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RESEARCH

# A nutrition-based nomogram for predicting intra-abdominal infection after D2 radical gastrectomy for gastric cancer

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## Abstract

**Background** This study aims to construct a nutrition-based nomogram for predicting the risk of intra-abdominal infection (IAI) after D2 radical gastrectomy for gastric cancer (GC).

**Methods** We retrospectively analyzed the clinical data of 404 individuals who received D2 radical gastrectomy for GC. Four preoperative nutrition-related indicators, the nutritional risk screening (NRS) 2002 score, albumin (ALB), prognostic nutritional index (PNI), and controlling nutritional status (CONUT) score, were collected and calculated. Multivariate logistic regression analysis was utilized to screen the independent risk factors for IAI following D2 radical gastrectomy for GC. The area under the receiver operating characteristics (ROC) curve (AUROC) was computed. A nomogram was established to forecast postoperative IAI using the independent risk factors.

**Results** The NRS2002 score, ALB, PNI, CONUT score, fasting blood glucose (FBG), American Society of Anesthesiologists (ASA) score, type of resection, multi-visceral resection, perioperative blood transfusion, and the tumor, node, metastasis (TNM) stage were significantly associated with postoperative IAI. Considering the collinearity between these nutrition-related variables, four multivariate logistic regression analyses were separately performed, and four independent nutrition-based models were constructed. Of these, the best one was the model based on the three indicators of NRS2002 score, FBG, and multi-visceral resection, which had an AUROC of 0.744 (0.657–0.830), with a specificity of 75.6% and a sensitivity of 62.9%. Further, a nomogram was constructed to estimate the probability of IAI following D2 radical gastrectomy. The internal validation was carried out using the bootstrap method with self-help repeated sampling 1000 times, and the concordance index (c-index) was determined at 0.742 (95% CI = 0.739–0.745). The calibration curve revealed that the predictive results of the nomogram were in excellent concordance with the actual observations. The decision curve analysis (DCA) indicates that the nomogram has excellent clinical benefit.

**Conclusion** The nomogram constructed based on NRS2002 score, FBG, and multi-visceral resection has good predictive capacity for the incidence of IAI following D2 radical gastrectomy and provides a reference value for clinicians to assess the risk of IAI occurrence.

**Keywords** Gastric cancer · Nutrition · Intra-abdominal infection · Nomogram

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### Abbreviations

| | |
|---|---|
| ALB | Albumin |
| AUC | Area Under Curve |
| ASA | American Society of Anesthesiologists |
| BMI | Body Mass Index |
| COPD | Chronic Obstructive Pulmonary Disease |
| CONUT | Controlling Nutritional Status |
| CAR | CRP-to-Albumin Ratio |
| DCA | Decision Curve Analysis |
| ESPEN | European Society for Parenteral and Enteral Nutrition |
| FGB | Fasting Blood Glucose |

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| | |
|---|---|
| GC | Gastric Cancer |
| HGB | Hemoglobin |
| IAI | Intra-Abdominal Infection |
| IQR | Inter Quartile Range |
| LMR | Lymphocyte-to-Monocyte Ratio |
| NRS | Nutritional Risk Screening |
| NLR | Neutrophil-to-Lymphocyte Ratio |
| OR | Odd Radio |
| OS | Overall Survival |
| PNI | Prognostic Nutritional Index |
| PLR | Platelet-to-Lymphocyte Ratio |
| ROC | Receiver Operating Characteristic |
| SSI | Surgical Site Infection |
| SD | Standard Deviation |
| TNM | Tumour Node Metastasis |

## Introduction

Gastric cancer (GC), with over a million new instances and roughly 769,000 deaths in 2020, ranked fifth regarding incidence and fourth regarding mortality globally [1]. GC is the third leading cause of cancer-related deaths in China [2]. The radical stomach resection coupled with regional lymphadenectomy is the only confirmed and potentially curative therapy for GC with no distant metastases. The D2 radical gastrectomy is the standard procedure for treating curable GC in eastern Asia [3]. Nevertheless, the risk of severe surgical site infection (SSI) is considerable with this kind of procedure due to its high level of invasiveness [4]. Intra-abdominal infections (IAI), an essential component of SSIs, not only increase overall hospital expenditures and prolong postoperative hospital stays but also influence the long-lasting prognosis of GC patients [5, 6]. Therefore, identifying risk factors for postoperative IAI and individualizing the prediction of the probability of IAI is clinically significant.

Several prior studies have demonstrated that low prognostic nutritional index (PNI), comorbidities, body mass index (BMI)$\geq$25 kg/m$^2$, sarcopenia, open surgical procedure, operative time, intraoperative blood transfusion, tumor location at middle third, tumor size, and multi-visceral resection are independent predictors of postoperative infection following radical gastrectomy, and that some of which are modifiable factors that can be ameliorated by interventions preoperatively [5, 7, 8]. A few prior studies have developed models to predict IAI after surgery for GC. However, all of them are based on factors that are hard to change in the short term or are immutable and are limited in guiding the implementation of clinical interventions to prevent the occurrence of IAI [5, 9]. Hence, it is necessary to develop a clinical predictive model based on some modifiable factors to assist surgeons in predicting the risk of IAI following radical gastrectomy and taking some effective interventions.

The present study intended to investigate the independent factors linked to IAI following radical gastrectomy and to develop a nomogram containing nutrition-related indicators for predicting the occurrence of IAI following radical gastrectomy. Using this nomogram will assist surgeons in managing risk variables in patients following radical gastrectomy, decreasing the occurrence of postoperative IAI, reducing the duration of postoperative hospitalisation, and enhancing treatment outcomes.

## Methods

### Patients

Retrospectively, 404 patients who received D2 radical gastrectomy for GC at the Department of General Surgery, Lu'an Hospital, Anhui Medical University, between March 2019 and February 2021 participated in this study. The surgical treatment of GC was conducted according to the Japanese guidelines for treating gastric cancer. The criteria for inclusion were as follows: (1) GC Patients were verified by preoperative gastroscopic biopsy. (2) Radical gastrectomy performed. (3) Age over 18 years. (4) Patients having comprehensive clinical and pathological data. The following were the exclusion requirements: (1) Neoadjuvant chemotherapy before surgery; (2) R1/2 resection; (3) Gastric stump cancer; (4) Tumor with distant metastasis; (5) Palliative surgery. Under the principles of the Declaration of Helsinki, the Lu'an Hospital Ethics Committee of Anhui Medical University authorised the present research.

