Article

Incidence and Risk Factors of Postoperative Acute Kidney Injury in Colorectal Cancer Patients With Metabolic Syndrome: A Retrospective Cohort Study

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AIM: Postoperative acute kidney injury (AKI) is a serious complication commonly occurring after colorectal cancer surgery, primarily associated with prolonged hospitalization and poor prognosis. Metabolic syndrome (MetS) is accompanied by chronic inflammation, insulin resistance, and subclinical renal dysfunction—factors that could augment susceptibility to AKI in patients under surgical stress. This study aims to investigate the incidence and risk factors of postoperative AKI in colorectal cancer patients with MetS and provide a reference for perioperative risk management.
METHODS: In this retrospective cohort study, 209 patients with MetS who underwent radical resection for colorectal cancer at Ezhou Central Hospital from January 2023 to December 2025 were consecutively enrolled. According to whether AKI occurred after surgery, the patients were divided into AKI group (n = 63) and non-AKI group (n = 146). Demographic data, metabolic indicators, inflammatory markers, and surgery-related variables were collected. Univariate and multivariate logistic regression analyses were conducted to identify independent risk factors of AKI, and a predictive model was constructed. The model's performance was evaluated by analyzing the area under the curve (AUC) and the calibration curve.
RESULTS: Univariate analysis showed that fasting plasma glucose, 2-hour postprandial blood glucose, systolic blood pressure, diastolic blood pressure, components of metabolic syndrome, preoperative neutrophil-to-lymphocyte ratio (NLR), intraoperative blood loss, hypoalbuminemia, and intraoperative hypotension were significantly associated with AKI ($p < 0.05$). Multivariate analysis showed that diastolic blood pressure (odds ratio [OR] = 1.071, 95% confidence interval [CI]: 1.033–1.109), preoperative NLR (OR = 2.832, 95% CI: 1.381–5.804), intraoperative blood loss (OR = 1.040, 95% CI: 1.026–1.054), and intraoperative hypotension (OR = 3.499, 95% CI: 1.276–9.592) were independent risk factors for postoperative AKI. The AUC of the predictive model was 0.86, indicating good calibration.
CONCLUSIONS: Colorectal cancer patients with MetS are at an increased risk of postoperative AKI. Elevated diastolic blood pressure, a higher preoperative NLR, increased intraoperative blood loss, and episodes of intraoperative hypotension are independent risk factors of AKI. Therefore, optimizing perioperative blood pressure control, assessing the inflammatory status, adopting more delicate surgical techniques, and ensuring vigilant hemodynamic monitoring are essential strategies to reduce the risk of AKI in these patients.

Keywords: metabolic syndrome; colorectal cancer; acute kidney injury; risk factors

Introduction

Colorectal cancer is a type of malignant tumor of the lower gastrointestinal tract, commonly presenting with symptoms such as abdominal distension, abdominal pain, abdominal mass, and changes in stool shape [1]. Surgery is the primary treatment for colorectal cancer and exposes patients to a variety of perioperative stressors, which can trigger physiological stress responses, including changes in hormonal balance, metabolism, hematologic parameters, and immune function [2], thereby increasing the risk of postoperative complications. Colorectal cancer is accompanied by several notable postoperative complications, such as anastomotic leakage, suboptimal wound healing, and acute kidney injury (AKI). Among them, AKI is a common complication occurring after surgical resection of colorectal cancer, and it is associated with relatively high morbidity and postoperative mortality, which have an adverse impact on the prognosis of patients [3]. The occurrence of postoperative AKI is closely related to the prolonged hospitalization time, rising hospitalization costs, increased incidence of complications, and poor prognosis of patients. Therefore, perioperative strategies aiming to identify high-risk patients and implement early interventions are crucial to address the rising incidence of postoperative AKI.

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Metabolic syndrome (MetS) represents a group of metabolic disorders primarily attributed to hyperinsulinemia/insulin resistance. The prevalence of MetS is influenced by race, environment, age, sex, genetic factors, physical activity, and dietary habits [4]. At present, it is recognized that colorectal adenoma is a precancerous lesion of colorectal cancer. A study has shown that obesity, hypertension, low high-density lipoprotein cholesterol levels, high cholesterol levels, high triglyceride levels, and high fasting plasma glucose can promote the occurrence and development of colorectal polyps and increase the risk of colorectal adenoma [5]. In recent years, investigating the relationship between MetS and cancer has become a research hotspot. Of note, several studies have shown that drinking [6], obesity [7], diabetes [8], dyslipidemia [9], and other metabolism-related diseases are associated with the occurrence of colorectal cancer.

