 199 [CA199]) across different blurring grades (P>0.05). However, significant differences were observed in neutrophil percentage (F=13.467, P=0.004) and serum prealbumin levels (F=2.714, P=0.047) among the different blurring grade groups, suggesting that inflammation and nutritional status may be associated with local imaging findings.

Inter-rater reliability

Two radiologists independently assessed the peritumoral fat plane blurring grade in all 135 patients. The inter-rater agreement rate was 92.59%, with a Cohen's kappa coefficient of 0.892 (95% CI: 0.825-0.959, P<0.001), indi-

Table 1. Baseline characteristics of patients grouped by peritumoral fat plane blurring grade (n=135)

Variable	Grade 0	Grade 1	Grade 2	Grade 3	F/H/χ^2	*P*-value
Age (years)	68.01±7.92	66.81±8.54	65.29±10.47	66.25±9.54	0.441	0.751
BMI (kg/m^2)	24.16±3.44	23.86±3.41	23.26±3.65	24.75±3.71	5.235	0.155
White Blood Cell Count (×10^9/L)	7.58±1.74	6.99±2.05	6.68±2.06	6.89±1.72	1.151	0.331
Neutrophil Percentage (%)	70.96±8.79	64.03±10.15	67.66±10.81	62.89±8.93	13.467	0.004
Lymphocyte Count (×10^9/L)	1.90±0.71	1.94±0.41	1.84±0.56	1.89±0.69	0.114	0.952
Platelet Count (×10^9/L)	242.87±70.37	251.97±89.54	229.50±66.17	252.08±77.04	0.795	0.499
Hemoglobin (g/L)	126.82±21.27	127.70±16.12	128.76±18.75	132.58±20.76	0.636	0.593
NLR	3.40±2.14	2.39±0.95	2.85±1.67	2.71±1.57	3.746	0.290
PLR	160.14±106.87	130.81±39.91	137.27±63.33	150.54±70.86	1.009	0.799
Serum Albumin (g/L)	36.58±5.58	35.45±6.44	37.64±4.61	39.05±6.54	6.299	0.098
Prealbumin (g/L)	0.28±0.08	0.24±0.07	0.28±0.07	0.25±0.07	2.714	0.047
CRP (mg/L)	4.77±4.75	7.00±5.92	6.49±6.12	7.45±7.98	1.657	0.647
CEA (ng/mL)	5.69±4.63	6.87±6.47	5.79±5.01	5.37±6.04	1.335	0.721
CA199 (U/mL)	15.35±14.62	14.39±10.73	19.00±16.04	17.98±18.11	1.139	0.768
Gender					1.234	0.745
Female	10 (45.5%)	7 (50.0%)	18 (45.0%)	15 (25.4%)		
Male	12 (54.5%)	7 (50.0%)	22 (55.0%)	44 (74.6%)		
ASA Class						
I	7 (31.8%)	2 (14.3%)	4 (10.0%)	11 (18.6%)	*	0.354
II	10 (45.5%)	8 (57.1%)	20 (50.0%)	25 (42.4%)		
III	4 (18.2%)	3 (21.4%)	16 (40.0%)	19 (32.2%)		
Diabetes History						
No	18 (81.8%)	11 (78.6%)	33 (82.5%)	52 (88.1%)	*	0.751
Yes	4 (18.2%)	3 (21.4%)	7 (17.5%)	7 (11.9%)		
Hypertension						
No	16 (72.7%)	10 (71.4%)	32 (80.0%)	37 (62.7%)	3.505	0.320
Yes	6 (27.3%)	4 (28.6%)	8 (20.0%)	22 (37.3%)		
Coronary Heart Disease						
No	19 (86.4%)	12 (85.7%)	31 (77.5%)	46 (78.0%)	*	0.765
Yes	3 (13.6%)	2 (14.3%)	9 (22.5%)	13 (22.0%)		

*Fisher's exact test. Abbreviation: BMI, body mass index; WBC, white blood cell count; NLR, neutrophil-to-lymphocyte ratio; PLR, platelet-to-lymphocyte ratio; CRP, C-reactive protein; CEA, carcinoembryonic antigen; CA199, carbohydrate antigen 199; ASA, American Society of Anesthesiologists.

cating excellent agreement between the two reviewers.

Association between peritumoral fat plane blurring grade and postoperative complications

Postoperative complications occurred in 83 patients (61.5%), including 60 (44.4%) with severe complications (Clavien-Dindo ≥III). As shown in **Figure 2**, both overall and severe complication rates increased progressively with higher fat blur grades (both P for trend <0.001): overall complications ranged from 31.8% in Grade 0 to 88.1% in Grade 3; severe complications ranged from 9.1% to 81.4%.

Correlation between peritumoral fat plane blurring grade and other perioperative indicators

The peritumoral fat plane blurring grade showed significant correlations with various indicators reflecting tumor invasiveness, systemic inflammation, surgical complexity, and postoperative recovery.

Association with tumor pathological features: The fat plane blurring grade was significantly associated with the pathological T stage (pT) (P<0.001). As shown in **Figure 3**, the proportion of T3-T4 stage tumors increased significantly with higher blurring grades. In Grades 0 and 1, the proportion of T3-T4 tumors was relatively low, while in Grades 2 and 3, the

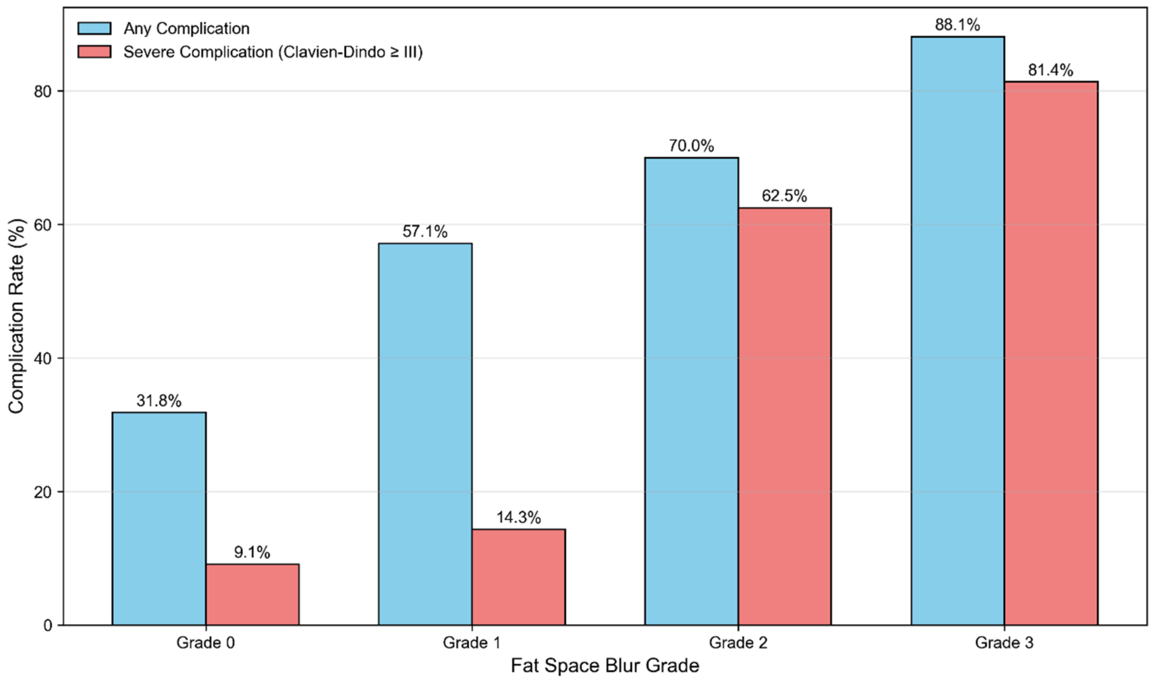

Figure 2. Postoperative complication rates by fat space blur grade.