### Data collection

The below information was retrospectively gathered and documented in this study: (1) The demographic and tumor-related data, including age, gender, smoking and drinking history, prior abdominal surgery, body mass index (BMI), nutritional risk screening (NRS) 2002 score, American Society of Anesthesiology (ASA) score, surgical approach, tumor location, type of resection, multi-visceral resection, reconstruction methods, operative time, intraoperative blood loss, perioperative blood transfusion, maximum tumor diameter, neural infiltration, vascular infiltration, tumor differentiation and 8th edition of American Joint Committee on Cancer (AJCC)-TNM classification. (2) Preoperative haematological indicators comprising neutrophil count, lymphocyte count, platelet count, haemoglobin (HGB), albumin (ALB), fasting blood glucose (FBG), and total cholesterol. PNI = albumin (g/L) + 5 × lymphocyte, neutrophil-to-lymphocyte ratio (NLR) = neutrophil / lymphocyte, platelet-to-lymphocyte ratio (PLR) = platelet / lymphocyte. The controlling nutritional status (CONUT) score was determined by assessing serum albumin levels, total cholesterol concentrations, and total lymphocyte count (Supplementary Table S1) [10]. The NRS2002 score involves three aspects: illness severity (0–3 points), damaged nutritional status (0–3 points), and age (add 1 point if ≥ 70 years old). The overall score was 7, with < 3 representing a no nutritional risk, ≥ 3 representing a low nutritional risk, and ≥ 5 representing a high nutritional risk [11].

### Diagnostic criteria for IAI

The IAI was diagnosed using the below criteria [12]: (1) postoperative symptoms of fever, abdominal pain, abdominal swelling, or evidence of peritonitis, with elevated leukocytes or neutrophils detected by routine blood tests; (2) positive bacteriological cultures of the abdominal drainage fluid or puncture fluid; and (3) the existence of an IAI, such as purulent exudate and localised abscesses, was confirmed by abdominal ultrasonography, CT examination, or re-operation.

### Statistical analysis

SPSS (26.0) and R (4.3.0) were employed for statistical analyses. The categorical variables were represented as numbers (%) and examined using the Chi-square or Fisher's exact test. The quantitative variables were displayed as the mean ± standard deviation (SD) and were analysed using either the student's t-test or the Mann-Whitney U test. The Kaplan-Meier technique with the Log-rank test assessed the overall survival (OS) differences. Risk factors for postoperative IAI were clarified using univariate and multivariate logistic regression analyses. A nomogram for predicting postoperative IAI was created from the outcomes by logistic regression. The nomogram conducted internal validation using the Bootstrap method with self-help repeated sampling 1000 times, and the performance of the model was evaluated by calculating the concordance index (C-index) or the area under the receiver operating characteristic (ROC) curve (AUROC). The calibration chart with predicted and actual values was drawn up for concordance testing. Lastly, the clinical utility of the nomogram was assessed by decision curve analysis (DCA). Statistical significance was determined when the P-values were less than 0.05.

## Results

### Patients' characteristics

This study comprised 404 patients undergoing D2 radical gastrectomy for GC. Among them, 294 (72.8%) were male, and 110 (27.2%) were female. The median age was 68.0 years (IQR = 63.0–74.0 years). Sixty-four patients (15.8%) and 68 patients (16.8%) had a history of drinking and smoking, respectively. Comorbidity included hypertension in 129 patients (31.9%), chronic obstructive pulmonary disease (COPD) in 19 patients (4.7%), and diabetes mellitus in 40 patients (9.9%). 61 (15.1%) patients had undergone abdominal surgery. 35 individuals out of 404 (8.7%, 27 males and eight females) were diagnosed with IAI using the aforementioned diagnostic criteria. Of the 35 cases, there were anastomotic leaks in 7 cases, duodenal stump leaks in 4 cases, pancreatic fistula in 1 case, and IAI in the other 23 patients was caused by bile leaks, lymphatic leaks, and other unknown causes. With the meticulous care of medical professionals, all 35 patients were successfully treated and released from the hospital following thorough drainage, abdominal lavage, administration of antibiotics, nutritional support, and other therapeutic interventions. Notably, there were no cases of fatality.

The non-IAI and IAI patients showed significant differences in NRS2002 score, ALB, PNI, CONUT score, ASA score, type of resection, multi-visceral resection, intraoperative blood loss, perioperative blood transfusion, and TNM stage. The clinical characteristics of the non-IAI and IAI patients are shown in Table 1. The Kaplan-Meier analysis indicated no statistically significant disparity in OS among individuals diagnosed with IAI and those without IAI ($P = 0.130$) (Fig. 1).

### Univariate and multivariate analysis

The findings from the univariate logistic regression analysis demonstrated statistically significant relationships between the occurrence of IAI and multiple variables, including NRS2002 score, ALB, PNI, CONUT score, FBG, ASA score, type of resection, multi-visceral resection, intraoperative blood loss, perioperative blood transfusion, and TNM stage (Table 2). Four multivariate logistic regression analyses were carried out, considering the collinearity among these nutrition-related variables (Supplementary Figs. S1–4). Four models were developed to identify postoperative IAI (Table 3). The AUROCs for the four models ranged from 0.682 to 0.744, with Model 4 being the most discrimination (Fig. 2).

**Table 1** Baseline characteristics of non-IAI and IAI patients

| Risk factors | Patients without IAI (*n* = 369) | Patients with IAI (*n* = 35) | *P*-value |
|---|---|---|---|
| Age, years, mean ± SD | 67.4 ± 8.7 | 69.5 ± 7.2 | 0.176 |
| Gender, n (%) | | | 0.543 |
| Male | 267 (72.4) | 27 (77.1) | |
| Female | 102 (27.6) | 8 (22.9) | |
| Smoking, n (%) | | | 0.371 |
| Yes | 64 (17.3) | 4 (11.4) | |
| No | 305 (82.7) | 31 (88.6) | |
| Drinking, n (%) | | | 0.454 |
| Yes | 60 (16.3) | 4 (11.4) | |
| No | 309 (83.7) | 31 (88.6) | |
| Comorbidity, n (%) | | | 0.590 |
| Yes | 141 (38.2) | 15 (42.9) | |
| No | 228 (61.8) | 20 (57.1) | |
| prior abdominal surgery, n (%) | | | 0.397 |
| Yes | 54 (14.6) | 7 (20.0) | |
| No | 315 (85.4) | 28 (80.0) | |
| BMI, kg/m$^2$, mean ± SD | 21.8 ± 3.2 | 22.7 ± 3.2 | 0.106 |
| NRS2002 score, n (%) | | | 0.016 |
| <3 | 162 (43.9) | 8 (22.9) | |
| ≥3 | 207 (56.1) | 27 (77.1) | |
| Hemoglobin, g/L, mean ± SD | 116.8 ± 25.4 | 112.9 ± 27.4 | 0.384 |
| ALB, g/L, mean ± SD | 41.8 ± 4.9 | 38.2 ± 6.3 | < 0.001 |
| FBG, mmol/L, mean ± SD | 5.5 ± 1.6 | 6.6 ± 3.5 | 0.158 |
| PNI, mean ± SD | 49.6 ± 6.0 | 45.9 ± 7.5 | 0.001 |
| CONUT score, mean ± SD | 1.7 ± 1.6 | 2.9 ± 2.8 | 0.027 |
| PLR, mean ± SD | 165.1 ± 91.3 | 147.9 ± 75.3 | 0.279 |
| NLR, mean ± SD | 2.7 ± 2.4 | 3.6 ± 3.3 | 0.210 |
| Tumor location, n (%) | | | 0.401 |
| Upper | 164 (44.4) | 19 (54.3) | |
| Middle | 81 (22.0) | 8 (22.9) | |
| Lower | 124 (33.6) | 8 (22.9) | |
| ASA score, n (%) | | | 0.004 |
| 1 + 2 | 364 (98.6) | 31 (88.6) | |
| 3 | 5 (1.4) | 4 (11.4) | |
| Surgical approach, n (%) | | | 0.785 |
| Laparoscopy | 202 (54.7) | 20 (57.1) | |
| Open | 167 (45.3) | 15 (42.9) | |
| Type of resection, n (%) | | | 0.023 |
| Subtotal | 134 (36.3) | 6 (17.1) | |
| Total | 235 (63.7) | 29 (82.9) | |
| Multi-visceral resection, n (%) | | | < 0.001 |
| Yes | 37 (10.0) | 13 (37.1) | |
| No | 332 (90.0) | 22 (62.9) | |
| Reconstruction methods, n (%) | | | 0.675 |
| Roux-en-Y | 328 (88.9) | 32 (91.4) | |
| Billroth I | 8 (2.2) | 0 (0.0) | |
| Billroth II | 33 (8.9) | 3 (8.6) | |
| Operation time, min, mean ± SD | 252.5 ± 60.2 | 271.4 ± 71.9 | 0.083 |
| Intraoperative blood loss, ml, mean ± SD | 234.3 ± 130.9 | 286.0 ± 144.7 | 0.027 |
| Perioperative blood transfusion, n (%) | | | 0.008 |
| Yes | 92 (24.9) | 16 (45.7) | |
| No | 277 (75.1) | 19 (54.3) | |
| Maximum tumor diameter, cm, n (%) | | | 0.194 |
| > 4 | 179 (48.5) | 21 (60.0) | |

