The Heart Surgery Forum

Heart Surg. Forum **2026**; 29(2): 46847
https://doi.org/10.31083/HSF46847

Article

Prognostic Value of Preoperative Geriatric Nutritional Risk Index for Long-Term Cardiovascular Mortality in Elderly Patients Undergoing Cardiac Valve Surgery: A Retrospective Cohort Study

Hailin He[1], Qi Liu[1], Qiufeng Liao[1], Simin Li[1], Rongxing Bao[1], Xiaolin Gu[1], Chongjian Zhang[1,*]

[1]Department of Cardiac Surgical Intensive Care Unit, Guangdong Provincial People's Hospital (Guangdong Academy of Medical Sciences), Southern Medical University, 510080 Guangzhou, Guangdong, China

*Correspondence: zhangchongjian@gdph.org.cn (Chongjian Zhang)

Academic Editor: Giuseppe Santarpino

Submitted: 23 September 2025 Revised: 28 November 2025 Accepted: 16 December 2025 Published: 9 February 2026

Abstract

Background: Malnutrition frequently occurs in older adults receiving cardiac surgery and is often linked to poor long-term prognosis. In geriatric care, the Geriatric Nutritional Risk Index (GNRI) offers a practical and efficient assessment tool to evaluate malnutrition risk, yet its relationship with cardiovascular mortality following cardiac valve surgery remains inadequately explored. **Methods**: This research employed a retrospective cohort design with a sample of 170 patients of ≥60 years or older who underwent valve surgery at a tertiary hospital in 2013. To evaluate nutritional status, we employed using GNRI. The principal outcome was cardiovascular death with a median 7.2 years follow-up. Our methodological framework for investigating the GNRI-cardiovascular mortality link integrated three key components: multivariable Cox regression (to estimate hazard ratios), restricted cubic spline modeling (to explore non-linear trends), and Kaplan–Meier analysis (to visualize survival curves). **Results**: The results indicated a significant inverse linear the correlation of GNRI with the risk of cardiovascular mortality (p for nonlinearity = 0.274). After multivariable adjustment, per unit increment in GNRI showed a significant association 41% decline in the risk of death from cardiovascular causes (hazard ratios (HR): 0.59, 95% CI: 0.38–0.90, p = 0.015). Individuals with GNRI ≤92 had significantly worse long-term survival than those with GNRI >92 (p = 0.0057). **Conclusions**: Preoperative GNRI is independently related to cardiovascular deaths in elderly postoperative cardiac valve surgery patients. A reduced GNRI signifies a significant marker for late cardiovascular death over the long term in cardiac valve surgery.

Keywords: cardiac valve surgery; older adults; geriatric nutritional risk index; cardiovascular mortality; nutritional risk; cardiovascular outcomes

1. Introduction

Surgery performed on the heart has become increasingly prevalent worldwide, driven by the growing burden of cardiovascular diseases such as valvular disorders, especially in elderly populations [1]. Despite advances in surgical techniques and perioperative care, these procedures continue to carry substantial risks of postoperative complications and mortality [2]. Malnutrition has been increasingly acknowledged as an essential and adjustable determinant of postoperative recovery and long-term survival [3].

Based on serum albumin and the actual-to-ideal body weight ratio, the Geriatric Nutritional Risk Index (GNRI) serves as a valuable instrument for assessing nutritional risk [4]. It reflects both visceral protein reserves (through albumin, a key marker of nutritional status and systemic inflammation levels) and somatic protein mass (through body weight), providing a composite measure of nutritional health [5]. Beyond its initial purpose of evaluating nutritional risk in elderly inpatients, the GNRI demonstrates utility in forecasting clinical outcomes in heart failure, coronary disease, and cardiac surgery [6–8].

In cardiac surgery, accumulating evidence has demonstrated the prognostic value of GNRI, though inconsistencies persist across studies. Investigations by Gürbak *et al.* [6] and Naganuma *et al.* [9] identified clear ties between low GNRI and elevated mortality in valve replacement surgical cohorts, with median follow-up durations of 4.2 and 2.7 years, respectively. Pavone *et al.* [10] also confirmed the impact of poor nutritional state on valve surgery results. Conversely, Luo *et al.* [11], analyzing studies with median follow-ups 4.5 years, pointed to ongoing discrepancies. These conflicting findings may arise from methodological variations in structural characteristics of the studies and cohort sizes, GNRI thresholds, and especially insufficient, follow-up duration, as relatively short observation periods likely obscure the true long-term prognostic significance of preoperative nutritional status.

To overcome these research limitations, we implemented a retrospective cohort study with a median 7.2 years follow-up-substantially longer than previous reports. This research purposes to examine the independent connection preoperative GNRI and cardiovascular death among older adults receiving cardiac valve surgery, to provide robust ev-

idence to guide the management of this clinically susceptible group over the long term.

