Retrospective Cohort Study

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Prognostic significance of preoperative nutritional status for postoperative acute kidney injury in older patients undergoing major abdominal surgery: a retrospective cohort study

Rao Sun, PhD[a], Zhiqiang Zhou, PhD[a], Xinhua Li, MD[a], Qiaoqiao Xu, PhD[a], Biyun Zhou, MD[a], Honghui Yu, PhD[a], Wanjun Zhang, MD[a], Qi Sun, MD[a], Xiang Zhang, MD[a], Xiaoxiao Luo, PhD[b,*], Shiyong Li, PhD[a,*], Ailin Luo, PhD[a,*]

Background: The association between malnutrition and postoperative acute kidney injury (AKI) has not been well studied. In this study, the authors examined the association between preoperative nutritional status and postoperative AKI in older patients who underwent major abdominal surgery, as well as the predictive value of malnutrition for AKI.

Materials and methods: The authors retrospectively included patients aged 65 or older who underwent major elective abdominal surgery. The nutritional status of the patient was evaluated using three objective nutritional indices, such as the geriatric nutritional risk index (GNRI), the prognostic nutritional index (PNI), and the controlling nutritional status (CONUT). AKI was determined using the KDIGO criteria. The authors performed logistic regression analysis to investigate the association between preoperative nutritional status and postoperative AKI, as well as the predictive value of nutritional scores for postoperative AKI.

Results: A total of 2775 patients were included in the study, of which 707 (25.5%), 291 (10.5%), and 517 (18.6%) had moderate to severe malnutrition according to GNRI, PNI, and CONUT calculations. After surgery, 144 (5.2%) patients developed AKI, 86.1% at stage 1, 11.1% at stage 2, and 2.8% at stage 3 as determined by KDIGO criteria. After adjustment for traditional risk factors, worse nutritional scores were associated with a higher AKI risk. In addition to traditional risk factors, these nutritional indices improved the predictive ability of AKI prediction models, as demonstrated by significant improvements in integrated discrimination and net reclassification.

Conclusions: Poor preoperative nutritional status, as assessed by GNRI, PNI, and CONUT scores, was associated with an increased risk of postoperative AKI. Incorporating these scores into AKI prediction models improved their performance. These findings emphasize the need for screening surgical patients for malnutrition risk. Further research is needed to determine whether preoperative malnutrition assessment and intervention can reduce postoperative AKI incidence.

Keywords: Acute kidney injury, major abdominal surgery, malnutrition, prediction model

[a]Department of Anesthesiology, Hubei Key Laboratory of Geriatric Anesthesia and Perioperative Brain Health, and Wuhan Clinical Research Center for Geriatric Anesthesia, Tongji Hospital and [b]Department of Oncology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, People's Republic of China

Rao Sun and Zhiqiang Zhou contributed equally to this article.

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**Corresponding author. Address: Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, No.1095 Jiefang Avenue, Wuhan 430030, Hubei Province, People's Republic of China. Tel.:/fax: + 86 278 366 3423. E-mail: alluo@hust.edu.cn (A. Luo), and Tel.:/fax: + 86 278 366 3173. E-mail: shiyongli@hust.edu.cn (S. Li), and Tel.:/fax: + 86 278 366 5480. E-mail: xxluo2happy@hust.edu.cn (X. Luo).*

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HIGHLIGHTS

- The nutritional status was evaluated by geriatric nutritional risk index, prognostic nutritional index, and controlling nutritional status scores.
- Poor nutritional status was independently associated with an elevated risk of acute kidney injury in older patients following major abdominal surgery.
- Including nutritional indices in prediction models of acute kidney injury improved their predictive performance.

Introduction

There is a high prevalence of postoperative acute kidney injury (AKI) in patients who undergo intra-abdominal surgery, which ranges from 3 to 35%[1], and it is particularly common in older patients. Patients with AKI are at an increased risk of developing chronic kidney disease and end-stage renal disease[2], which can lead to elevated morbidity and economic burden[1,3–5]. As defined by the Kidney Disease: Improving Global Outcomes (KDIGO) criteria[6], moderate and severe (stages 2 and 3) AKI are associated with increased in-hospital mortality[7]. Identifying high-risk patients for postoperative AKI early can facilitate the development of preventive and therapeutic management strategies. However, before such interventions can be implemented, it is important to first identify the predictive factors associated with postoperative AKI.

Malnutrition is prevalent among older patients as well as patients with chronic illnesses[8,9]. Poor nutritional status is associated with a number of adverse postoperative outcomes in older surgical patients[10–13], including infections, impaired wound healing, delayed recovery, and mortality. A number of previous studies[10–12] evaluated malnutrition using questionnaire-based tools, but these tools may be not suitable for older patients due to communication difficulties and recall bias. Until now, several objective nutritional tools have been developed to evaluate malnutrition risk, such as the geriatric nutritional risk index (GNRI)[14], prognostic nutritional index (PNI)[15], and controlling nutritional status (CONUT) score[16]. These objective nutritional indices overcome the limitations of questionnaire-based tools and have been applied to patients with heart failure[17], stroke[18,19], and critical illness[20,21]. These tools have also been utilized to determine the association between nutritional status and postoperative AKI in several previous studies[22–27]. However, their sample size was small, they primarily examined PNI, and they rarely evaluate these tools' prognostic value. In addition, older patients undergoing major abdominal surgery were rarely included in these studies. Among this patient population, there is a high-risk of AKI, and early detection of AKI risk may offer greater benefits.

In the present study, we aimed to determine the association between preoperative nutritional status, as measured by three scoring systems, and postoperative AKI in older patients undergoing major abdominal surgery. We also evaluated whether these nutritional indices can improve AKI prediction in addition to traditional risk factors.

Materials and methods

This retrospective observational study has been approved by the local Ethics Committee, and the requirement for informed consent was waived due to the retrospective nature of the study. This study was registered at ClinicalTrials. The present study was reported in accordance with the statement strengthening the reporting of cohort studies in surgery (STROCSS) criteria[28].

