

Poor nutritional status and frailty associated with acute kidney injury after cardiac surgery: A retrospective observational study

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Abstract

Background: Acute kidney injury (AKI) is a major determinant of short- and long-term morbidity and mortality following cardiac surgery. The present study examines the effect of preoperative nutritional status and frailty on this significant adverse event.

Methods: The data of 455 patients who underwent on-pump coronary artery bypass grafting (CABG) were analyzed retrospectively. Demographic data were recorded, and intraoperative and postoperative parameters, frailty score, geriatric nutritional risk index (GNRI), and prognostic nutritional index (PNI) were calculated. Risk factors for AKI within 7 postoperative days were investigated in accordance with the kidney disease improving global outcomes classification.

Results: Preoperative urea and creatinine values were significantly higher ($p = .006$ vs. $p = .006$), while hemoglobin, hematocrit, and estimated glomerular filtration rate values were significantly lower ($p = .011$, $p = .008$ vs. $p = .006$) in the AKI group than no AKI group. In the intraoperative period, the cardiopulmonary bypass time was longer in the AKI group ($p = .031$), and the need for dopamine, steradine, and red blood cells transfusion was greater ($p = .026$, $p = .038$ vs. $p = .015$) than no AKI group. The number of patients with a frailty score of 1–3 was significantly higher in the AKI group ($p = .042$). Similarly, the GNRI and PNI values, indicating nutritional status, were higher in the AKI group ($p = .047$ vs. $p = .024$). The independent risk factors for AKI were a GNRI of <91 , the intraoperative need for dobutamine, preoperative serum creatinine of >1.3 , and hemoglobin of <10 ($p < .05$).

Conclusions: Malnutrition and frailty are strongly associated with AKI after CABG. Clinicians can effectively predict the risk of AKI through an evaluation of frailty and nutritional scores, which can be easily calculated in the preoperative period.

KEYWORDS

acute kidney injury, coronary artery bypass graft, frailty, geriatric nutritional risk index, prognostic nutritional index

1 | INTRODUCTION

Acute kidney injury (AKI) occurring after cardiovascular surgery has been shown to be an independent risk factor that increases costs, morbidity, and in-hospital mortality.^{1,2} The reported incidence of AKI associated with cardiac surgery is 7.7%–40% and the reported incidence of renal replacement therapy (RRT) is 2%–8%,^{3–6} being further increased by an increase in the number of operations performed on older adults and severely comorbid patients. There is, thus, a growing need to develop strategies for accurate preoperative risk estimation to support early diagnosis and intervention for the optimization of AKI.⁷

Frailty is a state of reduced physiological reserve and resistance to stress factors.⁸ Frailty, which is a better indicator of adverse outcomes than chronological age, has been shown to be significantly associated with postoperative complications,^{9,10} and is also an independent predictor of in-hospital mortality (1.8-fold) in cardiac surgery patients.¹¹ Frailty is a multifactorial process, and poor nutritional status is considered to contribute to its pathophysiology. Like frailty, malnutrition is also associated with medium- and long-term mortality after cardiac surgery.^{12,13} The most commonly applied nutritional scoring systems in recent studies aimed at assessing nutritional status are the geriatric nutritional risk index (GNRI)¹⁴ and the prognostic nutritional index (PNI).¹⁵ A preoperative assessment of both scoring systems in cardiac surgery has reported them to be useful and safe.^{12,15}

The present study investigates the role of preoperative nutritional status and frailty, which have been shown to affect mortality after cardiac surgery, in AKI, as a complication with a high incidence after cardiac surgery.

2 | MATERIALS AND METHODS

After being granted approval for the study by the local ethics committee of Ankara City Hospital (Decision No: E1-22-2697, date: 29.06.2022), a retrospective review was made of the electronic medical records and anesthesia and intensive care observation reports of 467 adult patients who underwent coronary artery bypass grafting (CABG) with a cardiopulmonary bypass (CPB) and aortic cross-clamp (CC) between February 2019 and February 2020. Excluded from the study were seven patients with preoperative dialysis-dependent chronic kidney disease (CKD), three patients without preoperative serum creatinine (sCr) values, and two patients who died within the first 24 postoperative hours. The data of the remaining 455 patients were statistically assessed. The need for informed consent was deemed unnecessary for this retrospective study.