2. Methods

2.1 Study Cohort

This research employed a retrospective cohort design utilizing data from all consecutive elderly patients who received valvular heart surgery at a tertiary hospital during 2013. After applying the exclusion criteria, 170 out of 213 adults who had surgery with cardiopulmonary bypass were included in the analysis. Eligible patients were aged ≥60 years and received cardiopulmonary bypass (CPB)-supported cardiac surgery. Reasons for exclusion included missing data on cardiopulmonary bypass (n = 2) and missing data on albumin, height, or body weight. A total of 41 patients were excluded due to these missing data criteria, accounting for overlapping cases with multiple missing variables. On the basis of its retrospective design and use of anonymized data, this study received ethical clearance (No. KY2024-043-01) from the institutional ethics committee with an accompanying waiver of informed consent. The flow diagram for the enrollment of this population is presented in Fig. 1.

2.2 Assessment Method

As a tool for nutritional assessment, the standard GNRI equation, scores were computed based on serum albumin (g/L) and the ratio of actual to ideal body weight (kg), specifically: $1.489 \times \text{albumin} + 41.7 \times (\text{actual weight} / \text{ideal weight})$. Ideal body weight (kg) was derived from the Lorentz equations: for males, (height in cm × 0.75) – 62.5; for females, (height in cm × 0.60) – 40. For any participant whose actual weight surpassed this ideal value, the actual-to-ideal weight ratio used in the GNRI was capped at 1 [12]. Based on their scores, the cohort was categorized into a group with lower nutritional risk (GNRI >92) and a group with higher nutritional risk (GNRI ≤92) [10,13].

2.3 Data Collection and Follow-up

Patient data, comprising baseline demographics and clinical characteristics were systematically obtained from medical records, including male, female, height, weight, age, comorbidities (hypertension, diabetes, atrial fibrillation), preoperative laboratory values (albumin, hemoglobin, platelet count), ejection fraction, and operative parameters (cardiopulmonary bypass and cross-clamp time). Follow-up extended for a median of 7.2 years, combining electronic medical record reviews and structured telephone interviews to evaluate long-term cardiovascular mortality. Cardiovascular mortality was rigorously defined