Study population

Older patients (aged ≥ 65 years) who underwent a major elective abdominal surgery under general anesthesia at our hospital between July 2018 and December 2021 were included in our study. Major abdominal surgery included gastrectomy, colorectal resection, pancreatic resection, prostatectomy, and cystectomy by either laparotomy or a laparoscopic approach[29,30]. Less extensive surgery (e.g. appendicectomy and inguinal hernia repair) was not considered in our study. If a patient had more than one surgery meeting the inclusion criteria during the study period, only the first surgery was included in the analysis. The following patients were excluded: (1) patients with an American Society of Anesthesiologists (ASA) physical status V, (2) those with concurrent cardiac or renal surgeries, (3) those with end-stage renal disease (i.e. a glomerular filtration rate of 15 ml/min/1.73 m^2 or receiving hemodialysis), (4) those without laboratory measurements of hemoglobin, total lymphocyte count, serum albumin, creatinine, and total cholesterol obtained within 7 days prior to surgery, or (5) those who did not have sufficient data required for nutritional evaluation or AKI evaluation.

Data collection

The extracted information included patient demographics (age, sex, weight, and height), comorbidities (hypertension, diabetes mellitus, coronary artery disease, and chronic obstructive pulmonary disease), medication history (use of angiotensin-converting enzyme inhibitors or angiotensin receptor blockers), and ASA physical status. Comorbidities were defined using validated algorithms based on the International Statistical Classification of Diseases Ninth and Tenth Revision (ICD-9 and ICD-10) codes[31,32] (Supplemental Table 1, Supplemental Digital Content 1, http://links.lww.com/JS9/B267). We also extracted preoperative laboratory findings [hemoglobin, total lymphocyte count, serum albumin, creatinine, total cholesterol, and eGFR (estimated glomerular filtration rate)], surgical characteristics (type, approach, and duration of surgery), intraoperative fluid infusion rate, and postoperative serum creatinine within 7 days after surgery. For patients with multiple laboratory measurements prior to surgery, the most recent value was used.

Nutritional assessment and classifications

The GNRI, PNI, and CONUT scores were used to evaluate the nutritional status of patients prior to surgery. The indices were calculated retrospectively using data from the electronic database of the medical record system.

The GNRI was calculated using the formula[14]: $1.489 \times$ serum albumin (g/l) + [$41.7 \times$ weight (kg)/ideal body weight (kg)]. For male patients, the ideal body weight was calculated as $0.75 \times$ height (cm) – 62.5, and for female patients, it was calculated as $0.60 \times$ height (cm) – 40. Patients were divided into four groups according to their malnutrition risk: no nutritional risk (GNRI > 98), mild nutritional risk (GNRI ranging from 92 to 98), moderate nutritional risk (GNRI ranging from 82 to 91), and severe nutritional risk (GNRI <82).

PNI is calculated using the formula[15]: serum albumin (g/l) + $0.005 \times$ total lymphocyte count ($\times 10^9$/l). The patients were divided into three groups: those without nutritional risk (PNI > 38), those with moderate nutritional risk (PNI ranging from 35 to 38), and those who had severe nutritional risk (PNI <35). There is no mild category for the PNI. There is no mild category for the PNI.

The CONUT score[16] was calculated using serum albumin, total cholesterol, and total lymphocyte count according to the CONUT scoring system. Patients were grouped according to malnutrition risk: normal (CONUT 0–1), mild (CONUT 2–4), moderate (CONUT 5–8), and severe (CONUT 9–12).

AKI assessment

The postoperative AKI was defined in accordance with the KDIGO creatinine criteria[6]. That is, a serum creatinine increases of 26.5 mmol/l within 48 h or 1.5 times baseline within 7 days after surgery. The most recent serum creatinine level within 7 days prior to surgery served as the baseline. According to the KDIGO criteria[6], we staged postoperative AKI as follows: stage 1 was defined as an increase in serum creatinine of 26.5 mmol/l or to 2.9 times baseline, stage 2 as a rise of 2.5 to 2.9 times baseline, and stage 3 as an increase of 353.6 mmol/l or to three times baseline or the initiation of renal replacement therapy. As a primary outcome, we included all stages of AKI.

Statistical analysis

In this study, continuous variables were not normally distributed, as determined by the Shapiro–Wilk test. Therefore, they were expressed as median (interquartile range [IQR]) and compared with the Mann–Whitney U test. Categorical variables were expressed as counts (percentages) and compared using the χ^2 or Fisher exact test. Venn diagrams were utilized to illustrate the relationship between the three nutritional indices. The Pearson's correlation coefficients (r) were calculated as a measure of linear association among the three nutritional indices.

The association between preoperative nutritional indices and postoperative AKI was investigated using logistic regression, and the nutritional indices were treated as both continuous and categorical (malnutrition risk) variables. We first conducted a univariate analysis, and then conducted a multivariate analysis to adjust for potential confounders. To evaluate the robustness of the association between nutritional indices and postoperative AKI, two multivariate models were developed. Model 1 was adjusted for preoperative factors such as age, sex, comorbidities, medication history, ASA physical status, and preoperative hemoglobin and eGFR. Model 2 included the same variables as model 1 as well as surgical characteristics including type, approach, and duration of surgery, and intraoperative fluid infusion rate. Results are reported as odds ratio (OR) and 95% CI. To avoid multicollinearity, parameters that were used to calculate malnutrition scores were not included in these models, such as weight, height, BMI, lymphocyte count, serum albumin, and total cholesterol. We also visualized the multivariable association between preoperative nutritional indices (as continuous variables) and AKI by fitting restricted cubic splines.

To evaluated the additive predictive value of the three nutritional indices for AKI, we added each of these indices in turn to the base models (model 1 and model 2) to establish updated models. We calculated the area under the receiver operating characteristic curve (AUC) to quantify the predictive ability of each model, and determined the change in AUCs using DeLong's method. We used the continuous net reclassification index (NRI) and integrated discrimination improvement (IDI) to assess and to compare the discrimination capacity of the three nutritional indices to predict AKI. We also conducted a χ^2 likelihood ratio test to determine if the updated models including nutritional indices provided a more accurate fit than the models without that. Finally, we conducted decision curve analysis to assess the usefulness of different models.