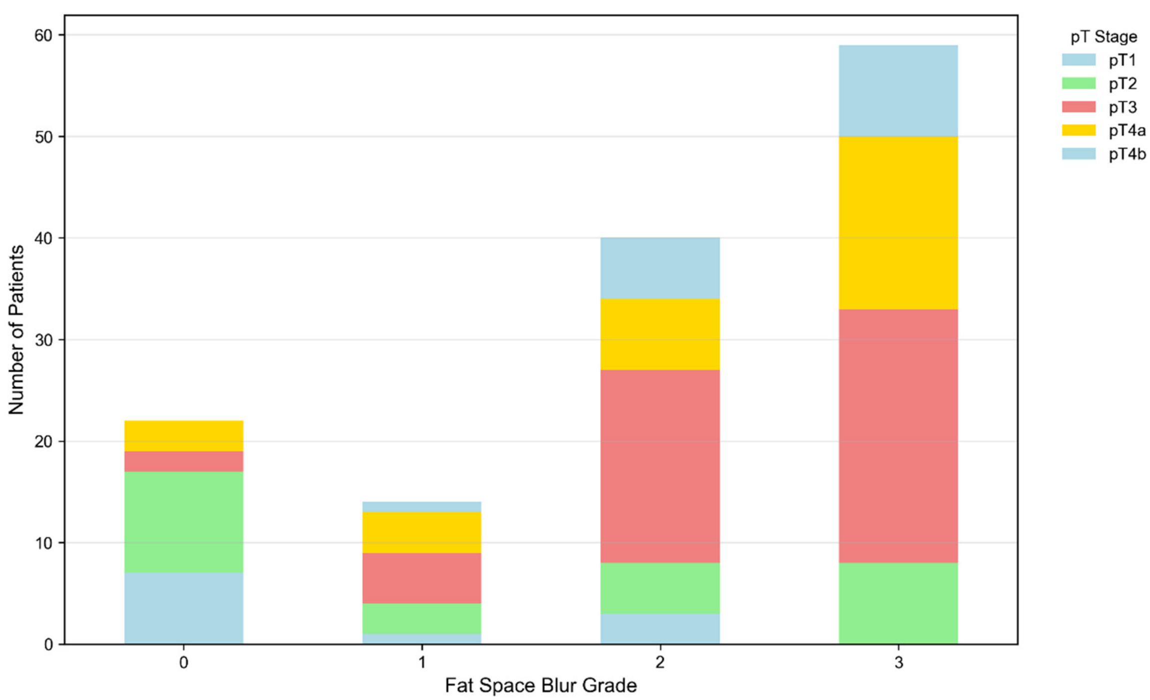

Figure 3. Distribution of pT Stage by fat space blur grade. Abbreviation: pT, pathological T stage.

majority of tumors had progressed to T3-T4 stages.

Association with systemic inflammation and tumor markers: The distribution of laboratory parameters across different blurring grade groups is illustrated in **Figure 4**. While white blood cell count (WBC) levels were similar across groups and showed no significant trend (**Figure 4A**), markers of systemic inflamma-