Preoperative metabolic status is recognized as a risk factor for postoperative AKI. First, from the perspective of renal function, each component of MetS is a known risk factor for kidney injury, and long-term hypertension can lead to glomerular atherosclerosis and ischemic nephron loss, while hyperglycemia causes glomerular hyperfiltration, basement membrane thickening, and interstitial fibrosis through advanced glycation end-products, activation of the polyol pathway, and other mechanisms [10]. On the other hand, obesity can lead to obesity-related nephropathy through intraglomerular hypertension, activation of the renin-angiotensin-aldosterone system, and the effects of adipocytokines [11]. Therefore, patients with MetS may experience varying degrees of subclinical renal dysfunction or renal reserve depletion before surgery. Second, in terms of the pathophysiological response to surgical stress, patients with MetS present a state of "hyperresponsiveness". Insulin resistance and chronic inflammation, which are common in the MetS context, contribute to the intensification and prolongation of the body's endocrine and inflammatory responses to surgical trauma, anesthesia, pain, and other stimuli [12]. Excessive systemic inflammatory response syndrome can lead to excessive release of inflammatory cytokines, causing apoptosis of renal tubular epithelial cells and microcirculatory disorders [13].

Despite the extensive research on the risk factors for postoperative AKI in patients receiving general surgery, the risk factors of postoperative AKI in colorectal cancer patients with MetS—a specific and high-risk subgroup—remain unclear. Therefore, this retrospective cohort study aims to systematically investigate the independent risk factors for AKI in colorectal cancer patients with MetS undergoing surgery. The findings of this study are expected to provide robust, evidence-based guidance for accurate preoperative risk assessment and perioperative goal-directed management in this high-risk population.

Methods

Study Participants

In this retrospective cohort study, patients who underwent elective radical surgery for colorectal cancer at the Department of General Surgery of Ezhou Central Hospital from January 2023 to December 2025 were consecutively enrolled. The study protocol strictly adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Ezhou Central Hospital (approval number: [2025]-12). Due to the retrospective nature of the study and the use of anonymized data, the requirement for written informed consent was formally waived by the Institutional Review Board. All patients' clinical data were obtained from the electronic medical record system, and data collection and analysis were performed after anonymization to fully protect patient privacy. Inclusion criteria of the present study included: (1) age $\geq$18 years; (2) histopathologically confirmed colorectal adenocarcinoma following surgery; (3) receipt of standard radical surgery for colorectal cancer; and (4) availability of complete preoperative clinical and laboratory data sufficient for the diagnosis and staging of MetS. Exclusion criteria included: (1) emergency, palliative, or non-radical surgery; (2) use of nephrotoxic drugs (e.g., non-steroidal anti-inflammatory drugs, aminoglycoside antibiotics, or contrast media) within 3 months before surgery; (3) presence of other active malignancies; and (4) substantial missing perioperative clinical data.

Diagnostic Criteria for MetS

Metabolic syndrome (MetS) was defined as the presence of three or more of the following five criteria: (1) central obesity, defined as waist circumference $\geq$90 cm in men and $\geq$85 cm in women; (2) fasting plasma glucose (FPG) $\geq$6.1 mmol/L and/or 2-hour postprandial blood glucose (2hPBG) $\geq$7.8 mmol/L, and/or a diagnosis of diabetes under treatment; (3) blood pressure $\geq$130/85 mmHg, and/or a diagnosis of hypertension under treatment; (4) fasting triglyceride (TG) $\geq$1.7 mmol/L; and (5) fasting high-density lipoprotein cholesterol (HDL-C) $<$1.04 mmol/L in men and $<$1.30 mmol/L in women [14].

Diagnostic Criteria for Postoperative Acute Kidney Injury

The primary outcome of this study was postoperative AKI, defined and staged according to the Kidney Disease: Improving Global Outcomes (KDIGO) Clinical Practice Guideline for Acute Kidney Injury [15]. AKI was diagnosed if any of the following criteria were met within 7 days after surgery: an increase in serum creatinine by $\geq$0.3 mg/dL ($\geq$26.5 µmol/L) within 48 hours, and/or an increase in serum creatinine to $\geq$1.5 times baseline, which is known or presumed to have occurred within the prior 7 days. Baseline serum creatinine was defined as the most recent preoperative serum creatinine value measured within 30 days prior to surgery. For patients without a preoperative value,

Table 1. Baseline characteristics of patients.