The minimum sample size required for our models was calculated using the R package 'pmsamplesize'[33]. We estimated a requirement of 2697 individuals based on an AUC of 0.77, 15 model parameters, and 5% postoperative AKI incidence.

All analyses were performed with R version 4.2.1 (http://www.R-project.org, The R Foundation). In our study, a two-tailed P-value of <0.05 was considered statistically significant.

Results

Clinical characteristics

The patient selection process is shown in Figure 1. A total of 2775 patients were included for analysis. As shown in Table 1, these patients had a median age of 69 years (IQR: 67–74 years) and 70.3% were male. The most common surgeries were colorectal resection (43.1%) and gastrectomy (29.3%), while 89.3% of the patients had laparoscopic surgery. The median duration of surgery was 213 min (IQR: 164–270 min), and the median intraoperative fluid infusion rate was 8.0 ml/kg/h (IQR: 6.2–10.5 ml/kg/h).

Among all eligible patients, 144 (5.2%) had postoperative AKI, comprised of 86.1% stage 1 ($n=122$), 11.1% stage 2 ($n=16$), and 2.8% stage 3 ($n=4$) according to KDIGO criteria. Table 1 shows the characteristics of the study cohort, both globally and stratified by the presence of AKI (at any stage). Patients with AKI were more likely to be older, had a worse ASA class, and a longer duration of surgery. They also had lower hemoglobin, eGFR, lymphocyte count, serum albumin, and total cholesterol prior to surgery (Table 2). In these patients, the CONUT score was significantly higher, and the PNI and GNRI were significantly lower (Table 2).

Prevalence and clinical associations of malnutrition

The percentage of patients with malnutrition varied from 10.5% with the PNI, to 48.5% with the GNRI, and to 72.4% with the CONUT score. By GNRI, PNI, and CONUT calculations, 707 (25.5%), 291 (10.5%), and 517 (18.6%) patients had moderate to severe malnutrition, respectively. Although all malnutrition scores were correlated with each other (GNRI vs. PNI: r = 0.73; GNRI vs. CONUT: r = − 0.58; PNI vs. CONUT: r = − 0.82), only

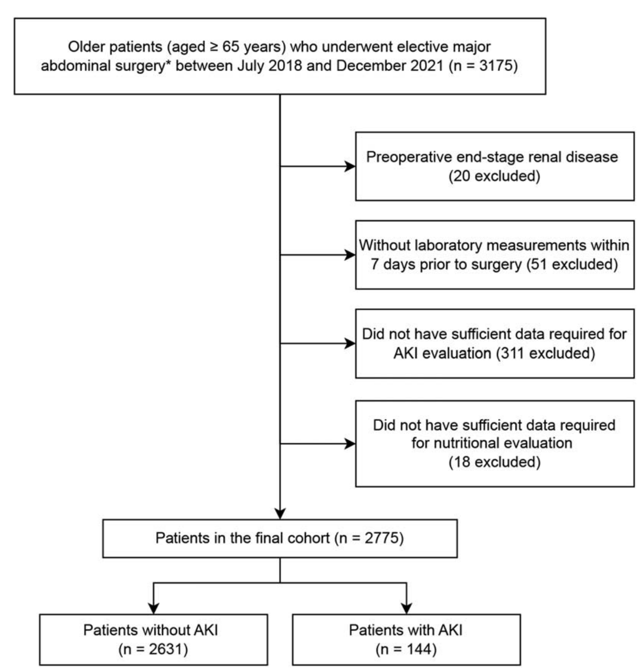

Figure 1. Flow diagram for patient selection. *Major abdominal surgery included gastrectomy, colorectal resection, pancreatic resection, prostatectomy, and cystectomy by either laparotomy or a laparoscopic approach. AKI, acute kidney injury.

Table 1

Baseline characteristics of study participants.

	Overall (*N*=2775)	No AKI (*n*=2631)	AKI (*n*=144)	*P*
Age, years	69 (67, 74)	69 (67, 73)	71 (67, 76)	0.001
Male sex	1951 (70.3%)	1841 (70.0%)	110 (76.4%)	0.122
Weight, kg	60 (54, 68)	60 (54, 68)	60 (55, 69)	0.759
Height, cm	165 (160, 170)	165 (160, 170)	166 (160, 170)	0.228
BMI, kg/m^2	22.3 (20.2, 24.4)	22.3 (20.2, 24.4)	22.0 (20.1, 24.2)	0.447
Morbidity				
Hypertension	1365 (49.2%)	1286 (48.9%)	79 (54.9%)	0.189
Diabetes mellitus	351 (12.6%)	325 (12.4%)	26 (18.1%)	0.061
Coronary artery disease	306 (11.0%)	290 (11.0%)	16 (11.1%)	1.000
COPD	279 (10.1%)	262 (10.0%)	17 (11.8%)	0.565
Use of ACEIs/ARBs	197 (7.1%)	186 (7.1%)	11 (7.6%)	0.926
ASA physical status				0.015
I/II	1573 (56.7%)	1506 (57.2%)	67 (46.5%)	
III/IV	1202 (43.3%)	1125 (42.8%)	77 (53.5%)	
Type of surgery				< 0.001
Gastrectomy	812 (29.3%)	781 (29.7%)	31 (21.5%)	
Colorectal resection	1197 (43.1%)	1145 (43.5%)	52 (36.1%)	
Pancreatic resection	257 (9.3%)	239 (9.1%)	18 (12.5%)	
Prostatectomy	299 (10.8%)	279 (10.6%)	20 (13.9%)	
Cystectomy	210 (7.6%)	187 (7.1%)	23 (16.0%)	
Laparoscopic surgery	2478 (89.3%)	2378 (90.4%)	100 (69.4%)	< 0.001
Duration of surgery, min	213 (164, 270)	211 (163, 268)	250 (187, 333)	< 0.001
Intraoperative fluid infusion rate (ml/kg/h)	8.0 (6.2, 10.5)	8.0 (6.2, 10.5)	8.0 (6.3, 10.1)	0.710

Values are expressed as median (interquartile range) or number of patients (%).
ACEIs, angiotensin-converting enzyme inhibitors; AKI, acute kidney injury; ARBs, angiotensin receptor blockers; ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease.