**Table 1** (continued)

| Risk factors | Patients without IAI ($n$=369) | Patients with IAI ($n$=35) | $P$-value |
|---|---|---|---|
| ≤4 | 190 (51.5) | 14 (40.0) | |
| T stage, n (%) | | | 0.127 |
| T1+T2 | 120 (32.5) | 7 (20.0) | |
| T3+T4 | 249 (67.5) | 28 (80.0) | |
| N stage, n (%) | | | 0.102 |
| N0 | 158 (42.8) | 10 (28.6) | |
| N1+N2+N3 | 211 (57.2) | 25 (71.4) | |
| p TNM stage, n (%) | | | 0.032 |
| I | 104 (28.2) | 4 (11.4) | |
| II+III | 265 (71.8) | 31 (88.6) | |
| Tumor differentiation, n (%) | | | 0.814 |
| Well | 39 (10.6) | 3 (8.6) | |
| Moderate | 64 (17.3) | 5 (14.3) | |
| Poor | 266 (72.1) | 27 (77.1) | |
| Vascular infiltration, n (%) | | | 0.149 |
| Yes | 164 (44.4) | 20 (57.1) | |
| No | 205 (55.6) | 15 (42.9) | |
| Neural infiltration, n (%) | | | 0.368 |
| Yes | 171 (46.3) | 19 (54.3) | |
| No | 198 (53.7) | 16 (45.7) | |

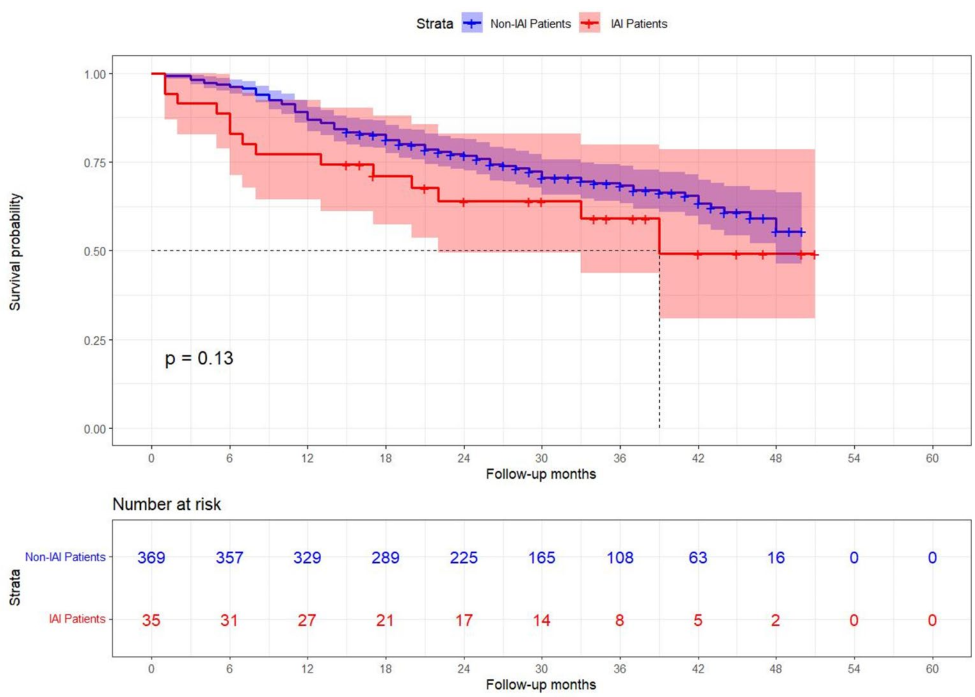


**Fig. 1** Kaplan-Meyer curves for OS in IAI and non-IAI patients

## Constructing and validating the nomogram

According to the outcomes of the multivariate analyses in model 4, NRS2002 score≥3, FBG, and multi-visceral resection were used to construct a nomogram for predicting postoperative IAI (Fig. 3). Every predictor received a score between 0 and 100. A total score specific to each patient was determined by adding the results for each variable. A vertical line was drawn at the point on the horizontal axis where the total score was found to determine the likelihood of postoperative IAI. The internal validation was conducted by Bootstrap method with self-help repeated sampling 1000 times. The c-index was determined at 0.742 (95% CI=0.739–0.745). The calibration curve revealed that the nomogram's prediction of the risk of IAI following D2