Variables	Total (n = 209)	Non-AKI group (n = 146)	AKI group (n = 63)	Statistic	p
Age (years)	67.923 ± 7.359	67.740 ± 7.216	68.349 ± 7.723	t = –0.548	0.584
Sex [n (%)]				χ^2 = 1.021	0.312
Male	115 (55.024)	77 (52.740)	38 (60.317)		
Female	94 (44.976)	69 (47.260)	25 (39.683)		
FPG (mmol/L)	6.282 ± 1.060	6.178 ± 1.058	6.522 ± 1.031	t = –2.174	0.031
2hPBG (mmol/L)	7.783 ± 1.212	7.649 ± 1.180	8.095 ± 1.237	t = –2.475	0.014
SBP (mmHg)	127.144 ± 16.364	125.445 ± 16.079	131.079 ± 16.467	t = –2.308	0.022
DBP (mmHg)	81.000 (74.000, 90.000)	78.500 (71.000, 86.000)	87.000 (80.500, 94.000)	Z = –4.525	<0.001
TG (mmol/L)	2.051 ± 0.696	2.038 ± 0.686	2.083 ± 0.721	t = –0.426	0.671
HDL-C (mmol/L)	1.074 ± 0.253	1.072 ± 0.241	1.078 ± 0.280	t = –0.154	0.878
WC (cm)	94.040 (86.520, 102.090)	93.090 (86.430, 100.267)	96.200 (88.175, 104.755)	Z = –1.847	0.065
MetS components [n (%)]				χ^2 = 11.929	0.003
3	109 (52.153)	87 (59.589)	22 (34.921)		
4	70 (33.493)	39 (26.712)	31 (49.206)		
5	30 (14.354)	20 (13.699)	10 (15.873)		
Preoperative NLR	2.900 (2.500, 3.300)	2.800 (2.500, 3.100)	3.100 (2.800, 3.700)	Z = –3.272	0.001
Surgical duration (min)	173.600 (167.200, 182.700)	172.750 (167.250, 180.275)	177.300 (166.600, 190.800)	Z = –1.301	0.193
Intraoperative blood loss (mL)	109.000 (82.000, 132.000)	97.500 (80.000, 119.000)	143.000 (107.000, 169.500)	Z = –6.612	<0.001
Intraoperative urine output (mL)	419.000 (369.000, 471.000)	428.000 (366.000, 481.250)	411.000 (377.500, 447.000)	Z = –1.351	0.177
Intraoperative fluid infusion volume (mL)	1485.000 (1428.000, 1545.000)	1479.000 (1435.250, 1533.750)	1495.000 (1372.500, 1617.500)	Z = –1.062	0.288
History of coronary heart disease [n (%)]	23 (11.005)	15 (10.274)	8 (12.698)	χ^2 = 0.264	0.607
Tumor location [n (%)]				χ^2 = 0.143	0.705
Rectum	107 (51.196)	76 (52.055)	31 (49.206)		
Colon	102 (48.804)	70 (47.945)	32 (50.794)		
TNM stage [n (%)]				χ^2 = 2.449	0.294
T1/T2	40 (19.139)	32 (21.918)	8 (12.698)		
T3	66 (31.579)	44 (30.137)	22 (34.921)		
T4	103 (49.282)	70 (47.945)	33 (52.381)		
Neoadjuvant therapy [n (%)]	13 (6.220)	10 (6.849)	3 (4.762)	χ^2 = 0.068	0.794
Hypoalbuminemia [n (%)]	55 (26.316)	31 (21.233)	24 (38.095)	χ^2 = 6.453	0.011
Intraoperative hypotension [n (%)]	28 (13.397)	15 (10.274)	13 (20.635)	χ^2 = 4.072	0.044
Intraoperative blood transfusion [n (%)]	19 (9.091)	15 (10.274)	4 (6.349)	χ^2 = 0.820	0.365

Abbreviations: DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; NLR, neutrophil-to-lymphocyte ratio; SBP, systolic blood pressure; TG, triglycerides; 2hPBG, 2-hour postprandial blood glucose; WC, waist circumference; AKI, acute kidney injury; MetS, metabolic syndrome; TNM, Tumor-Node-Metastasis.

the lowest serum creatinine value during hospitalization was used, or it was estimated by back-calculation under the assumption of a normal estimated glomerular filtration rate (eGFR) of 75 mL/min/1.73 m^2, as recommended by the KDIGO guidelines. Due to the retrospective nature of the study and the difficulty in obtaining accurate hourly urine output data from the electronic medical records, urine output criteria were not used to define AKI in this cohort.

Collection of Indicators

A standardized data extraction form was used to collect information, and variables, such as age, sex, waist circumference, and body mass index (BMI), were collected. Metabolic indicators included systolic blood pressure (SBP), diastolic blood pressure (DBP), FPG, 2-hour postprandial blood glucose, triglyceride, and HDL-C. Preoperative laboratory indices included neutrophil-to-lymphocyte ratio (NLR) and serum albumin (hypoalbuminemia was defined as <35 g/L [16]). Medical his-

Table 2. Results of univariate analysis.

Variables	β	S.E	Z	p	OR (95% CI)
Sex					
Male					1.000 (Reference)
Female	–0.309	0.306	–1.009	0.313	0.734 (0.403–1.338)
Age	0.011	0.021	0.550	0.582	1.011 (0.971–1.053)
History of coronary heart disease	0.239	0.466	0.513	0.608	1.270 (0.509–3.169)
Tumor location					
Rectum					1.000 (Reference)
Colon	0.114	0.302	0.378	0.705	1.121 (0.621–2.024)
TNM Stage					
T1/T2					1.000 (Reference)
T3	0.693	0.474	1.463	0.143	2.000 (0.790–5.062)
T4	0.634	0.448	1.415	0.157	1.886 (0.783–4.539)
Neoadjuvant therapy	–0.386	0.676	–0.570	0.568	0.680 (0.181–2.560)
Hypoalbuminemia	0.825	0.329	2.509	0.012	2.283 (1.198–4.351)
MetS components					
3					1.000 (Reference)
4	1.145	0.339	3.380	<0.001	3.143 (1.618–6.107)
5	0.682	0.455	1.499	0.134	1.977 (0.811–4.823)
WC	0.026	0.016	1.669	0.095	1.026 (0.995–1.058)
FPG	0.312	0.146	2.136	0.033	1.366 (1.026–1.820)
2hPBG	0.314	0.131	2.408	0.016	1.369 (1.060–1.769)
DBP	0.059	0.014	4.136	<0.001	1.061 (1.032–1.091)
SBP	0.021	0.009	2.264	0.024	1.022 (1.003–1.041)
TG	0.093	0.217	0.428	0.669	1.097 (0.717–1.681)
HDL-C	0.093	0.598	0.155	0.877	1.097 (0.340–3.540)
Preoperative NLR	0.881	0.264	3.341	<0.001	2.412 (1.439–4.043)
Surgical duration	0.010	0.011	0.934	0.350	1.010 (0.989–1.031)
Intraoperative blood loss	0.039	0.006	6.135	<0.001	1.039 (1.027–1.052)
Intraoperative urine output	–0.003	0.002	–1.303	0.192	0.997 (0.993–1.001)
Intraoperative fluid infusion volume	0.002	0.001	1.229	0.219	1.002 (0.999–1.005)
Intraoperative hypotension	0.820	0.414	1.982	0.047	2.271 (1.009–5.109)
Intraoperative blood transfusion	–0.524	0.584	–0.897	0.370	0.592 (0.188–1.861)