10.1% were classified as malnourished (any degree of malnutrition) by all three scores, and only 20.0% were not malnourished by any score (Fig. 2).

Compared with patients with normal nutritional status, those with malnutrition measured by any of the three nutritional indices were older, had a lower BMI, a worse ASA class, and were more likely to develop AKI after surgery (Supplemental Tables 2–4, Supplemental Digital Content 1, http://links.lww.com/JS9/B267).

The association between preoperative nutritional status and AKI

We firstly included the nutritional indices as continuous variables in the logistic model, and the results showed that all three

Table 2

Preoperative laboratory findings and nutritional indices of study participants.

	Overall (*N*=2775)	No AKI (*n*=2631)	AKI (*n*=144)	*P*
Hemoglobin, g/l	120 (103, 133)	121 (103, 133)	112 (91, 131)	< 0.001
eGFR, ml/min/1.73 m^2	84.3 (72.1, 90.9)	84.4 (72.7, 91.0)	77.6 (60.2, 89.7)	< 0.001
Lymphocyte, $\times 10^9$/l	1.42 (1.09, 1.79)	1.43 (1.11, 1.79)	1.23 (0.92, 1.62)	< 0.001
Albumin, g/l	38.0 (35.3, 40.7)	38.1 (35.5, 40.7)	35.9 (32.0, 39.5)	< 0.001
Total cholesterol, mg/dl	148 (127, 171)	148 (128, 171)	140 (122, 164)	0.002
GNRI	98.3 (91.9, 104.8)	98.4 (92.1, 104.9)	95.2 (86.2, 101.6)	< 0.001
Normal (>98),	1428 (51.5%)	1374 (52.2%)	54 (37.5%)	< 0.001
Mild malnutrition (92–98)	640 (23.1%)	610 (23.2%)	30 (20.8%)	
Moderate malnutrition (82–91)	547 (19.7%)	513 (19.5%)	34 (23.6%)	
Severe malnutrition (< 82)	160 (5.8%)	134 (5.1%)	26 (18.1%)	
PNI	45.5 (41.7, 48.9)	45.6 (42.0, 48.9)	42.0 (38.3, 45.5)	< 0.001
Normal (>38)	2484 (89.5%)	2374 (90.2%)	110 (76.4%)	< 0.001
Moderate malnutrition (35–38)	175 (6.3%)	165 (6.3%)	10 (6.9%)	
Severe malnutrition (< 35)	116 (4.2%)	92 (3.5%)	24 (16.7%)	
CONUT score	3 (1, 4)	2 (1, 4)	4 (2, 6)	< 0.001
Normal (0–1)	766 (27.6%)	741 (28.2%)	25 (17.4%)	< 0.001
Mild malnutrition (2–4)	1492 (53.8%)	1427 (54.2%)	65 (45.1%)	
Moderate malnutrition (5–8)	466 (16.8%)	428 (16.3%)	38 (26.4%)	
Severe malnutrition (9–12)	51 (1.8%)	35 (1.3%)	16 (11.1%)	

Values are expressed as median (interquartile range) or number of patients (%).
AKI, acute kidney injury; CONUT, controlling nutritional status; eGFR, estimated glomerular filtration rate; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

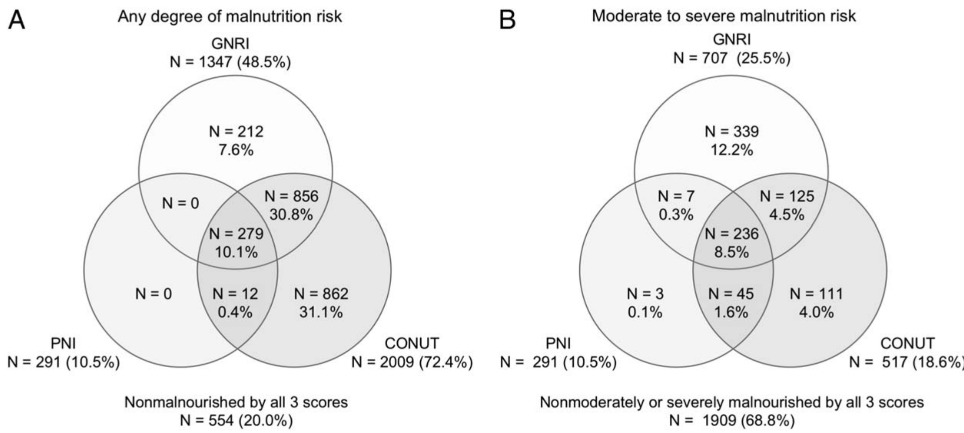

Figure 2. Venn diagram of malnutrition risk assessed by the three nutritional scores. Any degree (A) and moderate to severe (B) malnutrition risk according to each nutritional score. CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

malnutrition scores were associated with the risk of AKI, both in univariate and multivariate models (model 1: adjusting for preoperative factors such as age, sex, comorbidities, medication history, ASA physical status, and preoperative hemoglobin and eGFR; model 2: adjusting for variables in model 1 in addition to surgical characteristics including type, approach, and duration of surgery) (Table 3). We employed restricted cubic splines to illustrate the relationship between preoperative malnutrition scores and the multivariable-adjusted OR of AKI (adjusting for all variables in model 2). As shown in Figure 3A, the OR of AKI decreased sharply until the GNRI reached ~95, after which it tended to remain relatively constant. The association between PNI and the OR of AKI followed a similar pattern, with the OR of AKI declining sharply until the PNI reached ~45, after which it tended to remain relatively constant (Fig. 3B). With regard to the CONUT score, there is almost no association between it and the OR of AKI when the score is less than 4, but when the score is greater than 4, the OR of AKI increases as CONUT score increases (Fig. 3C).