**Table 2** Univariate logistic regression analysis of IAI risk factors

| Characteristics | Univariate Logistic Regression Analysis | |
|---|---|---|
| | OR (95% CI) | *P*-value |
| Age (years) | 1.030 (0.987–1.076) | 0.177 |
| Gender, Male vs. Female | 1.289 (0.567–2.931) | 0.544 |
| Smoking, Yes vs. No | 0.615(0.210–1.803) | 0.376 |
| Drinking, Yes vs. No | 0.665 (0.226–1.952) | 0.457 |
| Comorbidity, Hypertension / COPD / Diabetes | 1.213(0.601–2.446) | 0.590 |
| Prior abdominal surgery, Yes vs. No | 1.458 (0.607–3.506) | 0.399 |
| NRS 2002 score, ≥ 3 vs. < 3 | 2.641 (1.169–5.969) | 0.020 |
| BMI (kg/m$^2$) | 1.089 (0.982–1.208) | 0.107 |
| Hemoglobin (g/L) | 0.994 (0.981–1.007) | 0.383 |
| ALB (g/L) | 0.882 (0.827–0.941) | < 0.001 |
| PNI | 0.915 (0.868–0.965) | 0.001 |
| CONUT score | 1.314 (1.123–1.537) | 0.001 |
| NLR | 1.084 (0.987–1.191) | 0.091 |
| PLR | 0.997 (0.992–1.002) | 0.278 |
| FBG (mmol/L) | 1.223 (1.073–1.393) | 0.003 |
| CEA (ng/mL), > 5 vs. ≤ 5 | 1.105 (0.499–2.448) | 0.805 |
| CA125 (U/mL), > 35 vs. ≤ 35 | 0.957 (0.120–7.640) | 0.967 |
| CA19-9 (U/mL), > 37 vs. ≤ 37 | 1.981 (0.851–4.614) | 0.113 |
| Tumor location | | 0.409 |
| Middle vs. Upper | 0.853 (0.358–2.031) | 0.719 |
| Lower vs. Upper | 0.557 (0.236–1.314) | 0.181 |
| ASA score, > 2 vs. ≤ 2 | 9.394 (2.399–36.781) | 0.001 |
| Surgical approach, Open vs. Laparoscopy | 0.907 (0.450–1.827) | 0.785 |
| Type of resection, Total vs. Subtotal | 2.756 (1.116–6.808) | 0.028 |
| Multi-visceral resection, Yes vs. No | 5.302(2.467–11.396) | < 0.001 |
| Type of reconstruction, Billroth I + Billroth II vs. Roux-en-Y | 0.750(0.220–2.559) | 0.646 |
| Operation time, min | 1.005 (0.999–1.010) | 0.084 |
| Intraoperative blood loss, ml | 1.002 (1.000-1.004) | 0.031 |
| Perioperative blood transfusion, Yes vs. No | 2.535(1.252–5.135) | 0.010 |
| Maximum tumor diameter (cm), > 4 vs. ≤ 4 | 1.592 (0.786–3.227) | 0.197 |
| T stage, T3 + T4 vs. T1 + T2 | 1.928 (0.819–4.539) | 0.133 |
| N stage, N1 + N2 + N3 vs. N0 | 1.872 (0.874–4.010) | 0.107 |
| p TNM stage, II + III vs. I | 3.042 (1.048–8.829) | 0.041 |
| Tumor differentiation | | 0.815 |
| Moderate vs. Well | 1.016 (0.230–4.487) | 0.984 |
| Poor vs. Well | 1.320 (0.382–4.556) | 0.661 |
| Vascular infiltration, Yes vs. No | 1.667 (0.827–3.357) | 0.153 |
| Neural infiltration, Yes vs. No | 1.375 (0.686–2.757) | 0.370 |

radical gastrectomy has a good concordance with the actual risk of occurrence (Fig. 4).

### Decision curve analysis

The nomogram model's clinical value was analysed by DCA (Fig. 5). The DCA revealed that the nomogram has a high positive net benefit and good clinical utility in predicting the risk of IAI after D2 radical gastrectomy for GC.

## Discussion

Considering the high incidence and severe harm of IAI following radical gastrectomy, it is essential to study potential predictors and develop quantitative prediction models. The incidence of IAI after radical gastrectomy may vary between studies due to differences in diagnostic criteria, diversity in features of the study population, and disparities in surgical procedures. This study involved a retrospective analysis of 404 GC patients who underwent D2 radical gastrectomy. Within 30 days after the surgery, we observed an incidence of IAI of 8.7%. This finding is in line with the rates reported in prior studies by Mao CC et al. (8.9%) [5] and Akimoto E et al. (9.7% for open surgery and 9.8% for laparoscopic surgery) [6]. While earlier studies have examined the potential risk variables for IAI after radical gastrectomy, these studies mainly concentrated on a restricted range of variables or unchangeable factors [5, 9, 13, 14]. Consequently, they need to be improved in guiding clinical interventions. This study examined the independent risk variables linked to IAI following radical gastrectomy. Four models were created using nutrition-related variables to identify IAI. Among these models, the one incorporating three components (NRS2002 score, FBG, and multi-visceral resection) had the highest level of performance. In addition, we constructed a nomogram to predict postoperative IAI using this model. Further internal validation revealed a high degree of concurrence between the predicted values of the nomogram and the observed values. This nomogram may serve as an intuitive and simple tool to assist surgeons in predicting the probability of postoperative IAI and individualising medical interventions.

Malnutrition is frequently linked with immunological disorders, inflammatory processes, and delayed or failed wound healing, which directly contributes to an increased occurrence of complications after surgery [15, 16]. GC patients frequently encounter symptoms of indigestion, including stomach pain, abdominal bloating, nausea, and vomiting, which adversely impact their ability to consume meals. Consequently, individuals with GC are at greater risk of developing malnutrition than those with other kinds of

**Table 3** Multivariate logistic regression models for identifying IAI

| Model | Equation | AUROC (95% CI) | Cut-off value | Sensitivity | Specificity |
|---|---|---|---|---|---|
| Model 1 | Multi-visceral resection (yes)×1.600-ALB×0.114 + FBG×0.162 + 0.947 | 0.735 (0.639–0.831) | 0.121 | 0.843 | 0.543 |
| Model 2 | Multi-visceral resection (yes)×1.538-PNI×0.078 + FBG×0.181 + 0.007 | 0.703 (0.598–0.809) | 0.148 | 0.889 | 0.486 |
| Model 3 | Multi-visceral resection (yes)×1.505 + CONUT score×0.223 + FBG×0.169–4.153 | 0.682 (0.571–0.793) | 0.152 | 0.889 | 0.486 |
| Model 4 | Multi-visceral resection (yes)×1.628 + NRS 2002 score (≥3)×1.141 + FBG×0.227–4.813 | 0.744 (0.657–0.830) | 0.082 | 0.756 | 0.629 |