Abbreviations: S.E, standard error; OR, odds ratio; CI, confidence interval.

tory concerning comorbidities of patients, such as coronary heart disease, diabetes mellitus, and hypertension, was gathered. Tumor-related characteristics, including tumor location (colon/rectum), pathological Tumor-Node-Metastasis (TNM) stage, and receipt of neoadjuvant therapy, were collected. Surgical and anesthesia-related variables included operation time (from skin incision to the end of skin suture), estimated intraoperative blood loss, intraoperative urine volume, total intraoperative fluid volume, intraoperative hypotension (defined as SBP <90 mmHg for more than 10 minutes), and the intraoperative usage status of allogeneic red blood cell transfusion.

Statistical Analysis

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA), and R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria) was employed for the presentation of selected results. First, the Kolmogorov–Smirnov test was used to assess the normality of the continuous data. Variables conforming to normal distribution were expressed as mean ± standard deviation and compared using an independent sample *t*-test. Variables that were not normally distributed were presented as median and interquartile range, and the Mann–Whitney *U* test was employed for data comparison. Categorical variables were presented as counts and percentages, and the chi-square test or Fisher's exact test was used for analysis. Univariate logistic regression analysis was performed to identify related factors of postoperative AKI in colorectal cancer patients with MetS. Variables demonstrating $p <$ 0.05 in the univariate analysis were included in the multivariate logistic regression model, which was utilized for the identification of independent predictors of postoperative AKI. Results were expressed as odds ratios (ORs) and 95% confidence intervals (CIs), and a predictive model was subsequently developed. Receiver operating characteristic (ROC) curves were constructed to evaluate the model's discriminative ability, and the area under the curve (AUC) was

Table 3. Results of multivariate analysis.

Variables	β	S.E	Z	p	OR (95% CI)
DBP	0.068	0.018	3.774	<0.001	1.071 (1.033–1.109)
Preoperative NLR	1.041	0.366	2.842	0.004	2.832 (1.381–5.804)
Intraoperative blood loss	0.039	0.007	5.663	<0.001	1.040 (1.026–1.054)
Intraoperative hypotension	1.252	0.515	2.434	0.015	3.499 (1.276–9.592)

calculated. To reduce the risk of model overfitting, an adequate events-per-variable (EPV) ratio was ensured. The final multivariate model included four independent variables; with 63 AKI events, the EPV ratio was 15.75, which exceeded the recommended minimum of 10. Internal validation was performed using the bootstrap method (1000 resamples) to generate a calibration curve, assess agreement between predicted probabilities and observed outcomes, and calculate the mean absolute error. All tests were two-sided, and $p < 0.05$ was considered statistically significant.

Results

Baseline Characteristics of Patients

A total of 209 colorectal cancer patients with MetS were enrolled in this study, including 63 patients (30.14%) with postoperative AKI and 146 patients without AKI. The demographic and metabolic characteristics of the patients in the two groups, along with surgery-related data, are detailed in Table 1. There were significant differences in FPG, 2-hour postprandial blood glucose, SBP, DBP, components of MetS, preoperative NLR, intraoperative blood loss, hypoalbuminemia, and intraoperative hypotension between the AKI group and the non-AKI group ($p < 0.05$). However, there were no significant differences in age, sex, waist circumference, TG, HDL-C, history of coronary heart disease, tumor location, TNM stage, usage of neoadjuvant therapy, surgical duration, intraoperative urine output, intraoperative fluid infusion volume, or intraoperative blood transfusion between the two groups ($p > 0.05$ for all).