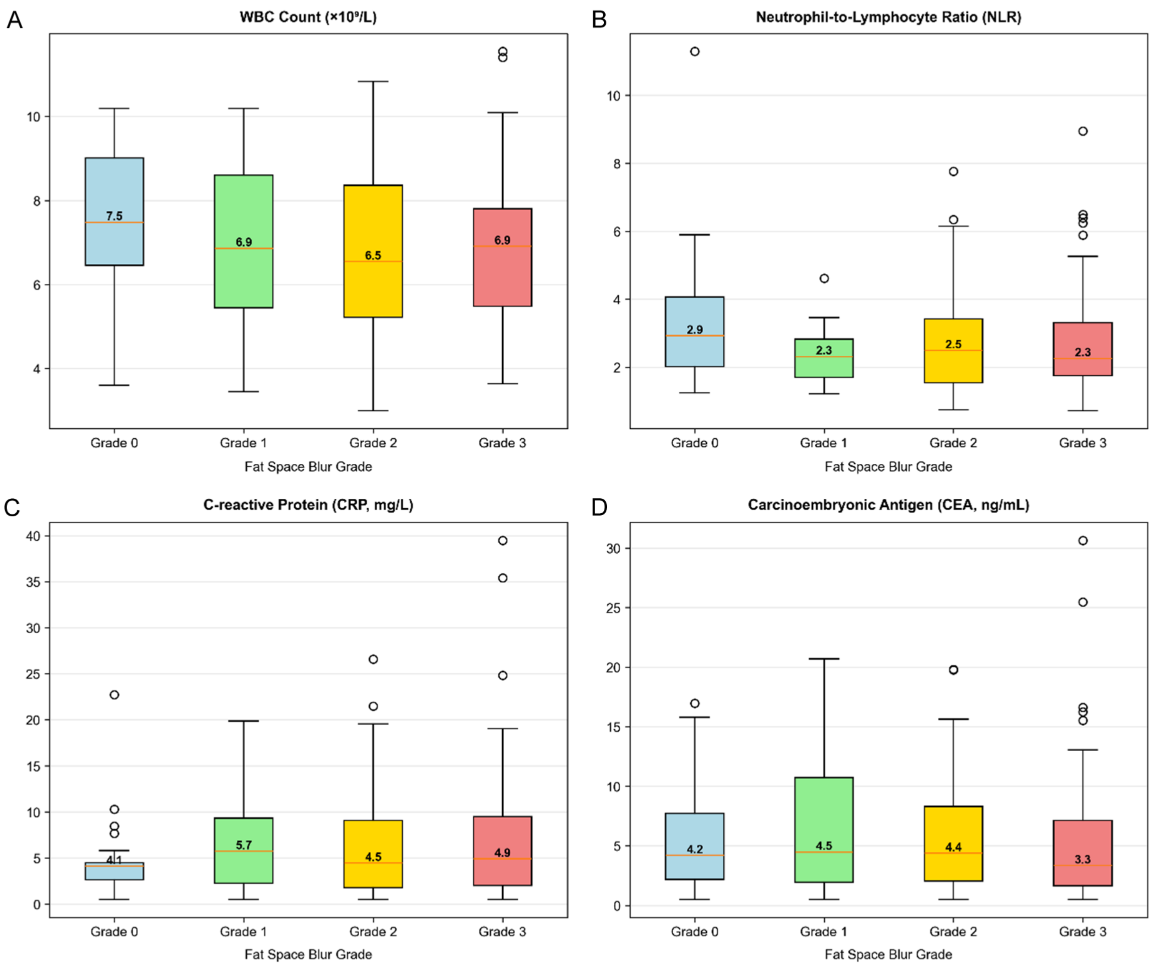

Figure 4. Laboratory values by fat space blur grade. A. WBC Count: Shows white blood cell count (×10^9/L) across Fat Space Blur Grades: 7.5 (Grade 0), 6.9 (Grade 1), 6.5 (Grade 2), 6.9 (Grade 3); no obvious trend, similar data dispersion. B. Neutrophil-to-Lymphocyte Ratio (NLR): Presents NLR across grades: 2.9 (Grade 0), 2.3 (Grade 1), 2.5 (Grade 2), 2.3 (Grade 3); small mean differences between grades, but some samples have significantly high NLR (large dispersion). C. C-reactive Protein (CRP): Displays CRP (mg/L) across grades: 4.1 (Grade 0, low mean but large sample dispersion), 5.7 (Grade 1), 4.5 (Grade 2), 4.9 (Grade 3); some samples have far higher CRP than the mean, with obvious data fluctuation. D. Carcinoembryonic Antigen (CEA): Shows CEA (ng/mL) across grades: 4.2 (Grade 0), 4.5 (Grade 1), 4.4 (Grade 2), 3.3 (Grade 3); close means between grades, some samples have slightly high CEA. Abbreviation: WBC, white blood cell count; NLR, neutrophil-to-lymphocyte ratio; CRP, C-reactive protein; CEA, carcinoembryonic antigen.

tion - such as the neutrophil-to-lymphocyte ratio (NLR) and C-reactive protein (CRP) levels - showed a positive correlation with blurring grade (NLR: $r=0.27$, $P<0.001$; CRP: $r=0.24$, $P=0.001$) (**Figure 4B**, **4C**). Carcinoembryonic antigen (CEA) levels were comparable across groups and did not show significant differences (**Figure 4D**).

Association with surgical parameters: Surgical complexity was closely related to the fat plane blurring grade. As depicted in **Figure 5**, operative time increased significantly with higher blurring grades, reaching a median of 200 minutes in Grade 3 (**Figure 5A**). Similarly, intraoperative blood loss also showed an upward trend, with the median blood loss in Grade 3 being significantly higher at 154 mL compared to lower grades (**Figure 5B**). Additionally, regarding surgical outcomes, patients with high blurring grades (Grade 3) had a significantly higher reoperation rate of 62.7% (**Figure 5C**).

Association with postoperative recovery indicators: Postoperative length of stay correlated positively with the fat plane blurring grade ($r=0.31$, $P<0.001$). As shown in **Figure 6**, the median postoperative hospital stay for Grade 0

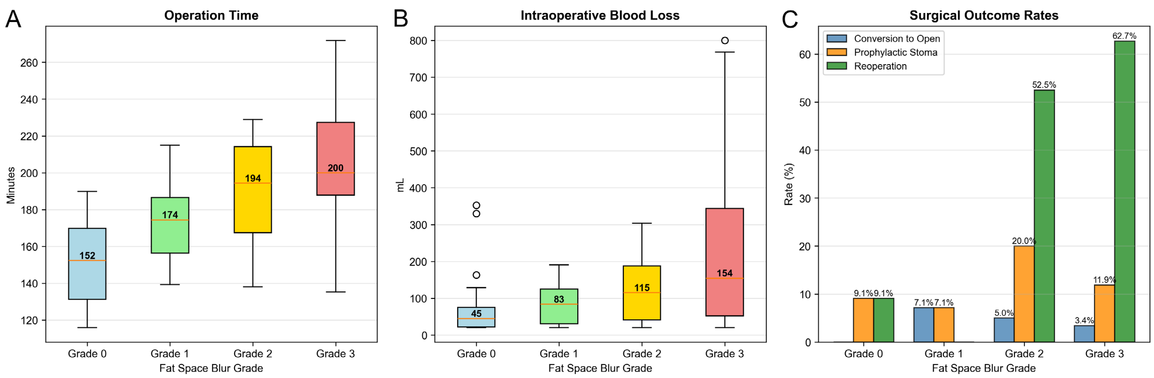

Figure 5. Surgical outcomes by fat space blur grade. A. Operation time: Presents operation duration (minutes) across Fat Space Blur Grades: 159 (Grade 0), 174 (Grade 1), 194 (Grade 2), 200 (Grade 3); time shows an upward trend with increasing blur grade. B. Intraoperative blood loss: Displays intraoperative blood loss (mL) across grades: 46 (Grade 0), 83 (Grade 1), 115 (Grade 2), 154 (Grade 3); blood loss increases gradually as blur grade rises. C. Surgical outcome rates: Shows rates of three outcomes (Converted to Open, Prophylactic Stoma, Reparation) by blur grade: Reparation rate rises sharply (to 62.7%) at Grade 3; other outcomes have relatively low rates across all grades.

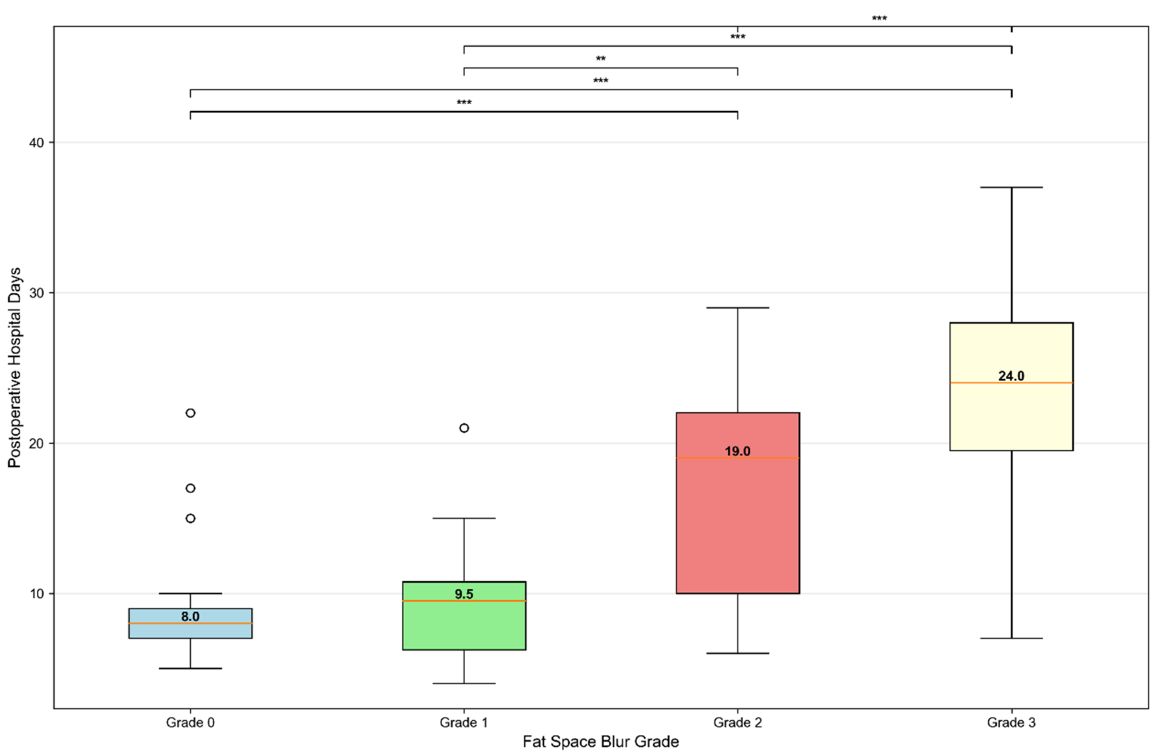

Figure 6. Distribution of postoperative hospital days by fat space blur grade. **P<0.001, ***P<0.001.

patients was 8.0 days, which extended significantly to 24.0 days for Grade 3 patients.