Demographic parameters (age, gender, and body mass index [BMI]), comorbidities (hypertension, diabetes mellitus, small vessel occlusion/transient ischemic attack, etc.), presence/absence of acute myocardial infarction and the need for preoperative intra-aortic balloon pump (IABP), extracorporeal membrane oxygenation (ECMO),

and/or inotropic support were ascertained from the records. The preoperative laboratory data were recorded, including blood urea, sCr, albumin, estimated glomerular filtration rate (eGFR), hemoglobin, hematocrit, platelet, C-reactive protein, and echocardiography data. Inotropic support, blood and blood product transfusion, total intravenous fluid and urine output amounts, and CPB and CC times in the intraoperative period were examined.

The primary outcome was the development of AKI within the first postoperative week, defined according to the kidney disease improving global outcomes (KDIGO) criteria in which AKI is classified based on the maximum change in sCr from the preoperative baseline levels.^{16,17} All patients who met the KDIGO criteria for Stages 1–3 were considered to have AKI. RRT was defined as the need for new dialysis therapy after surgery. The postoperative outcome variables included the time to extubation, inotropic support, need for ECMO, IABP, and RRT, reoperation, duration of hospital and intensive care unit stay, and 30-day mortality.

2.1 | Frailty score measurement

Frailty was measured based on five variables derived from a previously validated chart used for the assessment of preoperative patient characteristics.^{18,19} The preoperative frailty index took the following variables into account: age > 70 years, preoperative BMI < 18.5, serum albumin (an indicator of poor nutrition and inflammation^{20,21}) < 3.4 g/dl, sCr (an indicator of muscle mass loss and CKD^{22,23}) > 2 mg/dl, and hematocrit (an indicator of anemia^{20,24}) < 35% and a patient was considered frail when any of these five variables were present (frailty: absent if the score is 0, present if ≥1). The frailty score was calculated by summing the scores from each variable.

2.2 | Nutritional indices

The GNRI is calculated using the following equation:

$$\text{GNRI} = [14.89 \times \text{serum albumin (g/dl)}] + [41.7 \times \text{preoperative body weight (kg)/ideal body weight (kg)}].$$

GNRI was classified based on scores of <91 (1) and ≥91 (0).¹⁴ A total protein level of 65% was used when serum albumin levels were not available.

The PNI was calculated using the following equation:

$$\text{PNI} = [10.00 \times \text{serum albumin (g/dl)}] + [0.005 \times \text{total lymphocyte (count/mm}^3\text{)}],$$

PNI was classified based on scores of <48 (1) and a score of ≥48 (0).¹⁵

While calculating PNI and GRI scores, albumin and lymphocyte values were obtained from preoperative laboratory data, and body weight and height measurements required for ideal body weight were obtained from the hospital data recording system.

Continuous variables were categorized before analyzing the independent predictors of postoperative AKI. Frequently used

variables were categorized based on normal cutoff points, and the threshold levels for serum albumin and hemoglobin were taken from previous studies.²⁵

2.3 | Statistical analysis

The obtained data were recorded in a digital environment and subjected to a statistical assessment. $p < .05$ was considered statistically significant for all analyses. Descriptive statistics were presented as absolute numbers (n) and percentages (%) for categorical variables, the median-interquartile range (25th–75th percentiles) for non-normally distributed data, and the mean-standard deviation for normally distributed data. Categorical variables were compared using Fisher's exact test or an χ^2 test, depending on the expected numbers. Continuous variables were compared between those without AKI and those with all three KDIGO using a Kruskal–Wallis test. A comparison of the continuous variables of those with and without AKI was made using a Mann–Whitney U test or an independent samples t -test, based on a Kolmogorov–Smirnov test for normality. A univariate logistic regression analysis was used to identify potential risk factors for AKI, and the multivariate model only included variables that were significant in the univariate analysis. A Hosmer–Lemeshow test was used to test the model fit. A logistic regression analysis was used to calculate the correlation coefficients for the relationships

between variables that showed collinearity with each other and revealed the hazard ratios and 95% confidence intervals (CIs). A post hoc power analysis was performed for the independent risk factors for AKI. At a 0.005 margin of type I error, the power of clinical predictors for AKI was found to be over 0.8 for each in the given sample size.