Results of Univariate Analysis

Univariate logistic regression analysis showed that FPG (OR = 1.366, 95% CI: 1.026–1.820), 2hPBG (OR = 1.369, 95% CI: 1.060–1.769), DBP (OR = 1.061, 95% CI: 1.032–1.091), SBP (OR = 1.022, 95% CI: 1.003–1.041), preoperative NLR (OR = 2.412, 95% CI: 1.439–4.043), intraoperative blood loss (OR = 1.039, 95% CI: 1.027–1.052), hypoalbuminemia(OR = 2.283, 95% CI: 1.198–4.351) and intraoperative hypotension (OR = 2.271, 95% CI: 1.009–5.109) were significantly associated with postoperative AKI ($p < 0.05$) (Table 2). Specifically, compared to patients with three MetS components, those with four components had a significantly higher risk of AKI (OR = 3.143, 95% CI: 1.618–6.107), whereas the risk for those with five components was not statistically significant (OR = 1.977, 95% CI: 0.811–4.823).

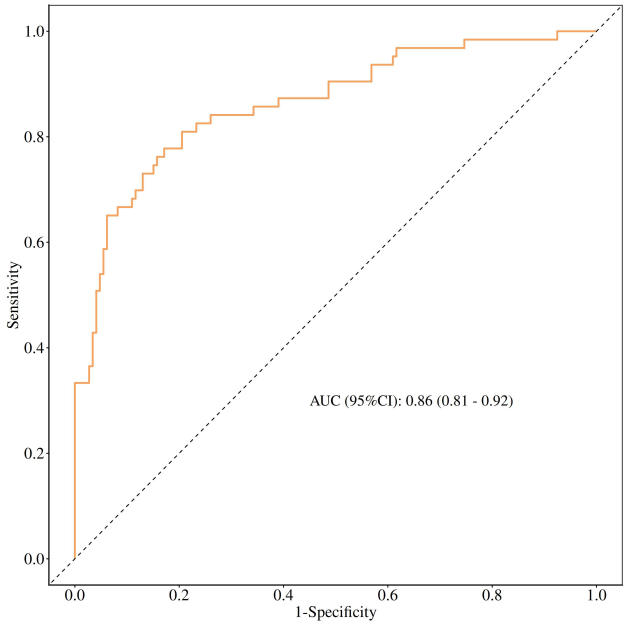

Fig. 1. Receiver operating characteristic (ROC) curve analysis of the predictive model for postoperative acute kidney injury. AUC, area under the curve; CI, confidence interval.

Results of Multivariate Analysis

Variables with $p < 0.05$ in the univariate analysis were included in a multivariate logistic regression model and screened using a stepwise backward method. Correlation analysis revealed a strong correlation between FPG and 2hPBG (Spearman's $r = 0.961$, $p < 0.001$). To avoid variable redundancy, 2hPBG was excluded from the multivariate model. Regarding blood pressure variables, although both SBP and DBP were significant in univariate analysis, DBP was retained and SBP was excluded because they reflect the same underlying physiological construct of systemic blood pressure load. Including both variables would introduce conceptual redundancy and hinder the independent interpretation of their effects. Collinearity diagnostics for the final model showed that all variance inflation factor (VIF) values were below 2.0, indicating no significant multicollinearity. The variable "MetS components" was also excluded, as it represents a composite measure derived from individual metabolic indicators (including DBP, FPG, TG, HDL-C, and waist circumference [WC]). Including both the composite score and its constituent components would introduce information redundancy and obscure the identification of specific, clinically modifiable risk factors. There-