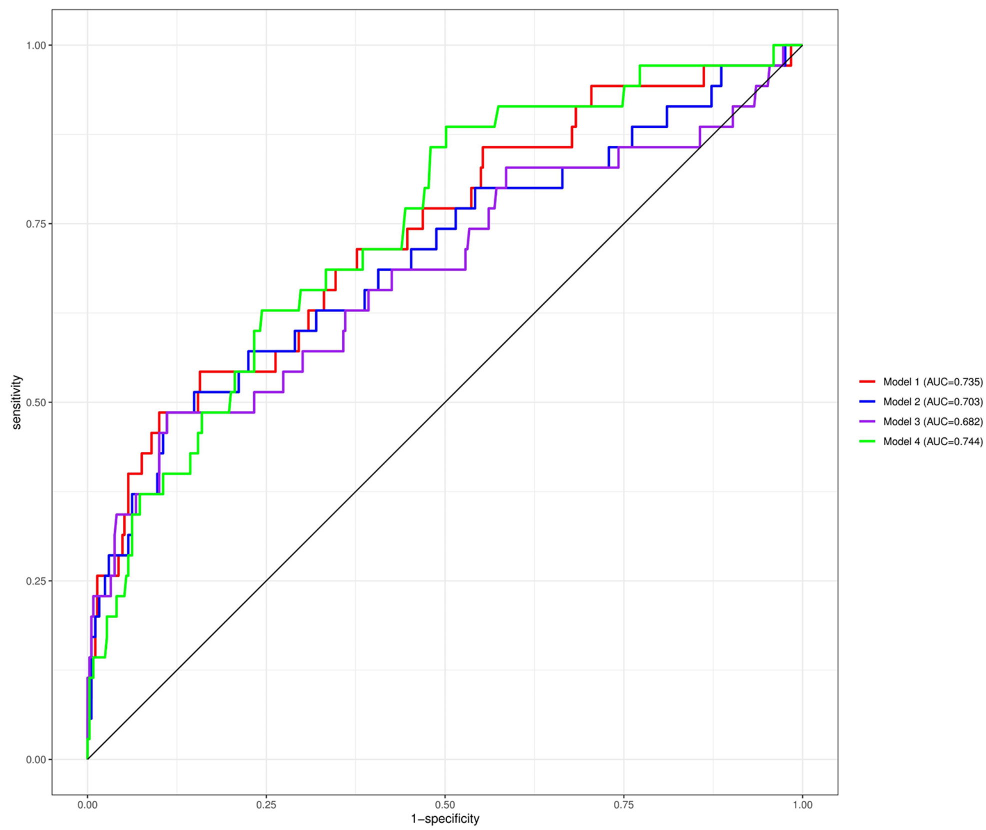


**Fig. 2** ROC curves of four nutrition-based models

tumors [17]. The patient's nutritional status is modifiable among various clinical factors, unlike age, tumor status, and comorbidities, which are essentially unchangeable. Hence, to enhance a patient's postoperative outcome, focusing on modifiable risk factors that may be wholly or partly changed is crucial. Timely recognition and intervention for patients who suffer from malnutrition or are at high nutritional risk are essential for the efficient treatment of tumor patients during the perioperative period.

The NRS2002 score, developed by the European Society for Parenteral and Enteral Nutrition (ESPEN), is an easy-to-apply and reproducible tool for predicting nutritional risk in hospitalised patients [11]. NRS2002 score has been extensively utilised since its first release in 2002 to determine the risk of complications after surgery [18–20] and long-term survival [21, 22]. Additionally, patients with cancer and those having surgery should employ the NRS2002 score to identify their nutritional risk, as recommended by the European Society of Clinical Nutrition and Metabolism (ESPEN) [23, 24]. Serum ALB, produced by the liver, regulates colloid osmotic pressure and nutritional metabolism, and its concentration indicates the body's nutritional state [25]. Various studies have revealed that preoperative hypoalbuminemia in patients is an independent predictor of the occurrence of surgical site infections (SSIs) in the postoperative period [26, 27]. Hypoalbuminemia-induced malnutrition may increase the patient's risk of IAI through two mechanisms. One aspect is that malnutrition affects wound healing by reducing fibroblast proliferation and collagen synthesis; another aspect is that malnutrition leads to a decline in the patient's immune function and reduces the body's ability to fight infection, at least in part through