3 | RESULTS

Of the total 455 patients, 141 (30.9%) developed AKI, based on the KDIGO criteria, and 10 (7.0%) required RRT within the first postoperative 7 days. The entire group according to the KDIGO classification had similar demographic data (age, gender, and BMI), comorbidities, and the number of grafts (Table 1).

All patients who met Stage 1, 2, or 3 of the KDIGO criteria were considered to have AKI. The preoperative, intraoperative, and postoperative parameters of the AKI group and non-AKI group were statistically compared (Table 2), revealing the urea and sCr values recorded based on preoperative laboratory parameters to be significantly higher in the AKI group ($p = .006$ vs. $p = .006$), while hemoglobin, hematocrit, and eGFR values were significantly lower in the AKI group ($p = .011$, $p = .008$ vs. $p = .006$). In the intraoperative period, the CPB time was longer in the AKI group ($p = .031$), and the need for dopamine, steradine, and packed RBC transfusion was greater ($p = .026$, $p = .038$ vs. $p = .015$).

TABLE 1 Demographic data, comorbidities, and number of grafts by the KDIGO stage of AKI

	KDIGO stage				p^*
	No AKI ($n = 314$)	Stage 1 ($n = 108$)	Stage 2 ($n = 16$)	Stage 3 ($n = 17$)	
Gender (M), n (%)	258 (82.2)	88 (81.5)	12 (75.0)	16 (94.1)	.521
Age (year), median (IQR)	61 (53–68)	62 (55–67)	63 (57–69.5)	62 (51–66)	.473
BMI (kg/m^2), median (IQR)	27.97 (25.3–30.8)	28.58 (25.7–31.9)	30.67 (26.8–32.8)	27.36 (25.1–31.0)	.148
LVEF %, median (IQR)	55 (50–60)	55 (50–60)	47.5 (40–57.5)	52 (44–55)	.151
HT, n (%)	135 (43.0)	53 (49.1)	9 (56.3)	4 (23.5)	.164
DM (n , %)	116 (36.9)	30 (27.8)	5 (31.3)	7 (41.2)	.337
COPD, n (%)	31 (9.9)	11 (10.2)	4 (25.0)	2 (11.8)	.292
Stroke/TIA, n (%)	8 (2.5)	4 (3.7)	1 (6.3)	2 (11.8)	.182
Number of grafts, n (%)					
CABG $\times$ 1	18 (5.7)	3 (2.8)	0 (0.0)	0 (0.0)	.886
CABG $\times$ 2	73 (23.2)	26 (24.1)	3 (18.8)	5 (29.4)	
CABG $\times$ 3	147 (46.8)	55 (50.9)	8 (50.0)	9 (52.9)	
CABG $\times$ 4	59 (18.8)	18 (16.7)	3 (18.8)	3 (17.6)	
CABG $\times$ 5	17 (5.4)	6 (5.6)	2 (12.5)	0 (0.0)	

Abbreviations: AKI, acute kidney injury; BMI, body mass index; CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; HT, hypertension; IQR, interquartile range; KDIGO, kidney disease improving global outcomes; LVEF, left ventricular ejection fraction; M, male; TIA, transient ischemic attack.

*For continuous variables (median, IQR), the Kruskal–Wallis test was used; for categorical variables (n , %), the χ^2 test was performed.