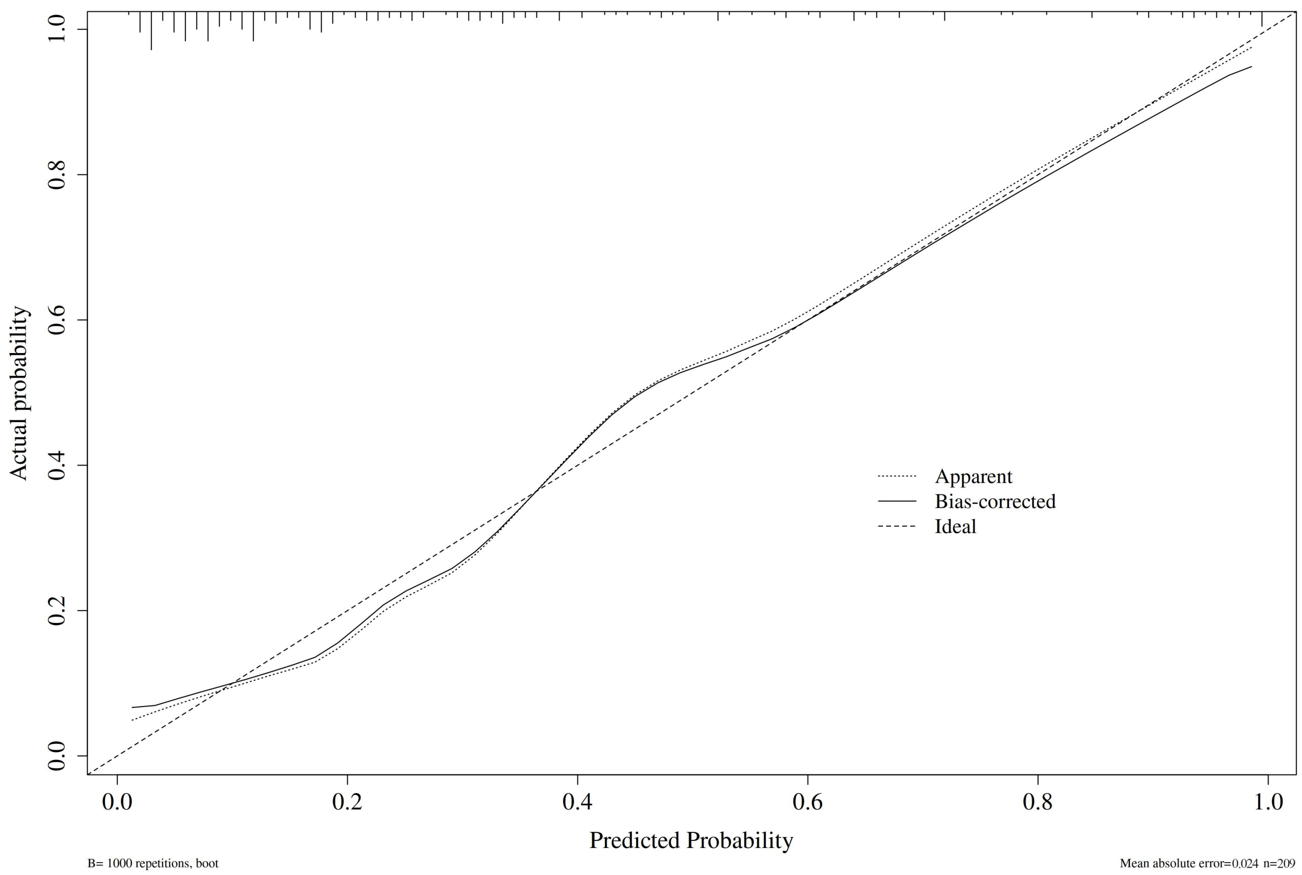

Fig. 2. Calibration curve analysis.

fore, individual metabolic components were prioritized to provide more precise and actionable insights for perioperative risk management. As shown in Table 3, DBP (OR = 1.071, 95% CI: 1.033–1.109), preoperative NLR (OR = 2.832, 95% CI: 1.381–5.804), intraoperative blood loss (OR = 1.040, 95% CI: 1.026–1.054) and intraoperative hypotension (OR = 3.499, 95% CI: 1.276–9.592) were identified as independent risk factors for postoperative AKI in colorectal cancer patients with MetS ($p < 0.05$) (Table 3).

Evaluation of Model Diagnostic Performance

Based on the four independent risk factors identified, a predictive model for postoperative AKI risk was developed, and an ROC curve was constructed (Fig. 1). The AUC of the model was 0.86 (95% CI: 0.81–0.92), indicating good discriminative performance.

Model Calibration Assessment

Internal validation was performed using 1000 bootstrap resamples with optimism correction. The model demonstrated good discriminative ability, with an apparent AUC of 0.864 and an optimism-corrected AUC of 0.853, indicating minimal overfitting. The bootstrap method (1000 repeated samples) was used to generate the model's calibration curve, which closely aligned with the ideal diagonal after bias correction. The optimism-corrected calibration slope was 0.932 and the calibration intercept was –0.052, indicating good agreement between predicted probabilities and observed outcomes without significant systematic bias. The mean absolute error was 0.024, indicating accurate calibration and strong concordance between predicted and observed risk (Fig. 2).

Clinical Utility Assessment via Decision Curve Analysis

Decision curve analysis was conducted to evaluate the clinical net benefit of the predictive model across different threshold probabilities for AKI (Fig. 3). Across a wide range of threshold probabilities, the model demonstrated positive net benefit. Specifically, at threshold probabilities between 2% and 6%, the model's net benefit exceeded that of both the "intervene-all" and "intervene-none" strategies. For example, at a 4% threshold probability, the net benefit of the model was 0.200, compared to 0.180 for the "intervene-all" strategy and 0.000 for "intervene-none". These findings indicate that using the model to guide perioperative interventions would result in a net clinical benefit across a range of clinically reasonable risk thresholds.

Discussion

This study focused on a high-risk group of colorectal cancer patients with MetS, in whom underlying metabolic disorders and chronic inflammation, compounded by tumor and