Predictive value of peritumoral fat plane blurring grade for postoperative complications

To evaluate the predictive performance of the peritumoral fat plane blurring grade for postoperative complications, we conducted receiver operating characteristic (ROC) curve analysis (**Figure 7**). The results showed that the area under the curve (AUC) for predicting postoperative complications using the fat plane blurring grade was 0.750 (P<0.001), indicating good discriminative ability. The optimal predictive cutoff point, determined by the Youden

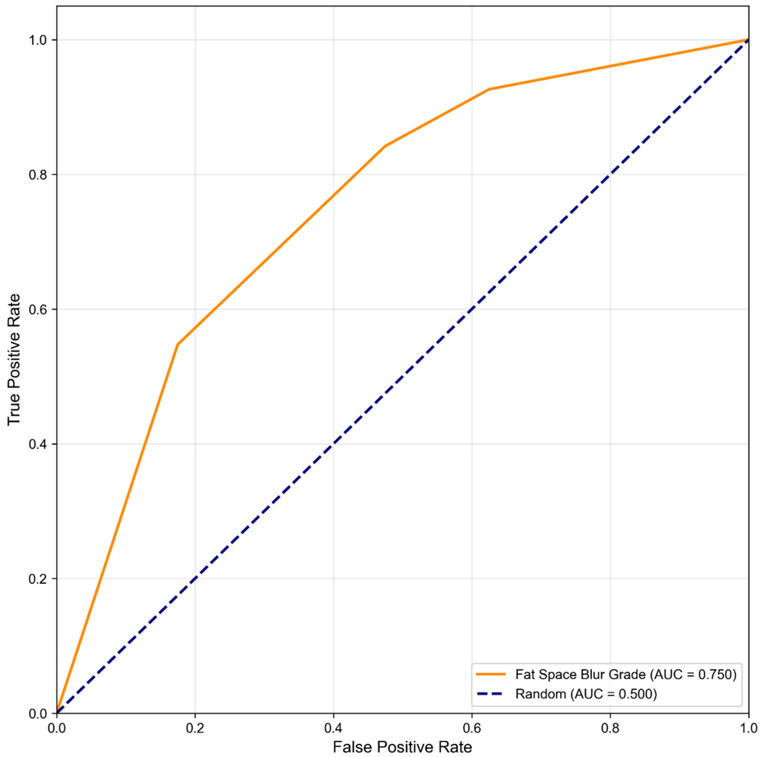

Figure 7. ROC curve: fat space blur grade for predicting complications.

index, was a blurring grade of ≥2. At this cutoff value, the sensitivity was 81.6%, specificity was 75.8%, positive predictive value (PPV) was 72.3%, and negative predictive value (NPV) was 83.9%. We further evaluated whether the fat blur grade could provide incremental predictive value over the conventional ASA classification. As shown in Supplementary Table 1, the fat blur grade alone yielded an AUC of 0.750 (95% CI: 0.660-0.845), with a sensitivity of 54.7% and specificity of 82.5% at the optimal cutoff. In contrast, the ASA classification alone showed poor discriminative ability, with an AUC of only 0.596 (95% CI: 0.504-0.688). Combining the fat blur grade with ASA resulted in an AUC of 0.778 (95% CI: 0.696-0.865), sensitivity of 69.5%, and specificity of 77.5%. However, the improvement in AUC compared to ASA alone did not reach statistical significance (ΔAUC=0.182, bootstrap P=0.458). Moreover, the combined model did not significantly outperform the fat blur grade alone (ΔAUC=0.028), indicating that the addition of ASA provided little incremental benefit. These findings suggest that the fat blur grade captures risk information that is largely independent of, and more relevant than, the traditional systemic assessment captured by ASA.

Distribution of postoperative complication types across peritumoral fat plane blurring grades

The types of postoperative complications differed significantly among the peritumoral fat plane blurring grade groups (**Figure 8**). In Grade 0, the majority of patients (68.2%) experienced no complications; only a few developed minor complications such as superficial wound infection or deep vein thrombosis/pulmonary embolism. As the blurring grade increased, the proportion of patients without complications declined sharply, while the incidence of various complications rose progressively.

In Grade 3, complications were predominantly moderate to severe in nature. The rates of intra-abdominal/pelvic infection, deep surgical site infection, and anastomotic leakage were markedly higher than those in the lower-grade groups, highlighting a shift toward more serious adverse events with increasing fat plane blurring severity.

Multivariate analysis of independent risk factors for postoperative complications

To evaluate the independent predictive value of peritumoral fat plane blurring grade, variables with P<0.1 in univariate analysis-including fat plane blurring grade, age, BMI, maximum tumor diameter, neutrophil-to-lymphocyte ratio (NLR), and C-reactive protein (CRP)-were entered into a multivariable logistic regression model.

After adjusting for potential confounders, multivariate analysis revealed that only peritumoral fat plane blurring grade remained an independent risk factor for postoperative complications (odds ratio [OR] =2.59; 95% confidence interval [CI]: 1.70-3.95; P<0.001). Age, BMI, tumor size, NLR, and CRP did not demonstrate independent predictive significance (**Table 2**).

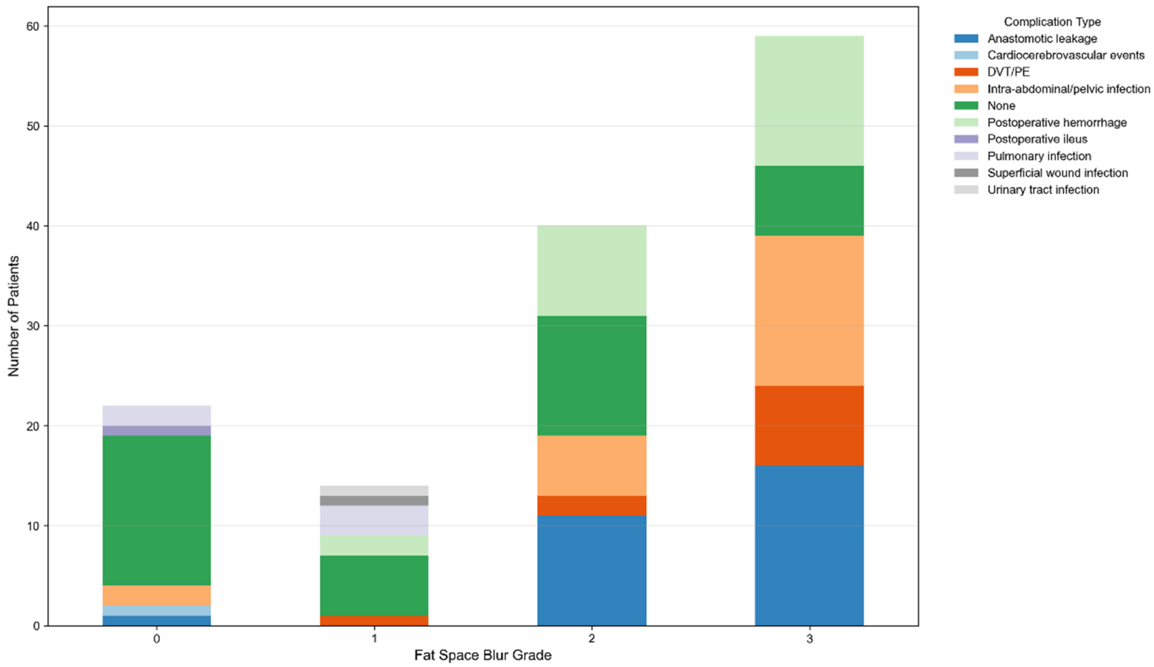

Figure 8. Distribution of complication types by fat space blur grade.