TABLE 2 Preoperative, intraoperative, and postoperative variables

	No AKI (n = 314) n (%)	Median (IQR)	AKI (n = 141) n (%)	Median (IQR)	p
Preoperative period					
IABP and/or ECMO	2 (0.6)		1 (0.7)		.930
Acute myocardial infarction	44 (14.0)		18 (12.8)		.720
Blood glucose (mg/dl)		113 (93–164)		120 (101–159)	.201
Blood urea (mg/dl)		34 (29–42)		38 (31–45)	.006
Serum creatinine (mg/dl)		0.91 (0.81–1.03)		0.95 (0.84–1.10)	.006
Serum albumin (g/dl)		4.24 (4.0–4.5)		4.16 (3.90–4.45)	.054
eGFR (ml/min/1.73 m ²)		87 (74–100)		80 (69–95)	.006
White blood cells (G/L)		8.15 (6.97–9.62)		7.87 (6.60–9.23)	.174
Hemoglobin (G/L)		13.9 (12.7–14.9)		13.6 (11.9–14.8)	.011
Hematocrit (%)		41.9 (37.8–44.6)		40.8 (36.0–43.8)	.008
C-reactive protein (mg/L)		3.15 (1.87–4.53)		3.11 (1.66–5.20)	.953
Intraoperative period					
CC time (min)		61 (48–78)		62 (48–78)	.738
CPB time (min)		98.5 (80–120)		108 (86–127)	.031
Intraoperative dopamine use	61 (19.4)		38 (27.0)		.072
Intraoperative dobutamine use	22 (7.0)		19 (13.5)		.026
Intraoperative adrenaline use	4 (1.3)		3 (2.1)		.494
Intraoperative steradine use	5 (1.6)		7 (5.0)		.038
PC transfusion	2 (0.6)		0 (0.0)		.342
pRBC transfusion 0 units	237 (75.5)		89 (63.1)		.015
0–3 units	72 (22.9)		46 (32.6)		
4+ units	5 (1.6)		6 (4.3)		
FFP transfusion 0 units	269 (85.7)		114 (80.9)		.298
1–2 units	31 (9.9)		21 (14.9)		
3–4 units	14 (4.5)		6 (4.3)		
Total intravenous fluid (ml)		1500 (1000–2000)		1500 (1300–2000)	.399
Urine output (ml)		800 (500–1200)		900 (550–1200)	.388
Postoperative period					
Need for inotropes	67 (21.3)		35 (24.8)		.410
IABP and/or ECMO	3 (1.0)		5 (3.5)		.052
Atrial fibrillation	11 (3.5)		4 (2.8)		.713
Extubation time > 8 h	41 (13.1)		22 (15.6)		.467
Revision	2 (0.6)		3 (2.1)		.158
Length of ICU stay (h)		24 (20–24)		24 (22–48)	.186
Length of hospital stay (days)		8 (6–12)		8 (6–14)	.523
Mortality 30-day	3 (1.0)		4 (2.8)		.132

Note: The Mann–Whitney *U* test was used for continuous variables (median, IQR); the χ^2 test was performed for categorical variables (n, %).

Abbreviations: AKI, acute kidney injury; CC, cross-clamp; CPB, cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation; eGFR, estimated glomerular filtration rate; FFP, fresh frozen plasma; IABP, intra-aortic balloon pump; ICU, intensive care unit; IQR, interquartile range; PC, platelet concentrate; pRBC, packed red blood cells.

TABLE 3 Frailty score and nutritional status

	No AKI (n = 314)		AKI (n = 141)		p*
	n (%)	Mean ± SD	n (%)	Mean ± SD	
GNRI score		116.41 ± 10.0		114.40 ± 9.6	.047
GNRI score < 91p	3 (1.0)		8 (5.7)		.002
PNI score		53.41 ± 5.5		52.10 ± 6.0	.024
PNI score < 48p	50 (15.9)		34 (24.1)		.037
Frailty score 0	234 (74.5)		92 (65.2)		
1	63 (20.1)		34 (24.1)		.018
2	17 (5.4)		12 (8.5)		
3	0 (0.0)		3 (2.1)		
Frailty score ≥ 1	80 (25.5)		49 (34.8)		.042

Abbreviations: AKI, acute kidney injury; GNRI, geriatric nutritional risk index; PNI, prognostic nutritional index.

*The independent samples t-test was used for continuous variables (mean ± SD); the χ^2 was performed for categorical variables (n, %).

There were 129 patients (28.3%) with a frailty score of 1–3, with scores of 3 points in 3 patients, 2 points in 29 patients, and 1 point in 97 patients. The number of patients with a frailty score of 1–3 was significantly higher in the AKI group ($p = .042$), as were the GNRI and PNI values indicating nutritional status ($p = .047$ vs. $p = .024$, Table 3).

A model was created for a multivariate regression analysis using the parameters identified as potential risk factors for AKI in the univariate logistic regression analysis (Table 4). The independent risk factors for AKI according to the results of the multivariate logistic regression analysis are presented in Table 5. According to the analysis results, patients with a GNRI score of <91p were 5.11 times more likely to develop AKI (1.2–20.2, 95% CI), while those who needed intraoperative dobutamine were 2.08 times more likely (1.0–4.0, 95% CI), those with a preoperative sCr of >1.3 mg/dl were 2.29 times more likely (1.0%–4.9% 95% CI) and those with preoperative hemoglobin scores of ≤10 g/L were 3.4 times more likely (1.2–9.3) to develop AKI ($p < .05$).