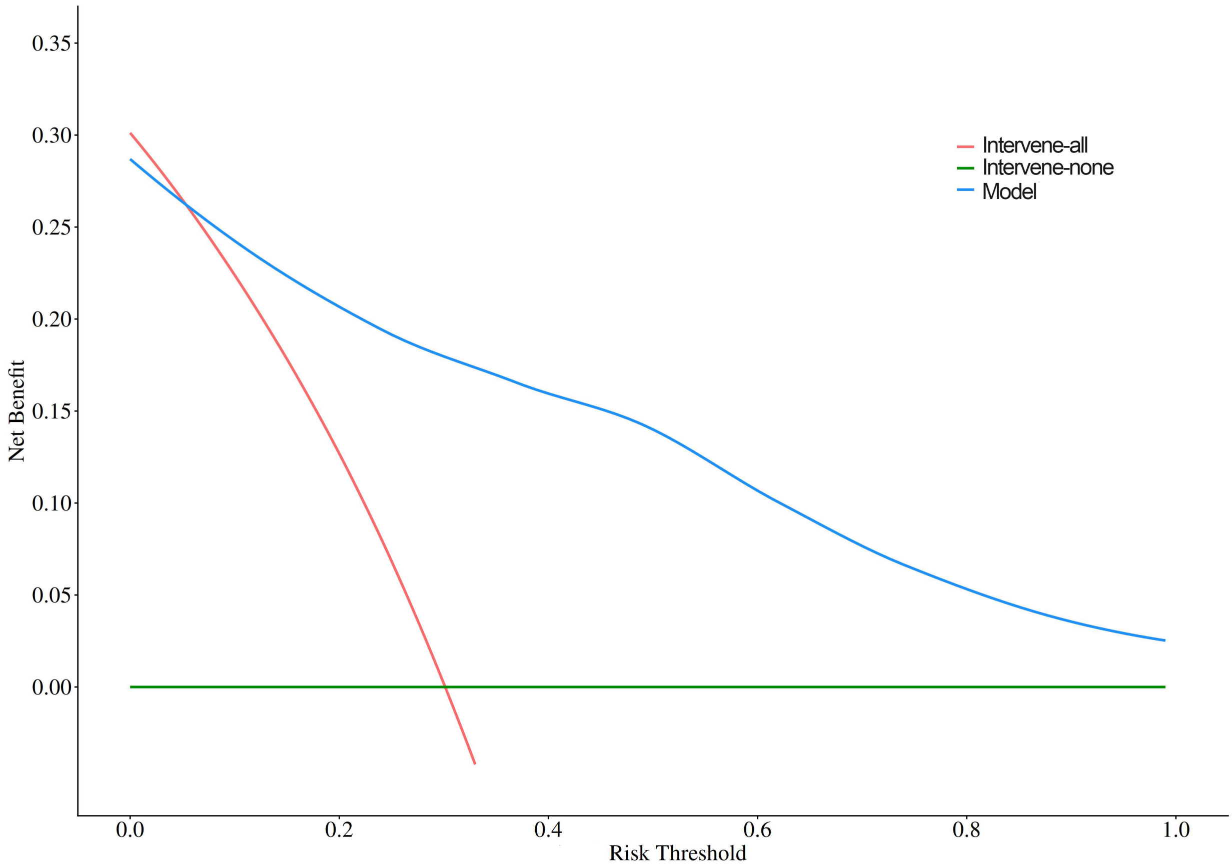

Fig. 3. Decision curve analysis of the predictive model for postoperative AKI.

surgical stress, significantly increased the risk of postoperative AKI. Currently, accurate predictive tools for postoperative AKI in this population remain limited. To our knowledge, this is the first study to systematically evaluate the predictive value of multidimensional indicators, such as preoperative metabolic status, inflammatory markers, and intraoperative management, for postoperative AKI in this group. Our findings identified higher preoperative DBP and NLR, as well as greater intraoperative blood loss and hypotensive events, as independent risk factors of postoperative AKI. The combined predictive model integrating these four variables showed excellent discriminative ability (AUC = 0.86), good calibration, and clinical utility, providing an objective basis for early identification of high-risk patients and targeted interventions. Nevertheless, prospective external validation is warranted to confirm its clinical utility and generalizability.

The 30.14% incidence of AKI observed in this study was higher than that reported in general colorectal cancer surgery patients. Compared with colorectal cancer patients without MetS, those with MetS face a higher risk of multiple metabolic disorders prior to surgery [17]. Baseline data in this study showed that patients who developed AKI had a greater metabolic burden, as reflected by higher DBP, elevated blood glucose levels, and a more complex MetS component profile, indicating more severe underlying impairment of renal reserve function. When kidneys with subclinical damage are exposed to surgical stress, patients with AKI tend to have a higher preoperative metabolic burden. Their renal compensatory capacity is significantly lower than that of patients with normal metabolic status, making them more susceptible to AKI. These findings suggest that colorectal cancer patients with MetS represent a high-risk subgroup, warranting tailored risk assessment and management strategies that are different from those prescribed to ordinary colorectal cancer patients. More rigorous and targeted organ function monitoring and protection measures should be implemented to mitigate the risk of AKI during the perioperative period.

Through multivariate logistic regression analysis, this study successfully identified four independent risk factors for postoperative AKI, namely the elevated DBP, increased preoperative NLR, greater intraoperative blood loss, and intraoperative hypotensive events. Although elevated SBP was significant in univariate analysis, it was excluded from the multivariate model due to conceptual overlap with DBP—both reflecting systemic blood pressure load—and because DBP demonstrated a stronger association with AKI. Long-term hypertension can lead to arteriosclerosis of glomeruli and weakened renal self-regulation, which collectively predispose the kidney to ischemia when it is exposed to intraoperative blood pressure fluctuations. At the same time, hypertension-related vascular endothelial dysfunction and oxidative stress can directly damage renal tubular epithelial cells [18]. A meta-analysis of AKI following colorectal cancer surgery similarly identified preoperative uncontrolled hypertension as a significant risk factor for postoperative AKI [19]. The findings of this study further emphasize that in colorectal cancer patients with MetS, active and stable perioperative blood pressure control is not only essential for controlling the underlying disease but also crucial for protecting renal function and preventing AKI.