We also included the three indices as categorical variables (i.e. malnutrition risk) in the logistic model. We conducted both univariate and multivariate analyses. The results showed that severe malnutrition, measured by any of the three indices, was associated with a higher risk of AKI; the odds of AKI were more than four times higher than those without malnutrition (Table 3). As regards moderate malnutrition, only moderate malnutrition as determined by CONUT was associated with an increased risk of AKI (Table 3).

Additive value of malnutrition scores in AKI risk prediction

We first treated the three nutritional indices as continuous variables. The results showed that the addition of each of the three indices to the base model 1 resulted in a significant increase in NRI and IDI, but only CONUT and PNI significantly improved AUC (Table 4). When adding the three indices to the base model 2, the NRI and IDI of the base model were significantly increased, but they did not increase the AUC of the base model (Table 4). In

Table 3

Univariable and multivariable analyses of three nutritional indices to predict postoperative acute kidney injury.

	Univariable analysis		Multivariable analysis model 1		Multivariable analysis model 2	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
GNRI, Per 1-point increment	0.95 (0.94–0.97)	< 0.001	0.96 (0.94–0.98)	< 0.001	0.96 (0.94–0.98)	< 0.001
Normal (>98)	Ref.		Ref.		Ref.	
Mild malnutrition (92–98)	1.25 (0.78–1.96)	0.336	1.15 (0.71–1.84)	0.553	1.05 (0.63–1.72)	0.848
Moderate malnutrition (82–91)	1.69 (1.08–2.61)	0.020	1.51 (0.92–2.45)	0.102	1.42 (0.84–2.38)	0.186
Severe malnutrition (< 82)	4.94 (2.96–8.07)	< 0.001	4.62 (2.50–8.44)	< 0.001	4.10 (2.10–7.95)	< 0.001
PNI, Per 1-point increment	0.90 (0.88–0.93)	< 0.001	0.91 (0.88–0.94)	< 0.001	0.92 (0.89–0.95)	< 0.001
Normal (>38)	Ref.		Ref.		Ref.	
Moderate malnutrition (35–38)	1.31 (0.63–2.43)	0.430	0.90 (0.42–1.73)	0.762	0.85 (0.39–1.67)	0.653
Severe malnutrition (< 35)	5.63 (3.39–9.05)	< 0.001	4.56 (2.61–7.79)	< 0.001	4.25 (2.35–7.50)	< 0.001
CONUT, Per 1-point increment	1.28 (1.20–1.37)	< 0.001	1.24 (1.15–1.34)	< 0.001	1.22 (1.12–1.32)	< 0.001
Normal (0–1)	Ref.		Ref.		Ref.	
Mild malnutrition (2–4)	1.35 (0.86–2.20)	0.210	1.21 (0.76–1.98)	0.443	1.13 (0.70–1.87)	0.625
Moderate malnutrition (5–8)	2.63 (1.58–4.47)	< 0.001	1.94 (1.09–3.49)	0.024	1.84 (1.02–3.37)	0.044
Severe malnutrition (9–12)	13.55 (6.56–27.56)	< 0.001	9.88 (4.42–21.82)	< 0.001	7.87 (3.30–18.51)	< 0.001

Multivariable analysis model 1: adjusting for preoperative factors such as age, sex, comorbidities, medication history, American Society of Anesthesiologists physical status, and preoperative hemoglobin and eGFR; Multivariable analysis model 2: adjusting for variables in model 1 as well as surgical characteristics including type, approach, duration of surgery, and intraoperative fluid infusion rate.
CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; OR, odds ratio; PNI, prognostic nutritional index; Ref, reference.

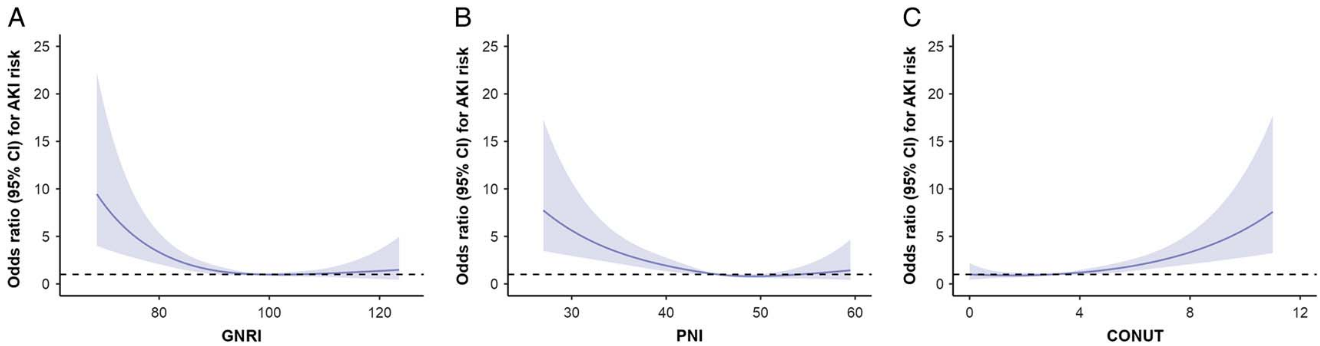

Figure 3. Restricted cubic spline curves for the relationship between the three nutritional scores and AKI in older patients undergoing major abdominal surgery. The purple bold line denotes the odds ratio, while the shaded area represents the 95% CI. AKI, acute kidney injury; CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

the likelihood ratio test, adding each of the three indices resulted in a better fit in the two base models (Table 4). In comparing the three indices, we found that PNI had higher risk reclassification capabilities compared to GNRI when adding to the base models, as demonstrated by higher NRIs and IDIs (Table 5). However, the results also showed that the three nutritional indices had similar AUCs (Table 5).

Next, we evaluated the additive predictive value of the three indices as categorical variables. Based on the results, adding each of the three indices to the base model 1 resulted in significant increases in AUC and IDI, but only CONUT and PNI yielded significant increases in NRI (Table 4). The addition of the three indices to base model 2 resulted in an increase in NRI and IDI, but did not exhibit a significant change in the AUC of the base model. In the likelihood ratio test, adding each of the three indices resulted in a better fit in the two base models (Table 5). When comparing the three indices, we found that they had similar AUCs, NRIs, and IDIs (Table 5).