4 | DISCUSSION

This retrospective study shows the poor nutritional status and a high incidence of frailty to be associated with a risk of postoperative AKI in patients undergoing CABG, while a low preoperative GNRI score is an independent risk factor for postoperative AKI. Other findings of our study, which are largely consistent with previous studies⁶ examining cardiac surgery-related AKI risk factors, are poor preoperative kidney function, hyperuricemia, hypoalbuminemia, anemia, need for intraoperative blood transfusion and inotropes, and prolonged CPB. Among these, we also found that preoperative hemoglobin < 10 g/L, sCr > 1.3 mg/dl, and the need for intraoperative dobutamine are independent risk factors for AKI. Our study recorded that the incidence of AKI increased to 30.9% and the incidence of RRT increased to 2.1% in patients who underwent CABG, which is consistent with previous literature.^{3–6} The mortality rate

TABLE 4 Univariate logistic regression

	p	OR	95% CI
Preoperative GNRI score < 91p	.008	6.236	1.629–23.870
Preoperative PNI score < 48p	.039	1.678	1.028–2.739
Preoperative frailty score ≥ 1	.043	1.558	1.014–2.394
Preoperative blood urea ≥ 40 mg/dl	.027	1.585	1.053–2.384
Preoperative sCr > 1.3 mg/dl	.004	2.938	1.405–6.143
Preoperative eGFR < 90 ml/min/1.73 m ²	.037	1.550	1.027–2.340
Preoperative serum albumin < 4 g/dl	.011	1.744	1.136–2.679
Preoperative hemoglobin ≤ 10 g/L	.008	3.711	1.407–9.785
Preoperative hematocrit < 35%	.003	2.246	1.320–3.822
Intraoperative dobutamine use	.028	2.067	1.080–3.956
Intraoperative steroid use	.049	3.228	1.007–10.354
pRBC transfusion during surgery	.053		
0 unit			
0–3 units	.126	1.414	0.907–2.206
4+ units	.042	3.799	1.048–13.773
CPB time > 120 min	.016	1.711	1.103–2.654

Abbreviations: CI, confidence interval; CPB, cardiopulmonary bypass; eGFR, estimated glomerular filtration rate; GNRI, geriatric nutritional risk index; OR, odds ratio; PNI, prognostic nutritional index; pRBC, packed red blood cell; sCr, serum creatinine.

approaches 60% in patients who need dialysis,²⁶ although there have been studies suggesting that promising results are likely to be achieved if therapeutic interventions are initiated within 24–48 h.²⁷ In this regard, identifying predictors of high AKI risk may aid clinicians in taking the necessary precautions.

TABLE 5 Multivariate predictors of AKI

Covariate	p	OR	95% CI
Geriatric nutritional risk index score < 91	.020	5.110	1.288–20.280
Intraoperative dobutamine use	.030	2.084	1.073–4.050
Preoperative sCr > 1.3 mg/dl	.036	2.296	1.058–4.986
Preoperative hemoglobin ≤ 10 g/L	.017	3.409	1.249–9.300
Constant	.011	3.247	

Abbreviations: AKI, acute kidney injury; CI, confidence interval; OR, odds ratio; sCr, serum creatinine.

Recently, frailty, a different construct from physiological age, has emerged as a concept that can help identify vulnerable older adult patients who may benefit from novel intervention methods.²⁸ Frailty is defined as a physiological decline in multiple organ systems that reduces the patient's capacity to tolerate the stress of surgery and illness. In older adult patients hospitalized for acute or chronic disease or complications, frailty has been shown to be a predictor of AKI.²⁹ Furthermore, the sympathetic reserve required for the autoregulation of renal blood flow is decreased in frail patients due to autonomic dysfunction,¹⁸ leading us to believe that frail patients may become more prone to AKI with renal ischemia-reperfusion injury and inflammation caused by CPB. This is supported by our finding of a significantly higher incidence of frailty in the AKI patients in our study group. On the other hand, while being a significant predictor for postoperative AKI in the univariate logistic regression analysis, frailty was not identified as an independent predictor by the multivariate analysis. This may be attributed to the absence of patients with a frailty score higher than 3, and the failure to assess frailty scores using different parameters with retrospective data.