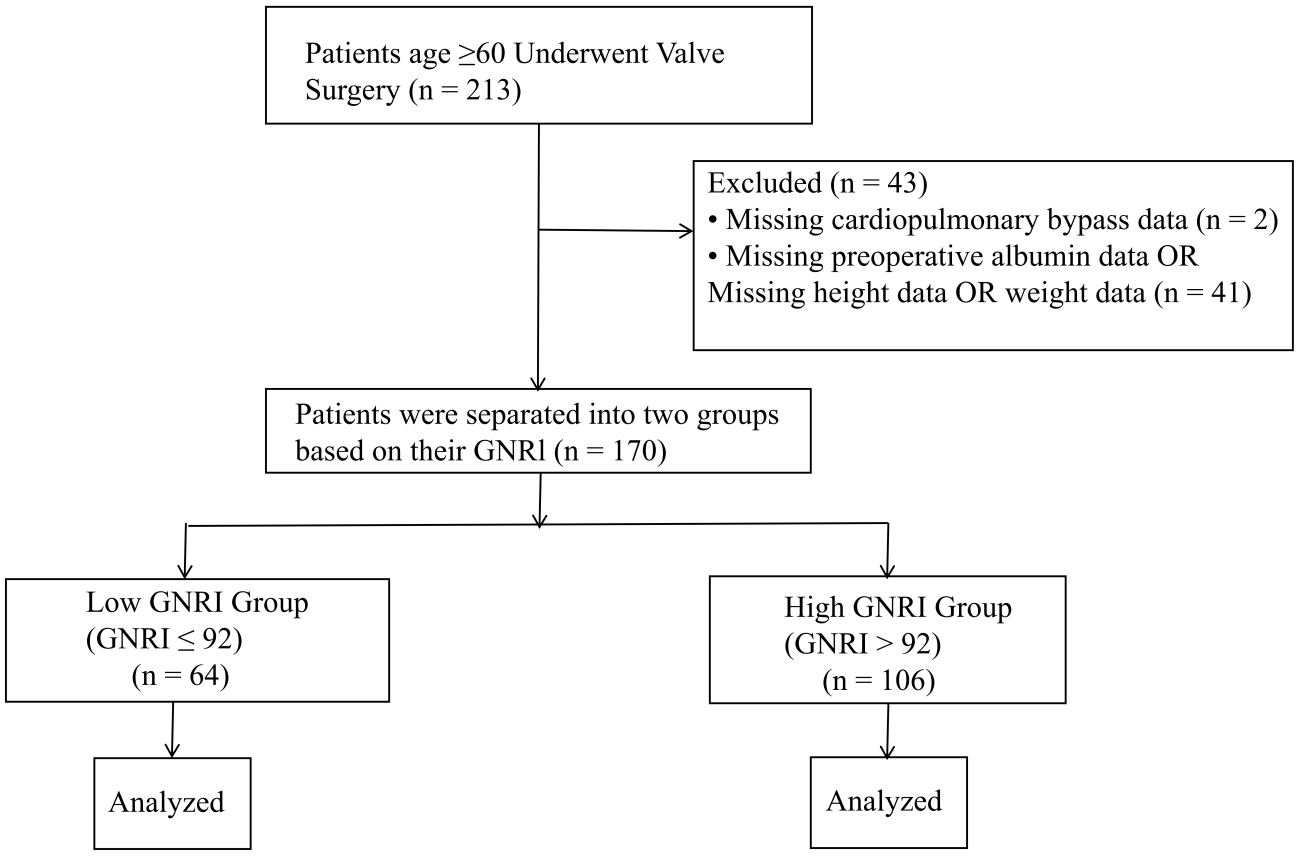

Fig. 1. Patient flow diagram. GNRI, Geriatric Nutritional Risk Index.

according to contemporary standards [14–16], including deaths attributable to: (1) acute myocardial infarction; (2) progressive heart failure; (3) sudden cardiac death; and (4) fatal malignant arrhythmias. An independent endpoint adjudication committee comprising two board-certified cardiologists reviewed all available clinical documentation, including hospital records, laboratory results, and death certificates. In cases of disagreement, a third senior cardiologist provided final arbitration. Survival duration was computed from surgery until cardiovascular death or the study's conclusion (July 1, 2021). Patient survival status was diligently ascertained via telephone by a team of well-trained researchers. In cases where patients had expired, the date and circumstances of death were meticulously documented. Duration of survival was calculated using a time-to-event analysis, spanning from the index cardiac procedure to the first occurrence of either death (all-cause) or the study termination date (July 1, 2021).

2.4 Data Analysis

For normally distributed continuous variables, data were presented as the mean ± standard. Data with a non-normally distributed data were summarized as median and interquartile range. We expressed categorical variables in terms of frequencies and percentages. Between-group comparisons for continuous variables employed independent *t*-tests, whereas associations between categorical variables were analyzed using Chi-square or Fisher's exact tests as indicated. Missing data were addressed via Multiple Imputation by Chained Equations (MICE), utilizing a Random Forest algorithm for imputation. We employed a hierarchical modeling approach, using three sequential Cox regression models, to examine the link of GNRI to cardiovascular death over the long term: Model 1: unadjusted; Model 2: With adjustment for gender, age, hypertension, diabetes, atrial fibrillation, preoperative hemoglobin, preoperative platelet count, and left ventricular ejection fraction; Model 3: Further adjusted for the durations of cardiopulmonary bypass and aortic cross-clamping. The functional form of the GNRI-mortality relationship was characterized using restricted cubic splines within the Cox framework. The Kaplan–Meier method was used to estimate survival, followed by group comparisons with the log-rank test. Associations are quantified using hazard ratios (HR), which were reported alongside 95% confidence intervals (CI). Analyses included subgroup assessments to verify the robustness of the GNRI-mortality relationship in various clinical strata. For all hypotheses tested, results were considered statistically significant if the two-tailed *p*-value was below 0.05.

3. Outcomes

3.1 Baseline Features

For analytical purposes, we stratified patients into two nutritional risk categories using established GNRI score thresholds: $\leq$92 and $>$92. The categories demonstrated significant disparities ($p < 0.05$) in age, weight, hypertension, preoperative albumin, preoperative hemoglobin, left ventricular ejection fraction, intensive care unit (ICU) stay, postoperative hospitalization, and long-term cardiovascular mortality. In contrast, demographic and clinical factors including gender, height, diabetes, atrial fibrillation, preoperative platelet count, operative times (cardiopulmonary bypass and aortic cross-clamp), mechanical ventilation duration, in-hospital death, and discharge follow-up days were comparable across the groups ($p > 0.05$) (Table 1).

3.2 Cox Univariate Regression Analysis

Univariate Cox regression revealed that a high GNRI (HR: 0.42, 95% CI: 0.23–0.79, $p = 0.007$), older age (HR: 1.09, 95% CI: 1.01–1.17, $p = 0.023$), lower left ventricular ejection fraction (HR: 0.97, 95% CI: 0.95–0.99, $p = 0.005$), and longer cardiopulmonary bypass time (HR: 1.01, 95% CI: 1.00–1.01, $p < 0.001$) were linked to cardiovascular mortality over the long term (Table 2).