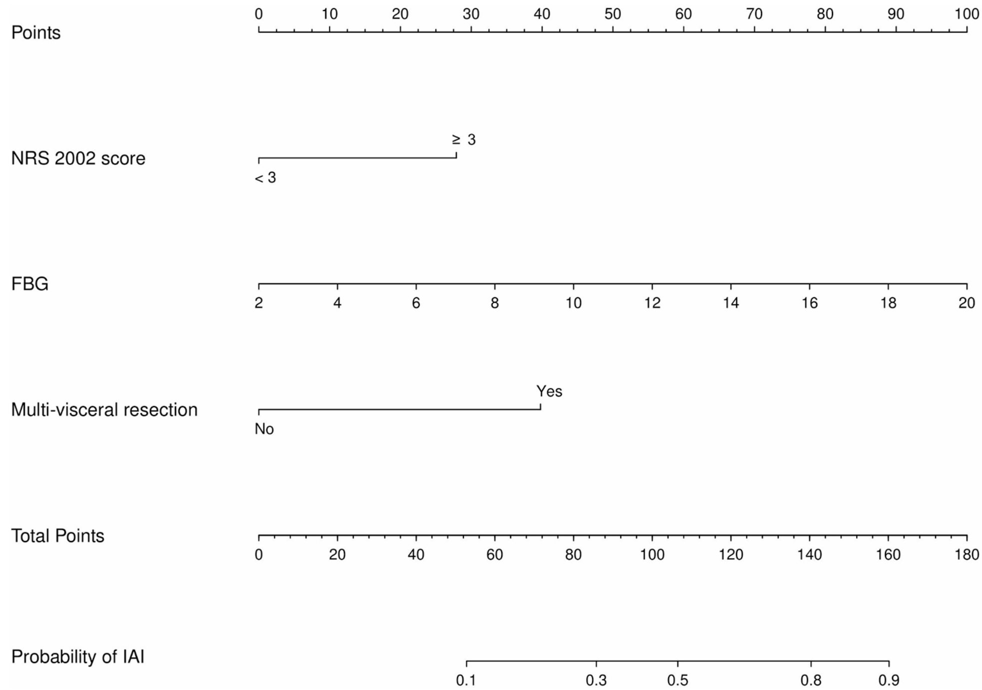


**Fig. 3** Nomogram for predicting IAI after radical gastrectomy

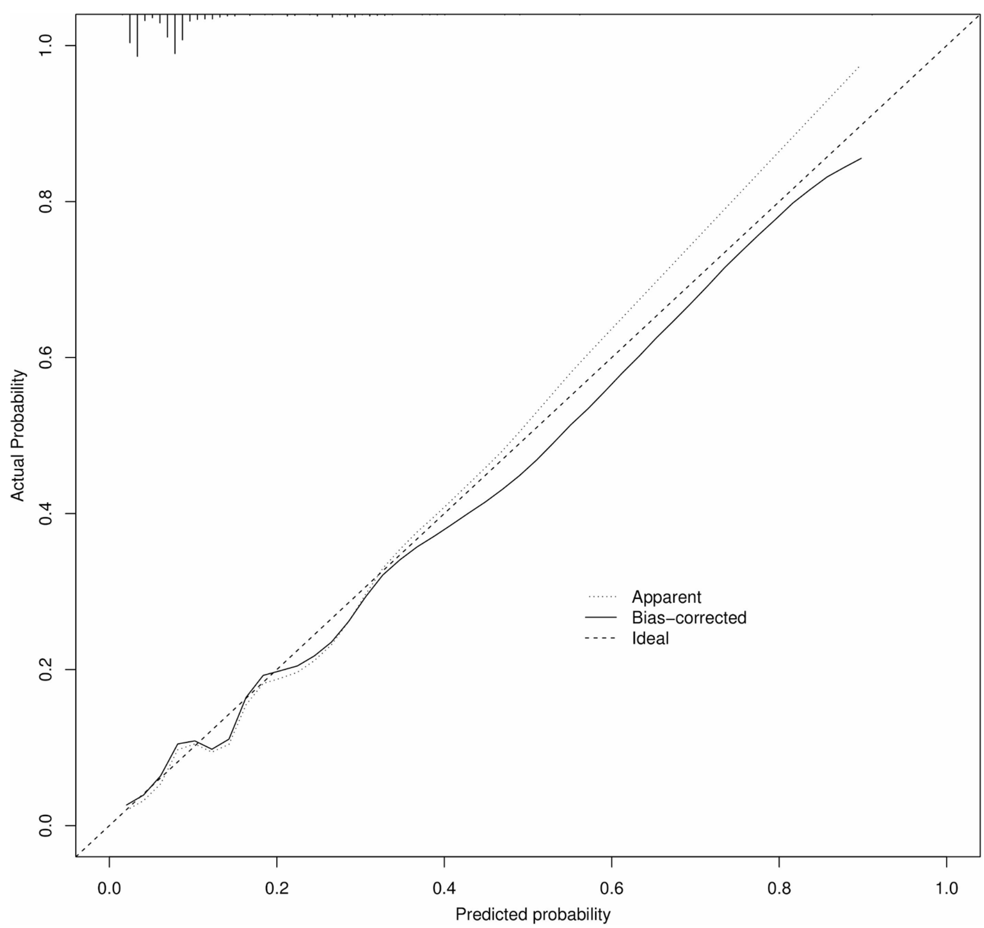


**Fig. 4** Calibration curve for predicting IAI after radical gastrectomy

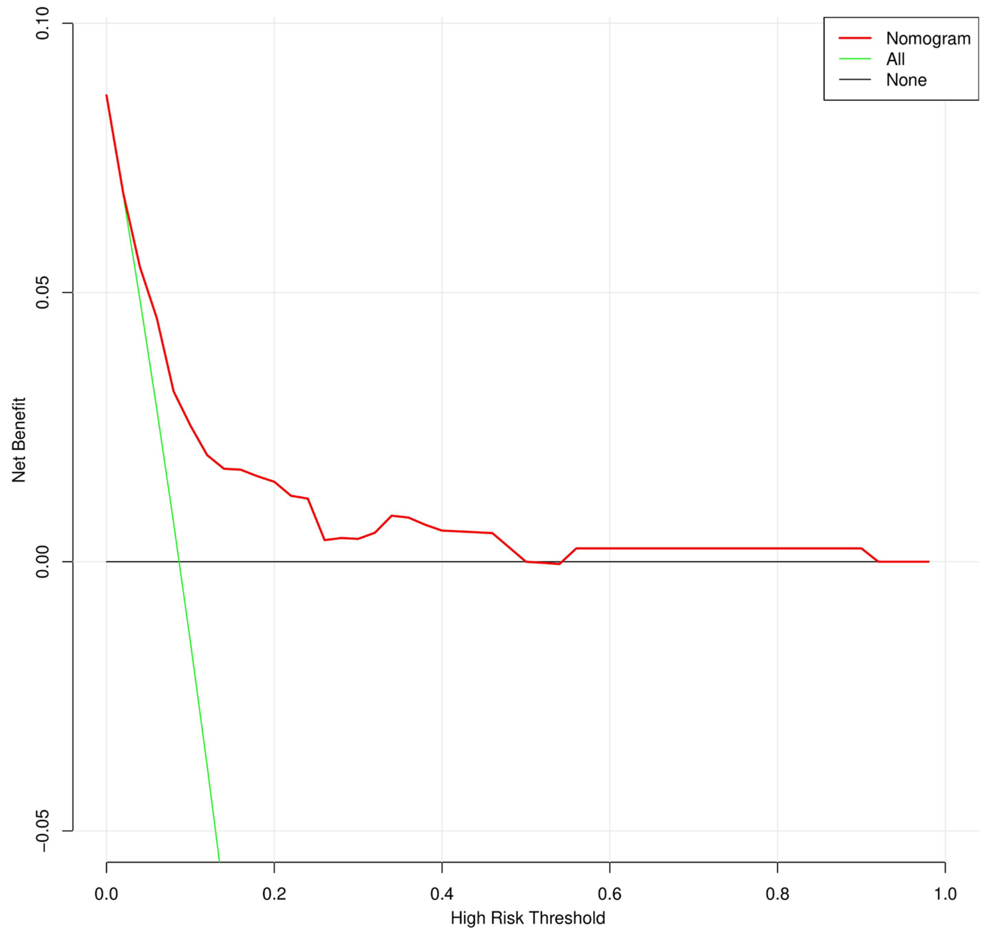


**Fig. 5** Decision curve analysis of the nomogram

a decrease in lymphocytes [28, 29]. The PNI, a marker of nutritional evaluation, is derived using ALB concentration and lymphocyte count, whereas the CONUT score is another nutritional assessment tool incorporating serum ALB level, cholesterol, and lymphocyte count. The PNI and CONUT scores are markers for evaluating the nutritional status and reflect the patient's immunological state. Several previous clinical studies have demonstrated the value of preoperative CONUT score and PNI in predicting postoperative complications and long-term survival of patients after radical gastrectomy [7, 30–32]. This study's four logistic regression outcomes revealed that patients' preoperative NRS2002 score, ALB, PNI and CONUT scores were independent predictors of developing IAI after radical gastrectomy, respectively.

Nowadays, haematological inflammatory markers derived from peripheral blood, such as NLR, PLR, Lymphocyte-monocyte ratio (LMR) and CRP-albumin ratio (CAR), are essential elements of the systemic inflammatory response and good predictors of postoperative infectious complications [33]. These inflammatory markers have recently gained much attention from clinicians for predicting tumor patients' postoperative outcomes and long-term survival [34, 35]. Our study also examined the predictive value of NLR and PLR for IAI after radical gastrectomy. However, after statistical analysis, we did not find an association between the two inflammatory indicators, NLR and PLR, with postoperative IAI, which is similar to the findings of Mao CC et al. [5]. One possible explanation is that IAI's risk factors differ from infections in other areas. The patient's nutritional status, surgical approach, degree of surgical resection, and length of surgery are more likely to have an impact on IAI because these factors can raise the patient's risk of tissue trauma, exposure to infection in the operative area, and anastomotic fistula, which can all increase the risk of abdominal infection after surgery [5, 15, 36].