Malnutrition is a central component of frailty that adversely affects the prognosis of cardiac surgery patients. GNRI and PNI used to measure nutritional status, can be easily obtained based on serum albumin, lymphocyte count, and body mass data, and even allow retrospective analysis. Low serum albumin levels, which are components of both scoring indices, are also associated with increased severity of inflammation.³⁰ A meta-analysis involving a large series of patients in which cardiac surgery was predominant revealed a low albumin level to be an independent predictor of AKI and mortality after AKI.³¹ Our findings have shown that preoperative nutritional status plays a crucial role in the emergence of postoperative AKI. We believe that the preoperative detection of malnutrition will have an effect on surgical decision-making and may influence anesthesiologists in taking early kidney-protecting measures, such as avoiding intraoperative nephrotoxic agents and optimizing perfusion during CPB.

5 | LIMITATIONS

Our study is limited by its single-center design. As a retrospective study, physical symptoms could not be measured directly, so functional impairment and cognitive impairment could not be

analyzed during the frailty assessment of the patients. We did not use traditional fragility indices but instead used a fragility score derived from a recently published chart that allows for ease of classification and places a minimal burden on the clinician. Patients without preoperative laboratory data were excluded from the study, and such a bias could be eliminated by a prospective study in which all patients have all preoperative clinical and laboratory values.

In conclusion, malnutrition and frailty are strongly associated with AKI after CABG. Clinicians can predict the risk of AKI effectively and easily by calculating the frailty index and additional nutritional scores preoperatively. Further prospective studies are needed to establish the effect of nutritional support and kidney-protecting strategies on clinical outcomes in these patients.

AUTHOR CONTRIBUTIONS

Idea/concept, design, and data collection and/or processing: Aslihan Aykut and Nevriye Salman. *Analysis and/or interpretation, literature review, and writing the article:* Aslihan Aykut. *Critical review and control/supervision:* Nevriye Salman.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

- Machado MN, Nakazone MA, Maia LN. Prognostic value of acute kidney injury after cardiac surgery according to kidney disease: improving global outcomes definition and staging (KDIGO) criteria. *PLoS One*. 2014;9:e98028.
- Hobson CE, Yavas S, Segal MS, et al. Acute kidney injury is associated with increased long-term mortality after cardiothoracic surgery. *Circulation*. 2009;119:2444–2453.
- Mehta RH, Grab JD, O'Brien SM, et al. Bedside tool for predicting the risk of postoperative dialysis in patients undergoing cardiac surgery. *Circulation*. 2006;114:2208–2216.
- Rahmanian PB, Kwiecien G, Langebartels G, et al. Logistic risk model predicting postoperative renal failure requiring dialysis in cardiac surgery patients. *Eur J Cardiothorac Surg*. 2011;40:701–707.
- Wijesundera DN, Karkouti K, Dupuis JY, et al. Derivation and validation of a simplified predictive index for renal replacement therapy after cardiac surgery. *JAMA*. 2007;297:1801–1809.
- Rosner MH, Okusa MD. Acute kidney injury associated with cardiac surgery. *Clin J Am Soc Nephrol*. 2006;1:19–32.
- Oh HJ, Shin DH, Lee MJ, et al. Early initiation of continuous renal replacement therapy improves patient survival in severe progressive septic acute kidney injury. *J Crit Care*. 2012;27:743.
- Rockwood K, Mitnitski A. Frailty defined by deficit accumulation and geriatric medicine defined by frailty. *Clin Geriatr Med*. 2011;27:17–26.
- Makary MA, Segev DL, Pronovost PJ, et al. Frailty as a predictor of surgical outcomes in older patients. *J Am Coll Surg*. 2010;210:901–908.
- Rocha V, Marmelo F, Leite-Moreira A, Moreira-Gonçalves D. Clinical utility of frailty scales for the prediction of postoperative complications: systematic review and meta-analysis. *Rev Port Cir Cardiorac Vasc*. 2017;24:132.