3.3 Multivariate Cox Regression Models

A quantitative link between the GNRI, measured on a continuous scale, and long-term cardiovascular mortality was established (change per 1 standard deviation (SD), HR: 0.59, 95% CI: 0.38–0.90, $p = 0.015$) and (change per 10, HR: 0.49, 95% CI: 0.28–0.87, $p = 0.015$). Patients categorized in the higher GNRI group exhibited a significantly reduced risk of long-term cardiovascular mortality compared to those in the lower group (HR: 0.38, 95% CI: 0.18–0.81, $p = 0.012$) in Model 2 (Table 3).

3.4 Restricted Cubic Splines (RCS) Investigation

An approximately linear relationship between GNRI and long-term cardiovascular mortality was observed, as assessed by RCS modeling (p for nonlinearity $= 0.274$) (Fig. 2).

3.5 Subgroup Analyses

We performed subgroup analyses to confirm the stability of our results from the fully adjusted Cox multivariate regression Model 3. These analyses stratified the cohort by several prespecified factors, including age, gender, hypertension, atrial fibrillation as a comorbidity, combined with valvular operations (mitral or aortic). These analyses attempted to investigate potential interactions among GNRI and long-term cardiovascular deaths and to identify any biases in different population groups. GNRI had a more significant effect on long-term mortality in the population without hypertension, with no significant interaction detected in other subgroups (Fig. 3), confirming the consistent and reliable results of the other subgroup analyses ($p > 0.05$).

Table 1. Baseline profile of the enrolled patients.

Characteristic	Overall (n = 170)	Low group (n = 64)	High group (n = 106)	*p*
Gender				0.177
Female	75 (44.12)	24 (37.50)	51 (48.11)	
Male	95 (55.88)	40 (62.50)	55 (51.89)	
Age (years)	67.00 (66.00–70.00)	68.50 (66.75–71.25)	67.00 (65.00–69.00)	<0.001
Height (cm)	160.00 (155.00–168.00)	163.00 (156.00–170.00)	160.00 (155.00–168.00)	0.621
Weight (kg)	57.97 ± 10.73	53.69 ± 9.96	60.56 ± 10.38	<0.001
Hypertension				0.033
No	125 (73.53)	53 (82.81)	72 (67.92)	
Yes	45 (26.47)	11 (17.19)	34 (32.08)	
Diabetes				0.749
No	158 (92.94)	60 (93.75)	98 (92.45)	
Yes	12 (7.06)	4 (6.25)	8 (7.55)	
Atrial fibrillation				0.313
No	117 (68.82)	47 (73.44)	70 (66.04)	
Yes	53 (31.18)	17 (26.56)	36 (33.96)	
Preoperative ALB (g/L)	36.24 ± 4.38	32.61 ± 3.38	38.44 ± 3.33	<0.001
Preoperative HGB (g/L)	130.00 (118.00–138.00)	123.50 (108.75–134.50)	132.00 (123.00–139.75)	0.003
Preoperative PLT (10^9/L)	164.00 (136.25–199.75)	167.00 (133.50–207.50)	162.00 (138.00–191.00)	0.723
LVEF	63.50 (57.00–69.00)	60.50 (48.75–68.00)	65.00 (60.00–69.00)	0.006
GNRI	93.74 (89.20–97.76)	87.72 (80.53–90.02)	96.84 (94.06–100.37)	<0.001
CPB time (min)	127.00 (97.50–164.00)	134.50 (97.00–164.25)	126.00 (104.50–159.50)	0.988
Aortic cross-clamp	87.50 (64.25–113.75)	86.50 (59.25–114.25)	88.00 (65.00–112.50)	0.903
Time (min)				
MV time (hours)	21.00 (14.00–43.75)	23.00 (16.25–66.25)	21.00 (13.25–34.00)	0.082
ICU stay (hours)	65.00 (40.25–137.00)	89.50 (45.00–165.00)	50.00 (27.25–111.50)	0.022
Postoperative hospital stay (days)	16.00 (9.25–25.00)	20.00 (9.75–31.25)	15.00 (9.25–21.00)	0.011
In-hospital death				0.154
No	162 (95.29)	59 (92.19)	103 (97.17)	
Yes	8 (4.71)	5 (7.81)	3 (2.83)	
Days of follow-up	2831.00 (2725.50–2938.25)	2843.50 (2071.00–2934.75)	2810.50 (2733.25–2939.75)	0.962
Cardiovascular mortality in long-term follow-up				0.003
No	130 (76.47)	41 (64.06)	89 (83.96)	
Yes	40 (23.53)	23 (35.94)	17 (16.04)	

ALB, albumin; HGB, hemoglobin; PLT, blood platelet; LVEF, left ventricular ejection fraction; GNRI, Geriatric Nutritional Risk Index; CPB, cardiopulmonary bypass; MV, mechanical ventilation; ICU, intensive care unit.