Table 2. Regression analysis results

Variable	coef	std err	z	*P* value	OR	95% CI
Fat_space_blur_grade	0.952	0.215	4.423	<0.001	2.591	(1.699, 3.952)
Age	-0.025	0.023	-1.065	0.287	0.976	(0.932, 1.021)
BMI	0.007	0.061	0.107	0.915	1.007	(0.893, 1.134)
Tumor_max_diameter_cm	-0.104	0.130	-0.800	0.424	0.901	(0.699, 1.163)
NLR	-0.131	0.133	-0.983	0.326	0.877	(0.676, 1.139)
CRP	-0.016	0.034	-0.482	0.630	0.984	(0.921, 1.051)
Const	1.518	2.190	0.693	0.488	4.564	(0.062, 334.096)

Abbreviation: BMI, body mass index; NLR, neutrophil-to-lymphocyte ratio; CRP, C-reactive protein.

As shown in **Table 2**, the regression coefficient for fat plane blurring grade was 0.952 (standard error =0.215), corresponding to an OR of 2.591 (95% CI: 1.699-3.952), further confirming its statistically significant role as an independent predictor of postoperative complications (P<0.001). None of the other variables reached statistical significance in the multivariate model.

Subgroup analyses: tumor location and surgical approach

To assess the robustness of the predictive value of peritumoral fat plane blurring grade, we performed subgroup analyses stratified by tumor location and surgical approach (**Figure 9**).

Stratification by tumor location: Within each anatomical subgroup-rectal, left-sided colon, and right-sided colon-the incidence of postoperative complications significantly increased with higher fat plane blurring grades (**Figure 9A**). Notably, at Grade 3 blurring, complication rates reached 88.9% in rectal tumors and 100% in both left- and right-sided colon tumors, indicating that this imaging predictor is applicable across different tumor locations.

Stratification by surgical approach: The positive association between fat plane blurring grade and complication risk remained consistent across patients undergoing laparoscopic, open, or robot-assisted surgery (**Figure 9B**). In all surgical subgroups, patients with

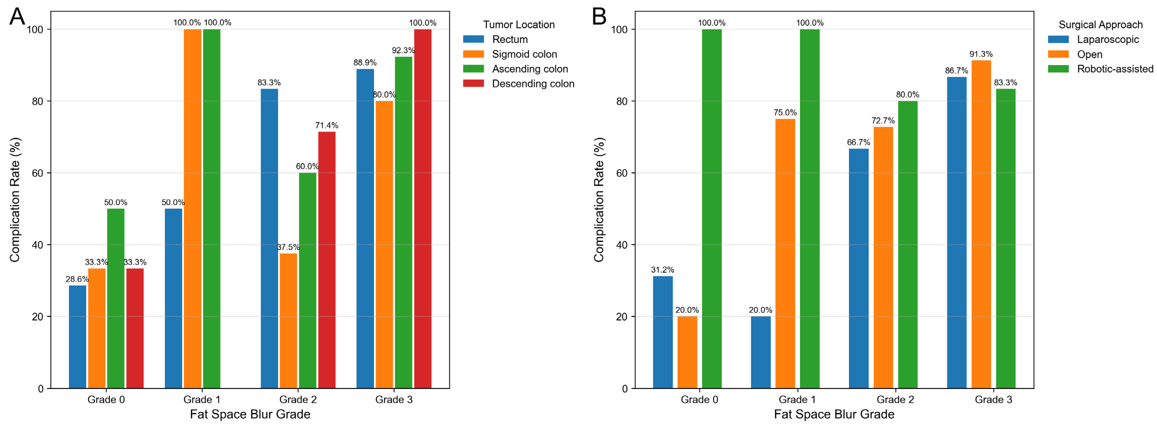

Figure 9. Subgroup analysis of complication rates stratified by tumor location (A) and surgical approach (B) across different fat space blur grades.

high-grade blurring (Grades 2, 3) exhibited significantly higher complication rates compared to those with low-grade blurring (Grades 0, 1), further supporting the generalizability of this predictor regardless of surgical technique.

Correlation analysis among clinical variables

The peritumoral fat plane blurring grade showed a moderate positive correlation with postoperative length of stay (r=0.63) and a weak positive correlation with maximum tumor diameter (r=0.35). In contrast, its correlations with age, BMI, and CRP were relatively weak. Additionally, among laboratory parameters, the neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) exhibited a moderate positive correlation (r=0.63, **Figure 10**).

Association between peritumoral fat plane blurring grade and patient survival outcomes

Survival analysis was performed in a subset of 91 patients with complete follow-up data. Kaplan-Meier survival curves demonstrated a significant association between peritumoral fat plane blurring grade and overall survival (Log-rank test, P<0.001) (**Figure 11**). As the blurring grade increased, patient survival probability progressively declined. Patients in Grade 0 exhibited the most favorable prognosis, whereas those in Grade 3 had the poorest survival outcomes, with clearly divergent survival curves observed throughout the follow-up period.

Distribution and correlations of key continuous variables

Using a scatterplot matrix, we further examined the distribution patterns and pairwise correlations among four key continuous variables: peritumoral fat plane thickness, maximum tumor diameter, neutrophil-to-lymphocyte ratio (NLR), and postoperative length of stay (**Figure 12**). The results showed a moderate positive correlation between peritumoral fat plane thickness and postoperative hospital stay (r=0.633, P<0.001). Additionally, fat plane thickness exhibited weak but statistically significant positive correlations with both tumor size (r=0.293, P<0.001) and NLR (r=0.298, P<0.001). Tumor size was also weakly positively correlated with postoperative length of stay (r=0.210, P<0.05).

Representative CT images of peritumoral fat space blur grades

To illustrate the four-tier grading system for peritumoral fat space blur, representative axial contrast-enhanced CT images from four patients with colon or rectal cancer are shown in **Figure 13**.

Grade 0 (**Figure 13A**): A 62-year-old patient with rectal cancer. The peritumoral fat space is clear, with no visible linear stranding or increased attenuation. The tumor margins are well-defined against the surrounding fat.