The decision curve analysis suggested that using multivariable models containing nutritional scores (as continuous variables) could yield a higher net benefit for decision thresholds between 6 and 12% (Fig. 4). We also found that the net benefits were higher for multivariable models with PNI or CONUT than those with GNRI (Fig. 4).

Discussion

In this retrospective study, we analyzed data from 2775 older patients who had undergone major abdominal surgery to assess the predictive capability of malnutrition scores (GNRI, PNI, and CONUT) for postoperative AKI. The results suggested that preoperative nutritional status, as assessed by these indices, was an

Table 4

Performance of models with nutritional indices to predict the postoperative acute kidney injury in older patients undergoing major elective abdominal surgery.

	AUC		Net reclassification improvement		Integrated discrimination improvement		Likelihood ratio test
	AUC (95% CI)	*P*	Index (95% CI)	*P*	Index (95% CI)	*P*	*P*
Nutritional indices as continuous variables							
Base model 1	0.653 (0.606–0.700)						
+ GNRI	0.676 (0.630–0.722)	0.135	0.246 (0.079–0.413)	0.004	0.012 (0.004–0.020)	0.002	< 0.001
+ PNI	0.696 (0.651–0.741)	0.017	0.445 (0.282–0.608)	< 0.001	0.020 (0.008–0.032)	0.001	< 0.001
+ CONUT	0.693 (0.648–0.738)	0.013	0.284 (0.117–0.452)	0.001	0.019 (0.008–0.031)	0.001	< 0.001
Base model 2	0.775 (0.736–0.814)						
+ GNRI	0.786 (0.748–0.825)	0.163	0.259 (0.093–0.425)	0.002	0.009 (0.002–0.017)	0.014	< 0.001
+ PNI	0.789 (0.750–0.828)	0.137	0.339 (0.173–0.504)	< 0.001	0.017 (0.007–0.027)	0.001	< 0.001
+ CONUT	0.787 (0.747–0.827)	0.160	0.296 (0.129–0.463)	0.001	0.016 (0.006–0.026)	0.002	< 0.001
Nutritional indices as category variables							
Base model 1	0.653 (0.606–0.700)						
+ GNRI	0.680 (0.633–0.728)	0.045	0.159 (− 0.004–0.321)	0.056	0.017 (0.008–0.026)	< 0.001	< 0.001
+ PNI	0.685 (0.639–0.732)	0.016	0.181 (0.026–0.337)	0.022	0.020 (0.008–0.031)	0.001	< 0.001
+ CONUT	0.685 (0.638–0.732)	0.007	0.253 (0.086–0.420)	0.003	0.026 (0.011–0.041)	< 0.001	< 0.001
Base model 2	0.775 (0.736–0.814)						
+ GNRI	0.790 (0.751–0.829)	0.062	0.330 (0.163–0.497)	< 0.001	0.012 (0.004–0.021)	0.004	< 0.001
+ PNI	0.789 (0.750–0.828)	0.046	0.335 (0.173–0.498)	< 0.001	0.017 (0.005–0.028)	0.004	< 0.001
+ CONUT	0.788 (0.748–0.828)	0.061	0.273 (0.106–0.441)	0.001	0.019 (0.007–0.032)	0.002	< 0.001

Base model 1 includes preoperative factors such as age, sex, comorbidities, medication history, American Society of Anesthesiologists physical status, and preoperative hemoglobin and eGFR; Base model 2 includes variables in model 1 as well as surgical characteristics including type, approach, duration of surgery, and intraoperative fluid infusion rate.

AUC, area under the receiver operating characteristic curve; CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

Table 5

Comparative analysis of the discrimination of each nutritional index for postoperative acute kidney injury in older patients undergoing major elective abdominal surgery.

	AUC		Net reclassification improvement		Integrated discrimination improvement	
	Difference in AUC	P	Index (95% CI)	P	Index (95% CI)	P
Nutritional indices as continuous variables						
Model 1 as the base model						
CONUT vs. GNRI	0.017	0.600	0.066 (– 0.101–0.234)	0.438	0.007 (0.001–0.013)	0.014
CONUT vs. PNI	– 0.002	0.812	– 0.010 (– 0.178–0.158)	0.908	0 (– 0.005–0.004)	0.876
PNI vs. GNRI	0.020	0.551	0.269 (0.104–0.434)	0.001	0.008 (0.002–0.014)	0.011
Model 2 as the base model						
CONUT vs. GNRI	0.001	0.942	0.012 (– 0.156–0.180)	0.887	0.001 (0.001–0.013)	0.035
CONUT vs. PNI	– 0.002	0.749	– 0.051 (– 0.219–0.116)	0.548	– 0.001 (– 0.006–0.004)	0.706
PNI vs. GNRI	0.002	0.735	0.320 (0.157–0.483)	< 0.001	0.007 (0.001–0.014)	0.018
Nutritional indices as category variables						
Model 1 as the base model						
CONUT vs. GNRI	0.005	0.655	– 0.043 (– 0.210–0.125)	0.617	0.009 (0.001–0.019)	0.064
CONUT vs. PNI	0.001	0.999	0.143 (– 0.025–0.310)	0.095	0.006 (– 0.004–0.017)	0.232
PNI vs. GNRI	0.005	0.699	– 0.021 (– 0.184–0.142)	0.799	0.003 (– 0.006–0.011)	0.537
Model 2 as the base model						
CONUT vs. GNRI	– 0.002	0.777	0.001 (– 0.166–0.168)	0.990	0.007 (– 0.002–0.016)	0.124
CONUT vs. PNI	– 0.001	0.892	0.094 (– 0.074–0.261)	0.274	0.003 (– 0.007–0.013)	0.595
PNI vs. GNRI	– 0.001	0.897	0.063 (– 0.101–0.227)	0.454	0.004 (– 0.005–0.013)	0.381

Base model 1 includes preoperative factors such as age, sex, comorbidities, medication history, American Society of Anesthesiologists physical status, and preoperative hemoglobin and eGFR; Base model 2 includes variables in model 1 as well as surgical characteristics including type, approach, duration of surgery, and intraoperative fluid infusion rate.
AUC, area under the receiver operating characteristic curve; CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

independent predictor of AKI after surgery. We also found that incorporating these indices into AKI prediction models also improved their predictive ability; adding PNI or CONUT scores may provide a higher predictive value than GNRI.