3.6 Kaplan–Meier Curve

A significantly reduction in survival probability was observed in patients with GNRI ≤92 relative to their counterparts with GNRI >92, as illustrated by the Kaplan–Meier curves in Fig. 4 (log-rank $p = 0.0057$).

4. Discussion

This study of elderly patients following valve surgery demonstrated that a lower preoperative GNRI was independently and significantly linked to a higher long-term risk of cardiovascular death. With a median 7.2 years follow-up, our findings provide compelling evidence that impaired nutritional status is substantially associated with adverse late cardiovascular outcomes in this vulnerable patient population.

Our results are consistent with, but substantially extend, previous reports investigating GNRI in cardiac surgery populations. Prior studies in transcatheter and surgical aortic valve replacement (transcatheter aortic valve implantation (TAVI) and surgical aortic valve replacement (SAVR), respectively) cohorts have demonstrated associations between GNRI and mid-term outcomes [6,9,17,18]. However, these investigations were characterized by considerably shorter follow-up periods, typically ranging from 2.7 to 4.5 years [6,9,11]. The consistent relationship observed across various cardiac procedures, including TAVI, SAVR, and coronary artery bypass grafting, suggests that association between nutritional status and cardiovascular mortality represents a fundamental biological relationship independent of the specific type of intervention. Impor-

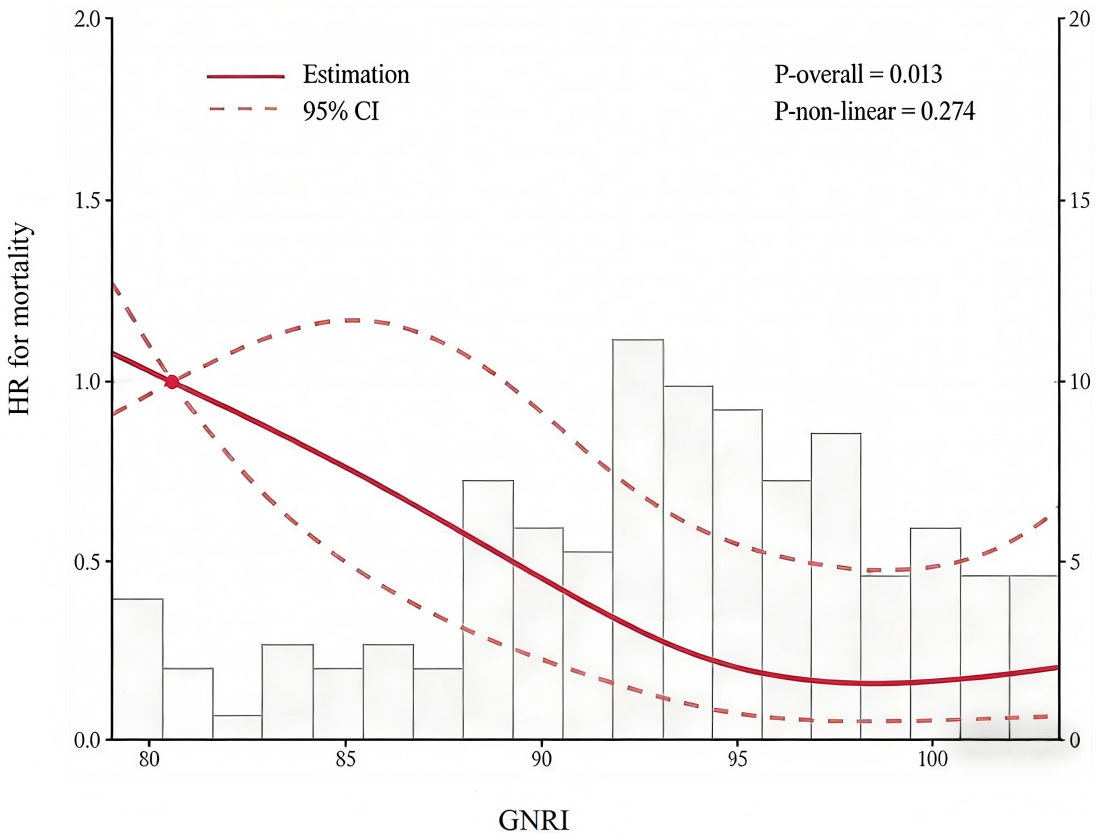

Fig. 2. RCS curve of GNRI for long-term follow-up cardiovascular mortality. GNRI, Geriatric Nutritional Risk Index; RCS, restricted cubic splines; CI, confidence interval.