The NLR integrates information from neutrophils, which reflect acute nonspecific inflammation, and lymphocytes, which represent immunomodulatory function, providing a comprehensive measure of the body's inflammation–immune balance. In this study, elevated preoperative NLR was a strong predictor of postoperative AKI. MetS is characterized by chronic, low-grade inflammation, with increased secretion of inflammatory factors such as interleukin-6 (IL-6) and tumor necrosis factor alpha (TNF-α) from adipose tissue [20]. Surgical trauma further amplifies the inflammatory response, and this superimposed inflammatory load can damage the kidney through multiple pathways, including direct cytotoxicity, induction of microthrombosis, and deterioration of endothelial damage [21]. In the context of our findings, the observed association between elevated preoperative NLR and postoperative AKI is consistent with the hypothesis that a heightened preoperative inflammatory state may increase renal susceptibility to surgical stress. However, as we did not directly measure specific inflammatory cytokines, the precise pathways—such as direct cytotoxicity, microthrombosis, or endothelial damage—remain speculative and require confirmation in mechanistic studies. Nonetheless, these results suggest that preoperative evaluation of inflammatory indicators, such as NLR, may help to identify patients with an augmented inflammatory response, who could be at higher risk of developing AKI.

Intraoperative blood loss and hypotension are critical risk factors for AKI. A decrease in effective circulating blood volume due to hemorrhage and a reduction in renal perfusion pressure due to hypotension are the classical mechanisms for AKI. In patients with MetS, the risk associated with these pathways was significantly increased. Renal self-regulation is often impaired due to microangiopathy and endothelial dysfunction, narrowing the tolerance window for blood pressure fluctuations [22]. Additionally, fluid resuscitation to correct hypotension and replenish volume may more readily lead to tissue edema and elevated renal interstitial pressure in MetS patients with underlying cardiac insufficiency or increased vascular permeability, further compromising renal perfusion [23].

The findings of this study have clear implications for clinical practice. First, a comprehensive preoperative evaluation is emphasized. For colorectal cancer patients with MetS who plan to undergo surgery, in addition to routine evaluation, a systematic assessment of blood pressure control and calculation of inflammatory markers should serve as an important basis for risk stratification. Second, perioperative management strategy should be optimized, with goal-directed hemodynamic strategies recommended for high-risk patients to prevent intraoperative hypotension and minimize blood loss. The predictive model based on the four readily available variables demonstrated strong performance (AUC = 0.86) and can rapidly identify patients at very high risk of AKI prior to surgery. For these patients, intensive care and preventive renal protection measures can be started in advance.

Certain limitations of this study should be acknowledged. First, this single-center, retrospective study has a relatively small sample size, with a limited number of outcome events (n = 63). The EPV ratio in the final model was approximately 15.75, which generally meets the minimum requirement for logistic regression; however, this ratio remains modest, and the use of stepwise regression to select predictors still carries a substantial risk of model overfitting and may lead to an overestimation of the model's predictive performance. Moreover, stepwise regression is known to produce unstable estimates that are highly dependent on the specific sample, and the variables selected may not be reproducible in independent datasets. Therefore, the generalizability of our findings needs to be rigorously verified in larger, prospective, multicenter cohorts with independent external validation. Thus, the predictive performance of this model (AUC = 0.86) should be interpreted with caution, as it may be likely optimistic due to overfitting, and its generalizability requires external validation. Second, due to the retrospective design, potentially confounding factors in this study, such as the specific anesthetic drug, vasoactive drug type, and dose, are unlikely to be fully controlled for. In the future, prospective cohort studies are needed to validate this risk predictive model in a broader population and to explore incorporating novel biomarkers to improve its early predictive ability. In addition, mechanism-directed translational research can be conducted using tissue samples or animal models to further explore how insulin resistance and chronic inflammation specifically alter the molecular mechanism of renal ischemia-reperfusion injury in the context of MetS. An interventional clinical trial can be conducted to evaluate whether an integrated management program targeting these risk factors could effectively reduce the incidence of postoperative AKI in this population.

Conclusions

In conclusion, this study demonstrated that colorectal cancer patients with MetS have a significantly higher incidence of postoperative AKI. Preoperative DBP, systemic inflammatory state (as reflected by NLR), intraoperative blood loss, and hypotensive events were identified as key, modifiable risk factors of AKI. The predictive model integrating these factors enables accurate preoperative risk stratification. In light of the findings, these patients warrant close monitoring in clinical practice, targeted management of preoperative metabolic disturbances and heightened inflammatory state, and optimized intraoperative hemodynamic control to minimize the risk of postoperative AKI and improve overall prognosis.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

QYZ and YJC designed the research study. KX and MW performed the research. QYZ and KX analyzed the data. YJC and MW drafted this article. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Ezhou Central Hospital (approval number: [2025]-12), and all procedures followed the principles of the Declaration of Helsinki. Due to the retrospective nature of the study and the use of anonymized data, the requirement for written informed consent was formally waived by the Institutional Review Board.

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Conflict of Interest

The authors declare no conflict of interest.

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