To date, a number of nutritional screening tools have been developed[34], including the widely used Mini Nutritional Assessment-Short Form[35], Malnutrition Universal Screening Tool (MUST)[36], and Nutritional Risk Screening 2002 (NRS-2002)[37]. The European Society for Clinical Nutrition and Metabolism (ESPEN) recommends the use of NRS-2002 and the MUST for screening for malnutrition[38]. Among hospitalized patients, the MUST correlates more closely with ESPEN criteria for the definition of malnutrition[39] and is also useful in older patients[40]. These tools are based on questionnaires that synthesize multidimensional information regarding weight status, weight loss history, nutritional intake, and severity of disease. However, they may yield inaccurate results due to recall bias and communication difficulties, particularly for older patients who are hospitalized. For example, weight loss during the past few months is often not known, and it is usually assumed[40]. In contrast, the GNRI, PNI, and CONUT are simple and objective indices that are primarily based on laboratory measurements, and

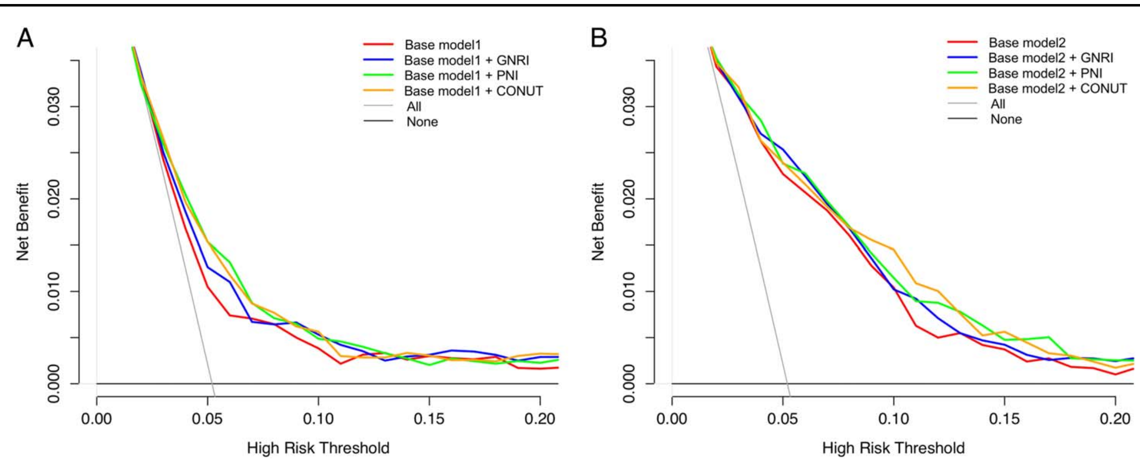

Figure 4. Decision curve analysis. The net benefit of using models with or without nutritional scores (as continuous variables) for prophylactic treatment decisions for postoperative acute kidney injury. (A) Base model 1 includes preoperative factors such as age, sex, comorbidities, medication history, American Society of Anesthesiologists physical status, and preoperative hemoglobin and eGFR; (B) Base model 2 includes variables in model 1 as well as surgical characteristics including type, approach, and duration of surgery, as well as intraoperative fluid infusion rate. CONUT, controlling nutritional status; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

do not require patient cooperation. Considering the economic costs of these laboratory tests, routine screening of the general population is not appropriate for these nutritional indices. Nonetheless, these laboratory tests are almost routinely performed on hospitalized patients, particularly those with severe illnesses or preparing for surgery, so these nutritional indices are appropriate for screening for malnutrition in these populations. Studies have shown that these indices have been utilized among patients with heart failure[17], stroke[18,19], and critical illness[20,21]. Furthermore, these indices have been suggested as a prognostic marker in geriatric surgical patients. Among older patients undergoing surgery, malnutrition as assessed by these indices has been demonstrated as a risk factor for heightened postoperative complications, protracted recovery, prolonged stays in the ICU and hospital, and increased mortality rates[41–45].

Previous studies have employed these objective indices to examine the correlation between nutritional status and postoperative AKI. Among noncardiac surgical patients, a correlation has been observed between high preoperative PNI and reduced AKI risk for those undergoing living donor liver transplantation[25], open hepatectomy[27], or colorectal cancer surgery[23]. Nonetheless, these studies did not explore the potential prognostic significance of GNRI and CONUT, nor did they consider the relevance of these tools for older patients. In the present study, we examined the predictive value of the three nutritional tools on postoperative AKI in older patients undergoing abdominal surgery. The results demonstrated that malnutrition, as measured by these indices, is independently associated with the development of postoperative AKI, and the addition of these indicators to AKI prediction models improves their predictive abilities. Furthermore, we compared the prognostic value of these indices and found that adding PNI or CONUT scores (in comparison with GNRI) demonstrated a greater incremental value for predicting AKI risk.

The specific mechanisms by which malnutrition causes kidney injury have not yet been fully elucidated, but several candidate mechanisms have been proposed. First, malnutrition causes cellular and tissue damage that promotes oxidative stress and inflammatory processes, which lead to renal injury[46,47]. Furthermore, protein-calorie malnutrition leads to altered renal hemodynamics, reduced renal blood flow, decreased glomerular filtration rate, and decreased tubular acid excretion, all of which contribute to the development of AKI[48,49].