Table 2. Univariate Cox regression analyses identified association of cardiovascular deaths.

Variables	HR	95% CI	*p*-value
GNRI			
Low	ref	ref	ref
High	0.42	0.23–0.79	0.007
Male	1.53	0.80–2.93	0.199
Age	1.09	1.01–1.17	0.023
Height	1.01	0.97–1.05	0.713
Weight	1.01	0.98–1.04	0.511
Hypertension	1.21	0.62–2.39	0.574
Diabetes	0.67	0.16–2.79	0.585
Atrial fibrillation	1.10	0.57–2.13	0.779
Preoperative HGB	0.99	0.97–1.01	0.258
Preoperative PLT	1.00	1.00–1.01	0.670
LVEF	0.97	0.95–0.99	0.005
CPB time (min)	1.01	1.00–1.01	<0.001

HR, hazard ratio; 95% CI, 95% confidence interval; GNRI, Geriatric Nutritional Risk Index; HGB, hemoglobin; PLT, blood platelet; LVEF, left ventricular ejection fraction; CPB, cardiopulmonary bypass.

tantly, our study demonstrates that this association remains robust beyond seven years of follow-up, representing the longest observation period reported in this clinical context.

The pathophysiological pathway underlying the link between malnutrition and increased long-term cardiovascular mortality likely involves a cascade of interconnected biological processes. Malnutrition initiates a state of chronic low-grade inflammation, which subsequently promotes muscle protein catabolism and cardiac cachexia, ultimately leading to progressive myocardial dysfunction [13,19]. Concurrently, hypoalbuminemia compromises the capacity for tissue repair, immune competence, and antioxidant defense mechanisms [6,11]. This multifaceted physiological deterioration significantly diminishes patients' stress tolerance and functional reserve, creating a vulnerable clinical phenotype that is less capable of withstanding the long-term challenges of cardiovascular disease progression and age-related physiological decline.

The robust relationship between GNRI and cardiovascular mortality, maintained throughout 7.2-year follow-up period, highlights the essential role of systematic nutritional evaluation during the preoperative assessment for elderly patients undergoing heart surgery. GNRI provides an efficient method for stratifying patients at elevated risk for late cardiovascular mortality, who may benefit from optimized long-term management strategies. These should include protocol-driven nutritional support, vigilant monitor-

Table 3. Multivariate Cox regression analyses for cardiovascular deaths.

Variables	Crude model		Model 1		Model 2	
	HR (95% CI)	*p*-value	HR (95% CI)	*p*-value	HR (95% CI)	*p*-value
GNRI (Per 1 SD)	0.67 (0.50–0.90)	0.007	0.64 (0.42–0.96)	0.32	0.59 (0.38–0.90)	0.015
GNRI (Per 10 SD)	0.59 (0.40–0.86)	0.007	0.55 (0.32–0.95)	0.32	0.49 (0.28–0.87)	0.015
GNRI						
Low group	ref		ref		ref	
High group	0.42 (0.23–0.79)	0.007	0.38 (0.18–0.81)	0.012	0.38 (0.18–0.81)	0.012

Crude model: Without any adjustment.

Model 1: With adjustment for male, age, hypertension, diabetes, atrial fibrillation, preoperative HGB, preoperative PLT and LVEF.

Model 2: Adjusted for Model I+CPB time and aortic cross-clamp time.

HR, hazard ratio; 95% CI, 95% confidence interval; SD, standard deviation; GNRI, Geriatric Nutritional Risk Index; HGB, hemoglobin; PLT, blood platelet; LVEF, left ventricular ejection fraction; CPB, cardiopulmonary bypass.