Grade 1 (**Figure 13B**): A 58-year-old patient with ascending colon cancer. Mild peritumoral

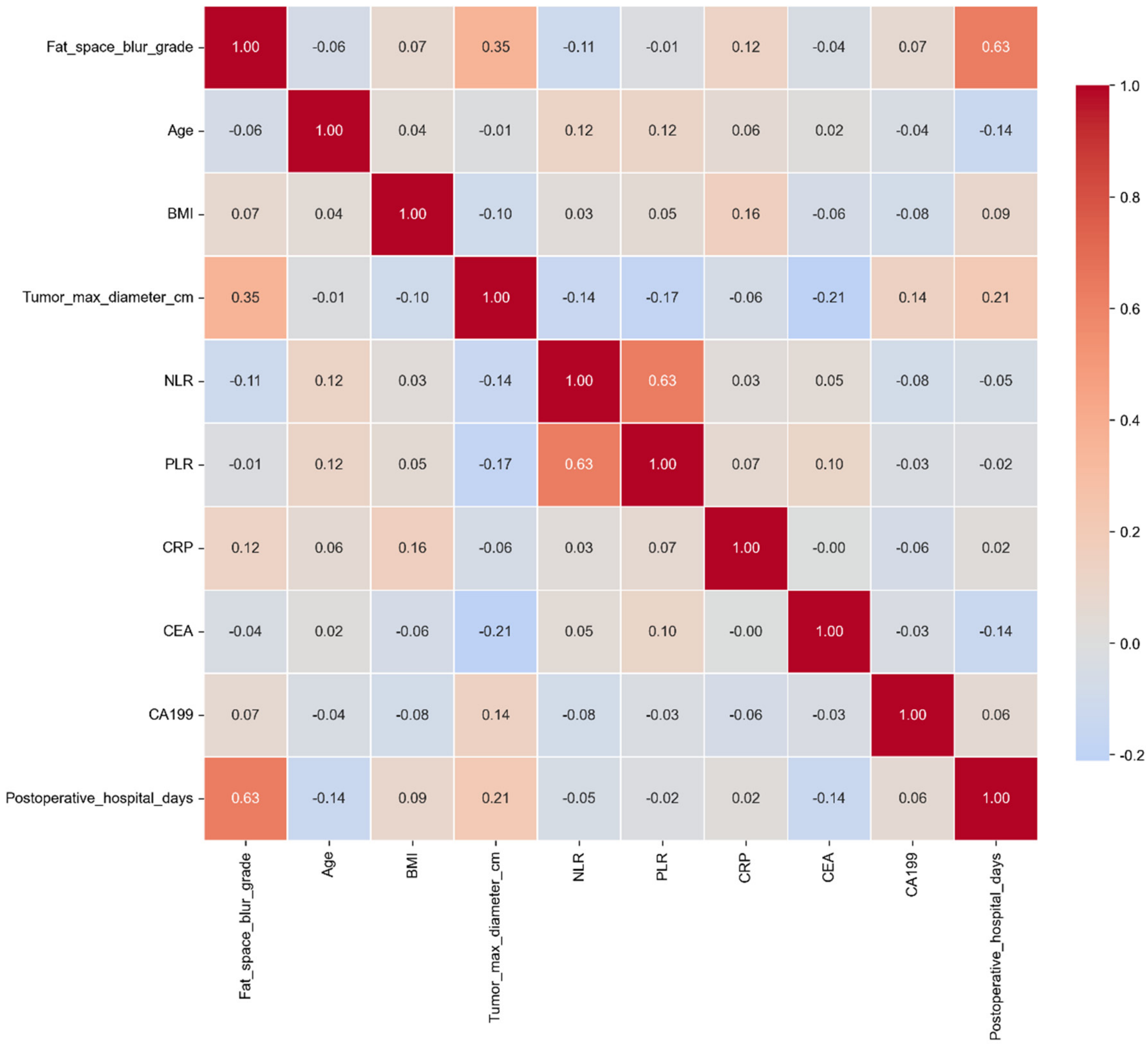

Figure 10. Correlation heatmap: clinical variables. Abbreviation: NLR, neutrophil-to-lymphocyte ratio; PLR, platelet-to-lymphocyte ratio.

fat stranding is present, characterized by a few fine linear opacities extending from the tumor edge into the adjacent fat, but without confluence or mass effect.

Grade 2 (**Figure 13C**): A 65-year-old patient with hepatic flexure colon cancer. Moderate peritumoral fat stranding is observed, with multiple thicker linear opacities and small ill-defined areas of increased density, partially obscuring the tumor boundary.

Grade 3 (**Figure 13D**): A 70-year-old patient with ascending colon cancer. Severe peritumoral fat stranding is evident, with confluent coarse linear and reticular opacities, patchy high-attenuation areas, and near-complete effacement of the fat plane surrounding the tumor.

Discussion

This study, based on a large single-center retrospective cohort, systematically evaluated the association between the quantified scoring of peritumoral fat plane blurring observed on preoperative contrast-enhanced CT and postoperative complications in colorectal cancer patients. The results showed a significant positive correlation between the degree of fat plane blurring and both overall postoperative complications (Clavien-Dindo grade ≥II) and severe complications (grade ≥III). Furthermore, multivariate logistic regression analysis con-

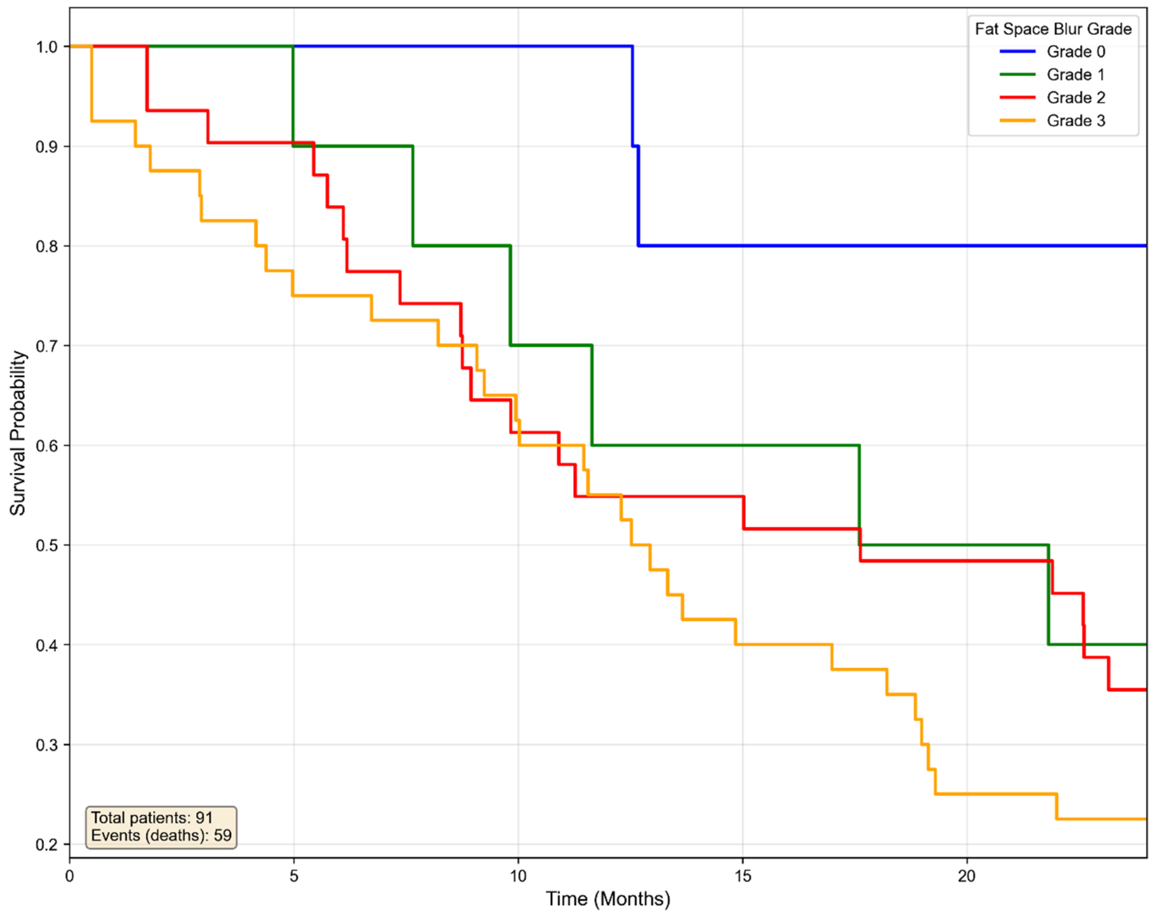

Figure 11. Kaplan-Meier survival curves by fat space blur grade.