Albumin is a component of objective nutritional indices, but its correlation with malnutrition is controversial. In healthy individuals, serum albumin levels tend to remain normal despite significant nutritional deprivation[50]. Thus, a causal relationship between malnutrition and hypoproteinemia cannot be established. However, malnutrition and hypoproteinemia often coexist in acutely ill patients[47], surgical patients[51], and older adults[52]. Therefore, it is suggested that a decrease in serum albumin is more likely to reflect the severity of the disease and inflammatory states than poor nutritional status[47,53,54]. Nevertheless, serum albumin plays a vital role in preserving renal function[55], and hypoalbuminemia is a known risk factor for postoperative AKI in both cardiac[56] and noncardiac surgeries[57,58]. Another component of the objective nutritional indices is lymphocytes. As a critical component of the immune system, lymphocytes have been found to play a key role in the initiation, propagation, and recovery of AKI[59]. Although different types of lymphocytes can have controversial effects on inflammation and renal function[60], previous research has linked low preoperative lymphocyte counts with an increased risk of postoperative AKI[61]. Total cholesterol is included in the CONUT score. Prior research has suggested that total cholesterol was a predictor of surgery-related AKI[62]. More recently, several studies have found that patients with lower preoperative serum high-density lipoprotein cholesterol levels are at greater risk of experiencing postoperative AKI[63,64]. In the present study, our results demonstrated that the PNI and CONUT scores possess greater predictive value than the GNRI in assessing risk. This finding may be explained by the more comprehensive assessment of malnutrition dimensions provided by the CONUT and PNI scores.

According to our research, preoperative malnutrition evaluation enhances the accuracy of AKI prediction models. The findings may assist in identifying patients at risk for AKI at an earlier stage, allowing certain preventive interventions to be used to reduce the incidence of AKI. There are several strategies that can be utilized to prevent postoperative AKI as recommended by the Acute Disease Quality Initiative and Perioperative Quality Initiative[65], such as discontinuing ACEIs and angiotensin receptor blockers before surgery, using goal-directed haemodynamic therapy during surgery, maintaining an intraoperative mean arterial blood pressure (MAP) > 65 mmHg, using balanced crystalloids instead of 0.9% saline, maintaining euvolaemia and treating hypotension and hyperglycemia following surgery. Generally, for patients at high-risk of AKI, monitoring and reducing nephrotoxic insults, as well as applying interventions to prevent secondary kidney injury and reduce the severity of AKI are necessary[65].

Nutritional management is an integral part of Enhanced Recovery after Surgery programs. ESPEN recently published a practical guideline that recommended a variety of nutritional strategies for surgical patients[66]. The guideline emphasizes the importance of early enteral feeding for surgical patients at nutritional risk, and initiating nutritional therapy as soon as a nutritional risk is detected. Additional recommendations include avoidance of long fasting periods before surgery, early re-establishment of oral feeding after surgery, metabolic control of blood glucose, and early mobilization to facilitate protein synthesis and muscle function. Studies have shown that perioperative nutritional support can reduce infectious complications, hospital stays, and costs as well as mortality[67–69]. Further research is needed to determine whether perioperative nutritional support can reduce postoperative AKI as well.

Our study has several strengths. First, we focused on the high-risk population of older patients undergoing major abdominal surgery, as early detection of AKI risk may offer greater benefits in this patient group. Second, the study incorporated a large sample size, allowing for the adjustment of numerous confounding factors. Third, we evaluated the prognostic value of nutritional indices in predicting AKI, beyond merely assessing their association with it.

Several limitations of our study should also be acknowledged. First, the nutritional indices we used have certain shortcomings. As we mentioned above, these indices require laboratory tests, which are costly from an economic perspective. Furthermore, these indices may not reflect the full extent of malnutrition because they do not account for factors such as vitamin deficiency, sarcopenia, and frailty[70]. These factors have been demonstrated to have an association with malnutrition and AKI[71–73]. Because these factors were not measured or assessed in the included patients, they were not adjusted in this study. Second, there were no MUST and NRS-2002 scores available for the included patients. As MUST and NRS-2002 are more widely used than the indices we used, the generalizability of our findings is limited. Third, the study excluded a certain number of patients due to the lack of necessary laboratory testing within 7 days of surgery, or because they lacked sufficient information to assess their nutritional status or AKI. This may lead to selection bias. Fourth, given the observational nature of our study, we were unable to establish a cause-and-effect relationship between malnutrition and AKI. Finally, the findings from our single-center cohort may limit generalizability. Further research involving multiple centers is needed to validate our findings.

Conclusion

In conclusion, our study demonstrated that poor nutritional status, as assessed by GNRI, PNI, and CONUT scores, was independently associated with an elevated risk of AKI in older patients following major abdominal surgery. Including these indices in the prediction models of AKI improved their predictive performance. Considering that these indices have limitations and are not as widely used as questionnaire-based tools, our findings are limited in their generalizability. Additional research is warranted to evaluate whether preoperative malnutrition assessment and intervention based on these scores could reduce postoperative AKI incidence.

Ethical approval

This study was approved by the Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science (TJ-IRB20210634).

Consent

The requirement for informed consent was waived due to the retrospective nature of the study.

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Author contribution

R.S.: conceptualization, data curation, formal analysis, software, validation, visualization, writing – original draft; Z.Z.: data curation, formal analysis, resources, validation, writing – review and editing; X.L.: investigation, resources, writing – review and editing; Q.X.: methodology, resources, visualization, writing – review and editing; B.Z.: investigation, writing – review and editing; H.Y.: methodology, writing – review and editing; W.Z.: investigation, writing – review and editing; Q.S.: investigation, writing – review and editing; X.Z.: investigation, writing – review and editing; X.L.: conceptualization, supervision, writing – review and editing; S.L.: conceptualization, formal analysis, methodology, project administration, software, writing – review and editing; A.L.: conceptualization, funding acquisition, project administration, supervision, writing – review and editing.

Conflicts of interest disclosure

The authors declare that they have no conflicts of interest.

Research registration unique identifying number (UIN)

1. Name of the registry: Clinicaltrials.gov.
2. Unique identifying number or registration ID: NCT04 967872.
3. 3.Hyperlink to your specific registration (must be publicly accessible and will be checked): https://clinicaltrials.gov/ct2/show/NCT04967872.

Guarantor

Ailin Luo and Shiyong Li had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author (Ailin Luo).

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