In the current study, multi-visceral resection was an independent risk factor for postoperative IAI. Multi-visceral resection procedures often involve a sizeable surgical area, limited surgical field of view, prolonged operative time, and intraoperative bleeding, and these factors increase the risk of postoperative surgical site infections [37]. This result is consistent with previous findings [5, 32]. Prior studies have suggested that diabetes mellitus and preoperative high blood glucose are risk factors for postoperative SSIs [32, 38]. Our study also revealed that elevated preoperative

FBG level was an independent risk factor for postoperative IAI. For GC patients with combined high blood glucose, the phagocytosis and bactericidal ability of their leukocytes decreases due to decreased autoimmunity and high blood glucose, which leads to decreased anti-infective ability of the patients and increases the risk of postoperative SSI [39]. In addition, high blood glucose can lead to increased proteolysis and decreased collagen synthesis, which prolongs postoperative wound healing time and raises the risk of postoperative SSIs [39].

In this study, we constructed a nomogram model based on the NRS2002 score and other clinical parameters to assist surgeons in predicting the probability of postoperative IAI and performing personalized medical interventions. Surely, our nomogram model is similar to some other nomogram models containing some surgical parameters (e.g., resection type, reconstruction method, and multi-visceral resection, etc.) [9, 13], which are dynamical, cannot be determined preoperatively, and are usually dependent on the surgical procedure. Additionally, most of these surgical parameters are non-modifiable parameters as we can't violate the clinical treatment procedures to prevent potential postoperative complications. In our model, however, the NSR2002 score, reflecting preoperative diet and nutritional status, is a modifiable parameter. Thus, in clinical practice, GC patients with high preoperative NRS2002 score should be provided with more effective nutritional interventions, including preoperative nutritional interventions and early postoperative nutritional support. Moreover, considering the effectiveness of targeted nutritional interventions, GC patients with high NRS2002 score may benefit from preoperative nutritional interventions [40, 41]. However, the current optimal nutritional intervention strategy to improve malnutrition in tumor patients has not been determined. Hence, it is necessary to evaluate further the effectiveness of preoperative nutritional interventions based on NRS2002 score in reducing postoperative infectious complications using prospective randomized controlled studies.

This study has certain limitations despite the positive outcomes that it has produced. Firstly, as a single-centre, retrospective analysis, we could only partially avoid some potential bias. Secondly, no data on patients' postoperative nutritional supplementation was gathered for analysis in this research. The findings of this study cannot thus determine the impact of postoperative nutritional support on postoperative IAI. Finally, this study lacked external validation, and the predictive utility of this nomogram model needs to be validated in other populations. Thus, we will conduct multicenter, broader population studies to verify our results further.

## Conclusion

In this study, the nomogram based on the NRS2002 score, FBG, and multi-visceral resection was a simple and reliable tool for predicting the risk of IAI following D2 radical gastrectomy. Focusing on the preoperative NRS2002 score and FBG, as well as early personalised treatment in gastric cancer patients, may assist in avoiding postoperative IAI and enhance patients' clinical outcomes.

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**Author contributions** XHM and XYJ designed the research, collected and analyzed the data, and drafted the manuscript. HG, JJW, and TTW collected and analyzed the data. XML designed and directed the study and offered advice and assistance in revising the manuscript at a later stage. All authors read and approved the final version of the manuscript.

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**Data availability** No datasets were generated or analysed during the current study.

## Declaration

**Ethical approval** This study was conducted per the ethical guidelines outlined in the World Medical Association Declaration of Helsinki for medical research. Lu'an Hospital, Anhui Medical University's research ethics committee approved the study.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