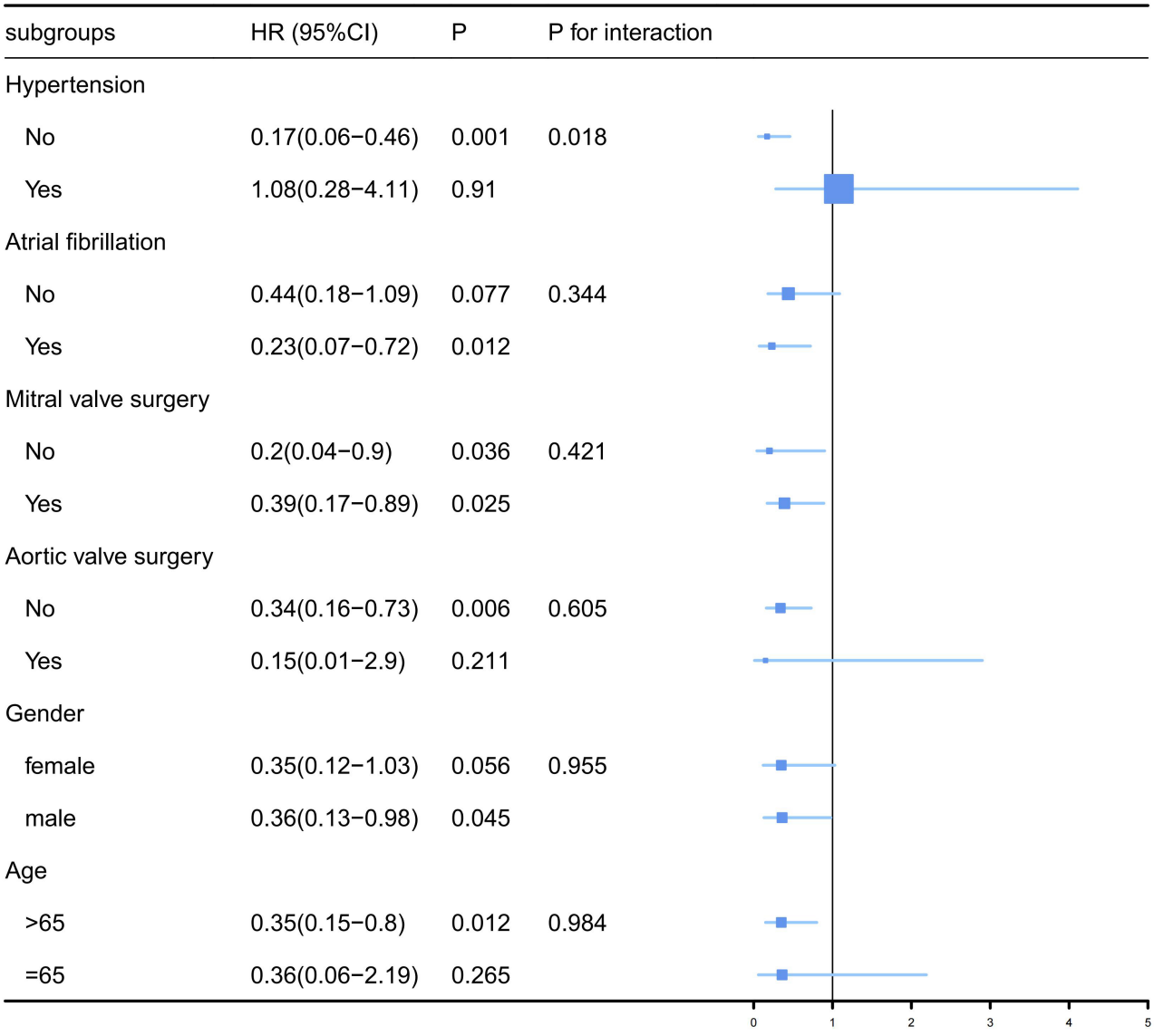

Fig. 3. Subgroup assessment of the connection between GNRI and cardiovascular deaths.