firmed that this imaging feature is an independent predictor of postoperative complications, with superior predictive performance compared to traditional clinical scoring systems such as the ASA score or POSSUM. These findings not only validate the critical role of the local inflammatory microenvironment in perioperative risk but also provide a simple, reproducible imaging biomarker for preoperative non-invasive risk stratification. This can potentially enhance the precision of surgical planning and patient management by offering an additional layer of prognostic information.

Our findings are highly consistent with previous studies on the relationship between the tumor microenvironment and surgical outcomes. Numerous pathological investigations have demonstrated that chronic inflammatory responses at the tumor invasive margin-characterized by infiltration of lymphocytes, macrophages, and neutrophils - can induce tissue edema, fibrosis, and microcirculatory impairment, thereby compromising anastomotic healing and increasing infection risk [16-19]. The peritumoral fat plane blurring observed on CT imaging represents the macroscopic radiological manifestation of this underlying pathological process.

For instance, Coutureau et al. [20] reported in gastric cancer patients that the preoperative CT finding of "peritumoral fat stranding" was significantly associated with postoperative anastomotic leakage (OR=3.21, $P<0.01$), attributing this association to elevated local expression of pro-inflammatory cytokines such as IL-6 and TNF-α. Similarly, Komono et al. [21] found in rectal cancer that fat plane blurring was independently associated with increased intraoperative blood loss and prolonged hospital stay.

Our study extends this concept across the entire spectrum of colorectal cancer and en-

Figure 12. Scatter plot matrix: key continuous variables. Abbreviation: NLR, neutrophil-to-lymphocyte ratio.

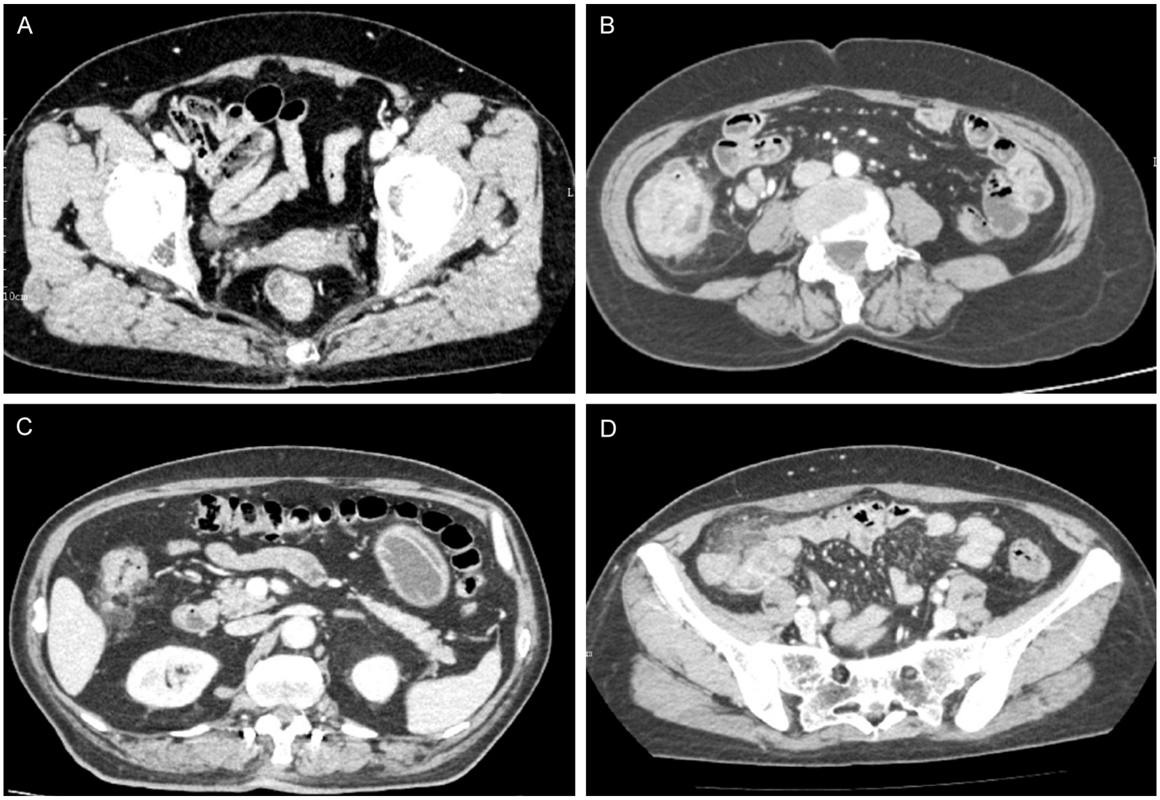

Figure 13. Representative axial contrast-enhanced CT images showing the four grades of peritumoral fat space blur. A. Grade 0: rectal cancer with clear peritumoral fat. B. Grade 1: ascending colon cancer with mild linear stranding. C. Grade 2: hepatic flexure colon cancer with moderate confluent stranding. D. Grade 3: ascending colon cancer with severe stranding and fat plane effacement.

hances assessment precision and reproducibility through a four-tier quantitative grading system.

Notably, this study is the first to clearly establish the predictive value of peritumoral fat plane blurring for severe complications (Clavien-Dindo grade ≥III). In subgroup analyses, even after adjusting for known inflammatory and oncological factors-including pathological T stage, preoperative albumin levels, and systemic markers such as the neutrophil-to-lymphocyte ratio (NLR) - a high blurring score (Grades 3, 4) remained significantly associated with more than a 2.5-fold increased risk of severe complications (adjusted odds ratio [aOR] =2.68; 95% CI: 1.74-4.13).

This finding suggests that the local inflammatory burden reflected by imaging may more accurately capture tissue vulnerability in the surgical field than systemic inflammatory markers. Indeed, although blood-based indicators such as NLR and CRP are widely used to assess systemic inflammation [22-25], they cannot distinguish the anatomical source of inflammation and are unable to reflect microstructural alterations at the tumor-host interface. In contrast, peritumoral fat plane blurring originates directly from tissues adjacent to the tumor, and its spatial specificity renders it a more "surgically relevant" risk signal.