11. Lee DH, Butth KJ, Martin BJ, Yip AM, Hirsch GM. Frail patients are at increased risk for mortality and prolonged institutional care after cardiac surgery. *Circulation*. 2010;121:973-978.
12. Tóth K, Szabó A, Nagy Á, et al. Preoperative nutritional state is associated with mid- and long-term mortality after cardiac surgery. *Ann Palliative Med*. 2021;10:11333-11347.
13. Tóth K, Szabó A, Menyhárd J, et al. Poor preoperative nutritional status, but not hormone levels, are associated with mortality after cardiac surgery. *J Cardiothorac Vasc Anesth*. 2022;36:3074-3083.
14. Unosawa S, Taoka M, Osaka S, et al. Is malnutrition associated with postoperative complications after cardiac surgery? *J Card Surg*. 2019;34:908-912.
15. Hayashi J, Uchida T, Ri S, et al. Clinical significance of the prognostic nutritional index in patients undergoing cardiovascular surgery. *Gen Thorac Cardiovasc Surg*. 2020;68:774-779.
16. Mehta RL, Kellum JA, Shah SV, et al. Acute kidney injury network: report of an initiative to improve outcomes in acute kidney injury. *Crit Care*. 2007;11:R31.
17. Thomas ME, Blaine C, Dawnay A, et al. The definition of acute kidney injury and its use in practice. *Kidney Int*. 2015;87:62-73.
18. James LA, Levin MA, Lin H-M, Deiner SG. Association of preoperative frailty with intraoperative hemodynamic instability and postoperative mortality. *Anesth Analg*. 2019;128:1279-1285.
19. Amrock LG, Neuman MD, Lin H-M, Deiner S. Can routine preoperative data predict adverse outcomes in the elderly? Development and validation of a simple risk model incorporating a chart-derived frailty score. *J Am Coll Surg*. 2014;219:684-694.
20. Robinson TN, Wu DS, Pointer L, Dunn CL, Cleveland JC, Moss M. Simple frailty score predicts postoperative complications across surgical specialties. *Amer J Surg*. 2013;206:544-550.
21. Don BR, Kaysen G. Poor nutritional status and inflammation: serum albumin: relationship to inflammation and nutrition. *Sem Dialysis*. 2004;17:432-437.
22. Dalrymple LS, Katz R, Rifkin DE, et al. Kidney function and prevalent and incident frailty. *Clin J Am Soc Nephrol*. 2013;8:2091-2099.
23. Shlipak MG, Stehman-Breen C, Fried LF, et al. The presence of frailty in elderly persons with chronic renal insufficiency. *Am J Kidney Dis*. 2004;43:861-867.
24. Chaves PHM, Semba RD, Leng SX, et al. Impact of anemia and cardiovascular disease on frailty status of community-dwelling older women: the Women's Health and Aging Studies I and II. *J Gerontol A Biol Sci Med Sci*. 2005;60:729-735.
25. Kim WH, Park JY, Ok SH, Shin IW, Sohn JT. Association between the neutrophil/lymphocyte ratio and acute kidney injury after cardiovascular surgery: a retrospective observational study. *Medicine*. 2015;94:e1867.
26. Landoni G, Zangrillo A, Franco A, et al. Long-term outcome of patients who require renal replacement therapy after cardiac surgery. *Eur J Anaesthesiol*. 2006;23:17-22.
27. García-Fernández N, Pérez-Valdivieso JR, Bes-Rastrollo M, et al. Timing of renal replacement therapy after cardiac surgery: a retrospective multicenter Spanish cohort study. *Blood Purif*. 2011;32:104-111.
28. Kim DH, Kim CA, Placide S, Lipsitz LA, Marcantonio ER. Preoperative frailty assessment and outcomes at 6 months or later in older adults undergoing cardiac surgical procedures. *Ann Intern Med*. 2016;165: 650-660.
29. Baek SH, Lee SW, Kim S, et al. Frailty as a predictor of acute kidney injury in hospitalized elderly patients: a single center, retrospective cohort study. *PLoS One*. 2016;11:e0156444.
30. Nochioka K, Sakata Y, Takahashi J, et al. Prognostic impact of nutritional status in asymptomatic patients with cardiac diseases: a report from the CHART-2 study. *Circ J*. 2013;77: 2318-2326.
31. Wiedermann CJ, Wiedermann W, Joannidis M. Causal relationship between hypoalbuminemia and acute kidney injury. *World J Nephrol*. 2017;6:176-187.

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