## References


1. Sung H, Ferlay J, Siegel RL et al (2021) Global Cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 71:209–249. https://doi.org/10.3322/caac.21660
2. Cao W, Chen HD, Yu YW et al (2021) Changing profiles of cancer burden worldwide and in China: a secondary analysis of the global cancer statistics 2020. Chin Med J (Engl) 134:783–791. https://doi.org/10.1097/CM9.0000000000001474
3. Japanese Gastric Cancer Association (2023) Japanese Gastric Cancer Treatment Guidelines 2021 (6th edition). Gastric Cancer 26:1–25. https://doi.org/10.1007/s10120-022-01331-8
4. Migita K, Takayama T, Matsumoto S et al (2012) Risk factors for surgical site infections after elective gastrectomy. J Gastrointest Surg 16:1107–1115. https://doi.org/10.1007/s11605-012-1838-1
5. Mao CC, Chen XD, Lin J et al (2018) A novel nomogram for predicting postsurgical Intra-abdominal infection in gastric Cancer patients: a prospective study. J Gastrointest Surg 22:421–429. https://doi.org/10.1007/s11605-017-3580-1
6. Akimoto E, Kinoshita T, Sato R et al (2023) Impact of postoperative intra-abdominal infectious complications on survival outcomes in patients with gastric cancer who underwent laparoscopic surgery. Surg Endosc 37:382–390. https://doi.org/10.1007/s00464-022-09522-1
7. Xiao Y, Wei G, Ma M et al (2022) Association among prognostic nutritional index, post-operative infection and prognosis of stage II/III gastric cancer patients following radical gastrectomy. Eur J Clin Nutr 76:1449–1456. https://doi.org/10.1038/s41430-022-01120-7
8. Xiao H, Zhou H, Liu K et al (2019) Development and validation of a prognostic nomogram for predicting post-operative pulmonary infection in gastric cancer patients following radical gastrectomy. Sci Rep 9:14587. https://doi.org/10.1038/s41598-019-51227-4
9. Zhang Y, Wang Z, Basharat Z et al (2022) Nomogram of intra-abdominal infection after surgery in patients with gastric cancer: A retrospective study. Front Oncol 12:982807. https://doi.org/10.3389/fonc.2022.982807
10. Ignacio de Ulibarri J, Gonzalez-Madrono A, de Villar NG et al (2005) CONUT: a tool for controlling nutritional status. First validation in a hospital population. Nutr Hosp 20:38–45
11. Kondrup J, Rasmussen HH, Hamberg O et al (2003) Nutritional risk screening (NRS 2002): a new method based on an analysis of controlled clinical trials. Clin Nutr 22:321–336. https://doi.org/10.1016/s0261-5614(02)00214-5
12. Lo CH, Chen JH, Wu CW et al (2008) Risk factors and management of intra-abdominal infection after extended radical gastrectomy. Am J Surg 196:741–745. https://doi.org/10.1016/j.amjsurg.2007.11.031
13. Eom BW, Joo J, Kim YW et al (2015) Nomogram estimating the probability of intraabdominal abscesses after gastrectomy in patients with gastric Cancer. J Gastric Cancer 15:262–269. https://doi.org/10.5230/jgc.2015.15.4.262
14. Ojima T, Hayata K, Kitadani J et al (2022) Risk factors of postoperative Intra-Abdominal infectious complications after robotic gastrectomy for gastric Cancer. Oncology 100:583–590. https://doi.org/10.1159/000526920
15. Pei G, Zhen S, Zhang B (2022) A novel nomogram based on nutritional and immune status predicting postoperative intra-abdominal infection in colorectal cancer. Asia Pac J Clin Nutr 31:626–635. https://doi.org/10.6133/apjcn.202212_31(4).0006
16. Qian Y, Liu H, Pan J et al (2021) Preoperative controlling nutritional status (CONUT) score predicts short-term outcomes of patients with gastric cancer after laparoscopy-assisted radical gastrectomy. World J Surg Oncol 19:25. https://doi.org/10.1186/s12957-021-02132-6
17. Hirahara N, Tajima Y, Fujii Y et al (2019) Controlling nutritional status (CONUT) as a prognostic immunonutritional biomarker for gastric cancer after curative gastrectomy: a propensity score-matched analysis. Surg Endosc 33:4143–4152. https://doi.org/10.1007/s00464-019-06723-z
18. Kwag SJ, Kim JG, Kang WK et al (2014) The nutritional risk is a independent factor for postoperative morbidity in surgery for colorectal cancer. Ann Surg Treat Res 86:206–211. https://doi.org/10.4174/astr.2014.86.4.206
19. Lee SY, Jung MR, Kim CH et al (2018) Nutritional risk screening score is an independent predictive factor of anastomotic leakage after rectal cancer surgery. Eur J Clin Nutr 72:489–495. https://doi.org/10.1038/s41430-018-0112-3
20. Shang J, Zhao G, Gong J et al (2023) Nutritional risk screening 2002 predicts surgical outcomes in 1532 patients undergoing total joint arthroplasty: A retrospective cohort study. Nutr Clin Pract 38:636–647. https://doi.org/10.1002/ncp.10934
21. Hersberger L, Bargetzi L, Bargetzi A et al (2020) Nutritional risk screening (NRS 2002) is a strong and modifiable predictor risk score for short-term and long-term clinical outcomes: secondary analysis of a prospective randomised trial. Clin Nutr 39:2720–2729. https://doi.org/10.1016/j.clnu.2019.11.041
22. Chen X (2022) A novel nomogram based on the nutritional risk screening 2002 score to predict survival in hepatocellular carcinoma treated with transarterial chemoembolization. Nutr Hosp 39:835–842. https://doi.org/10.20960/nh.03983
23. Arends J, Bachmann P, Baracos V et al (2017) ESPEN guidelines on nutrition in cancer patients. Clin Nutr 36:11–48. https://doi.org/10.1016/j.clnu.2016.07.015
24. Weimann A, Braga M, Carli F et al (2017) ESPEN guideline: clinical nutrition in surgery. Clin Nutr 36:623–650. https://doi.org/10.1016/j.clnu.2017.02.013
25. Zhang Y, Zhu JY, Zhou LN et al (2020) Predicting the prognosis of gastric Cancer by Albumin/Globulin ratio and the prognostic nutritional index. Nutr Cancer 72:635–644. https://doi.org/10.1080/01635581.2019.1651347
26. Tfaily MA, Ghanem P, Farran SH et al (2022) The role of preoperative albumin and white blood cell count in surgical site infections following Whipple surgery. Sci Rep 12:19184. https://doi.org/10.1038/s41598-022-21849-2
27. Rungsakulkij N, Vassanasiri W, Tangtawee P et al (2019) Preoperative serum albumin is associated with intra-abdominal infection following major hepatectomy. J Hepatobiliary Pancreat Sci 26:479–489. https://doi.org/10.1002/jhbp.673
28. Cross MB, Yi PH, Thomas CF et al (2014) Evaluation of malnutrition in orthopaedic surgery. J Am Acad Orthop Surg 22:193–199. https://doi.org/10.5435/JAAOS-22-03-193
29. Seibert DJ (1999) Pathophysiology of surgical site infection in total hip arthroplasty. Am J Infect Control 27:536–542. https://doi.org/10.1016/s0196-6553(99)70033-7
30. Sun F, Zhang C, Liu Z et al (2021) Controlling nutritional status (CONUT) score as a predictive marker for short-term complications following gastrectomy of gastric cancer: a retrospective study. BMC Gastroenterol 21:107. https://doi.org/10.1186/s12876-021-01682-z
31. Huang Y, Huang Y, Lu M et al (2019) Controlling nutritional status (CONUT) score is A predictor of Post-Operative outcomes in elderly gastric Cancer patients undergoing curative gastrectomy: A prospective study. Cancer Manag Res 11:9793–9800. https://doi.org/10.2147/CMAR.S233872
32. Xi X, Yang MX, Wang XY et al (2022) Predictive value of prognostic nutritional index on infection after radical gastrectomy: a retrospective study. J Gastrointest Oncol 13:569–580. https://doi.org/10.21037/jgo-22-192

33. Gulmez S, Senger A, Uzun O et al (2022) Comparative analysis of preoperative ratio based markers in predicting postoperative infectious complications after gastrectomy. Pol Przegl Chir 95:1–5. https://doi.org/10.5604/01.3001.0015.9662
34. Miyamoto R, Inagawa S, Sano N et al (2018) The neutrophil-to-lymphocyte ratio (NLR) predicts short-term and long-term outcomes in gastric cancer patients. Eur J Surg Oncol 44:607–612. https://doi.org/10.1016/j.ejso.2018.02.003
35. Bora Makal G, Yildirim O (2020) Are the C-reactive protein/albumin ratio (CAR), neutrophil-to-lymphocyte ratio (NLR), and platelet-to-lymphocyte ratio (NLR) novel inflammatory biomarkers in the early diagnosis of postoperative complications after laparoscopic sleeve gastrectomy? Obes Res Clin Pract 14:467–472. https://doi.org/10.1016/j.orcp.2020.07.003
36. Tu RH, Lin JX, Zheng CH et al (2017) Development of a nomogram for predicting the risk of anastomotic leakage after a gastrectomy for gastric cancer. Eur J Surg Oncol 43:485–492. https://doi.org/10.1016/j.ejso.2016.11.022
37. Steiner HL, Strand EA (2017) Surgical-site infection in gynecologic surgery: pathophysiology and prevention. Am J Obstet Gynecol 217:121–128. https://doi.org/10.1016/j.ajog.2017.02.014
38. Li Z, Li H, Lv P et al (2021) Prospective multicenter study on the incidence of surgical site infection after emergency abdominal surgery in China. Sci Rep 11:7794. https://doi.org/10.1038/s41598-021-87392-8
39. Chen M, Liang H, Chen M et al (2023) Risk factors for surgical site infection in patients with gastric cancer: A meta-analysis. Int Wound J 20:3884–3897. https://doi.org/10.1111/iwj.14264
40. Nikniaz Z, Somi MH, Nagashi S et al (2017) Impact of early enteral nutrition on nutritional and immunological outcomes of gastric Cancer patients undergoing gastrostomy: A systematic review and Meta-Analysis. Nutr Cancer 69:693–701. https://doi.org/10.1080/01635581.2017.1324996
41. Mudarra Garcia N, Naranjo Pena I, Olivares Pizarro SP et al (2020) Pre-Surgical nutrition support reduces the incidence of surgical wound complications in oncological patients. Nutr Cancer 72:801–807. https://doi.org/10.1080/01635581.2019.1653473