This may reflect differences in anatomy and microbial environment: the right colon has more liquid contents and lower bacterial load, while the left colon and rectum have denser microbiota, where anastomotic leaks more readily trigger severe infections. Consequently, even minor anastomotic leaks in these distal regions are more likely to trigger severe intra-abdominal infections [25-27]. Thus, in areas where a pro-inflammatory milieu coincides with high bacterial burden, the impairment of local tissue barrier function may be amplified, making the prognostic value of fat plane blurring particularly pronounced. This finding provides a rationale for developing site-specific perioperative management strategies tailored to tumor location.

From a pathophysiological perspective, peritumoral fat plane blurring reflects not only inflammatory infiltration but also hypoxia-driven fibrosis and aberrant angiogenesis. Rapid tumor growth can induce local hypoxia, activating the HIF-1α pathway, which in turn promotes TGF-β release, leading to fibroblast activation and collagen deposition [18, 19, 28]. This fibrotic microenvironment renders tissues stiffer and less vascularized, potentially compromising suture integrity during surgery and increasing the risk of anastomotic dehiscence. Concurrently, disorganized neovasculature with increased permeability exacerbates tissue edema and exudation, producing the characteristic "blurred" appearance on CT imaging. Therefore, fat plane blurring likely represents an integrated radiological phenotype of multiple adverse biological processes, underpinned by a complex interplay among immune cells, stromal components, and vasculature.

We further evaluated whether the fat blur grade could provide incremental predictive value over the conventional ASA classification. As shown in Supplementary Table 1, the fat blur grade alone demonstrated moderate discriminative ability, with an AUC of 0.750 (95% CI: 0.660-0.845), which was superior to ASA alone (AUC=0.596, 95% CI: 0.504-0.688). However, combining the two did not significantly improve prediction (combined model AUC=0.778, 95% CI: 0.696-0.865; ΔAUC vs. ASA alone =0.182, bootstrap P=0.458; ΔAUC vs. fat blur alone =0.028). These findings indicate that the fat blur grade captures risk information that is largely independent of, and more relevant to surgical outcomes than the systemic physiological status reflected by ASA. The lack of incremental value from ASA may be explained by the fact that postoperative complications in colorectal cancer are more strongly influenced by local tumor-host interactions and tissue integrity at the surgical site-directly visualized by peritumoral fat blurring-than by patients' baseline comorbidities. This reinforces the potential utility of this imaging biomarker as a simple, non-invasive tool for preoperative risk stratification, complementing rather than replacing clinical judgment, and potentially guiding individualized perioperative strategies.

It is worth emphasizing that current mainstream prediction models for postoperative complications-such as the ALP score or CR-POSSUM-primarily rely on intraoperative variables or early postoperative indicators, limiting their utility in preoperative decision-making [29]. In contrast, our study demonstrates that highly discriminative risk information can be extracted from routine preoperative CT scans alone. Integrating the fat plane blurring grade into existing predictive models - for instance, as an imaging-based dimension in a nomogram - has the potential to substantially improve preoperative risk stratification.

From a clinical perspective, the identification of patients with high blurring scores may prompt closer perioperative monitoring and consideration of enhanced recovery protocols. However, whether specific interventions - such as delaying surgery to optimize nutritional status, using prophylactic antibiotics, or performing a protective stoma - can effectively reduce complications in this high-risk group remains to be determined. Prospective interventional studies are needed to validate these potential strategies. Particularly in the context of neoadjuvant chemoradiotherapy for rectal cancer, dynamic changes in fat plane blurring may also serve as a biomarker for monitoring treatment response - some studies have suggested that improvements in fat plane blurring post-treatment correlate with pathological complete response [30], though its relationship with complications remains to be explored.

Of course, this study has certain limitations. Firstly, as a single-center retrospective study, there may be selection bias; secondly, although assessment of fat plane blurring utilized a standardized four-tier scale, it still relies on subjective judgment by radiologists. Despite reporting good intra- and inter-rater reliability (ICC>0.85), future development of automated or AI-assisted objective quantification tools is needed to enhance generalizability. Thirdly, postoperative pathological inflammation scores (such as Crohn-like reaction or tumor budding) were not included for direct comparison, limiting deeper exploration of imaging-pathology correlations. However, these limitations do not diminish the clinical implications of our findings: by simply paying attention to this straightforward sign during routine preoperative CT review, significant enhancement in risk identification can be achieved. Fourthly, although ASA classification showed limited predictive value and did not add incremental benefit to the fat blur grade, this may be influenced by the relatively small sample size or the distribution of ASA grades in our cohort; larger multicenter studies are needed to confirm these findings and further explore the interplay between systemic and local risk factors. Fifth, although the follow-up period extended up to 24 months, systematic data on long-term complications such as anastomotic stricture or chronic intestinal obstruction were not available for all patients, precluding analysis of the association between fat blur grade and late adverse events. Future studies with dedicated long-term follow-up are needed to address this question.

Future multicenter prospective studies are needed to validate the generalizability of fat blur grading. Integration with deep learning for automated quantification, and combination with radiomics, inflammatory markers, and microbiota data, may further enhance predictive accuracy. Whether preoperative anti-inflammatory interventions can improve outcomes in high-risk patients warrants investigation.

Clinically, this imaging sign offers the distinct advantage of being readily assessable on routine preoperative CT without additional examinations or post-processing. The four-tier grading system demonstrated excellent inter-rater reliability (κ=0.892) in this study, supporting its feasibility for clinical implementation. If standardized assessment protocols and grading thresholds can be established in future research, peritumoral fat space blurring has the potential to serve as a valuable complement to existing preoperative risk stratification tools. Notably, the local inflammatory-fibrotic microenvironment reflected by this imaging feature may also represent a potential therapeutic target for novel perioperative interventions. This seemingly subtle imaging detail may serve as a crucial bridge between radiographic phenotype and precision perioperative management.

Conclusion

This study demonstrates that quantitative grading of peritumoral fat space blurring on preoperative contrast-enhanced CT is an independent predictor of postoperative complications - particularly severe complications (Clavien-Dindo grade ≥III) - in patients with colorectal cancer. The imaging sign is simple to assess, requires no additional examination costs, and can be readily identified during routine radiological review, offering excellent clinical feasibility. With a sensitivity of 81.6% and specificity of 75.8% at the optimal cutoff (grade ≥2), this imaging biomarker demonstrates moderate predictive performance for identifying high-risk patients. Incorporating fat space blurring into preoperative risk assessment protocols may facilitate early identification of high-risk patients and inform individualized perioperative management strategies, such as nutritional optimization, decisions regarding prophylactic stoma creation, or timely multidisciplinary team involvement. The robustness of this association across different tumor locations and surgical approaches in subgroup analyses supports its generalizability. Future multicenter prospective studies are warranted to validate its universal applicability and to further explore its underlying associations with the inflammatory microenvironment, gut microbiota, and treatment response, thereby advancing the field of precision surgery.

Disclosure of conflict of interest

None.

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Supplementary Table 1. Comparison of predictive performance for postoperative complications: peri-tumoral fat plane blurring grade alone, ASA classification alone, and their combination

Model	AUC	AUC 95% CI	Sensitivity	Specificity	*P* value (vs. Combined)
Fat blur grade alone	0.750	(0.660, 0.845)	0.547	0.825	-
ASA alone	0.596	(0.504, 0.688)	0.400	0.750	-
Combined (grade + ASA)	0.778	(0.696, 0.865)	0.695	0.775	0.458