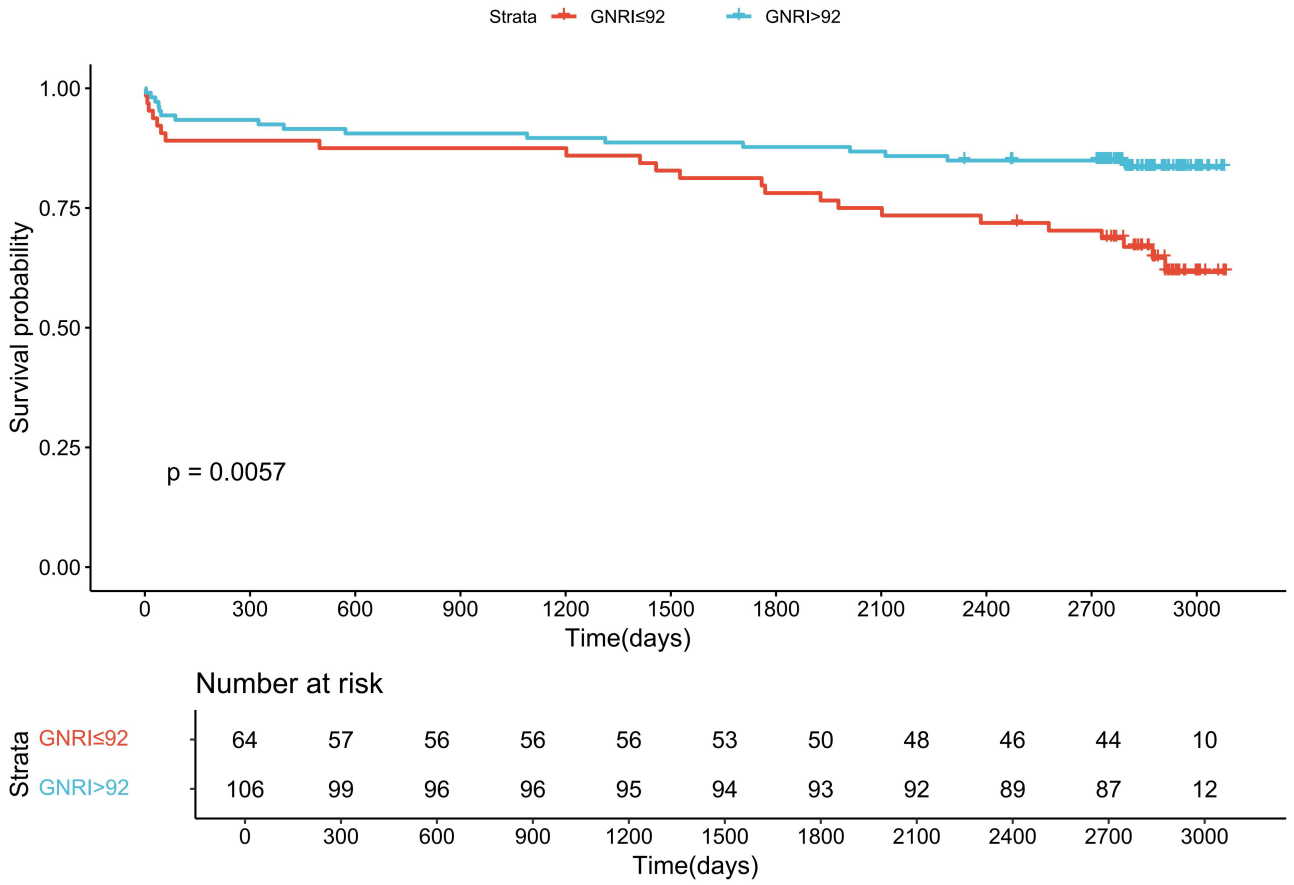

Fig. 4. Long-term cardiovascular survival stratified by GNRI category (Kaplan–Meier analysis). The solid blue line represents patients with GNRI >92, while the red dashed line corresponds to those with GNRI ≤92.

ing, and sustained cardiac rehabilitation programs that extend well beyond the conventional postoperative care stage.

Several constraints in our study design warrant consideration during results interpretation. The retrospective, single-institution nature combined with a limited cohort size (n = 170) could lead to selection bias and constrain the external validity of our conclusions. Additionally, determination of mortality relied on electronic medical records and telephone follow-up, and only four confirmed non-cardiovascular deaths were identified. Given the limited number of competing events, we utilized standard Cox proportional hazards models rather than competing risk analyses, as the latter approach would have generated hazard ratios with excessively wide confidence intervals, potentially compromising the statistical reliability of our conclusions. Future prospective studies with larger multicenter cohorts and more rigorous cause-specific mortality adjudication would help strengthen the evidence base for these observations.

5. Conclusions

This investigation establishes GNRI as an independent factor associated with long-term cardiovascular mortality in elderly valve surgery recipients, with 7.2-year, follow-up data representing the longest observation period reported in this population. Preoperative nutritional status emerges as a persistent determinant of late cardiovascular outcomes, supporting the value of nutritional assessment as an essential element in the multidisciplinary management of elderly surgical populations.

Availability of Data and Materials

All datasets generated and analyzed in this study are contained in this published article.

Author Contributions

CJZ: designed the study, data analysis, revised the manuscript; HLH: Conceptualization and Writing original draft; QL: data analysis, Writing & editing; RXB and SML: data curation, Writing & editing. XLG and QFL: contributed to follow-up data collection, patient tracking, outcome verification, and manuscript editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript to be submitted. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the guidelines of the Helsinki Declaration, and the study protocol was approved by the Research Ethics Committee of the Guangdong Provincial People's Hospital in September 2024 with code No. KY2024-043-01. The institutional review board waived the requirement for informed consent for this retrospective, anonymized study.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Vervoort D, Meuris B, Meyns B, Verbrugghe P. Global cardiac surgery: Access to cardiac surgical care around the world. The Journal of Thoracic and Cardiovascular Surgery. 2020; 159: 987–996.e6. https://doi.org/10.1016/j.jtcvs.2019.04.039.

[2] Shaw AD, Guinn NR, Brown JK, Arora RC, Lobdell KW, Grant MC, *et al*. Controversies in enhanced recovery after cardiac surgery. Perioperative Medicine (London, England). 2022; 11: 19. https://doi.org/10.1186/s13741-022-00250-7.

[3] Norman K, Haß U, Pirlich M. Malnutrition in Older Adults-Recent Advances and Remaining Challenges. Nutrients. 2021; 13: 2764. https://doi.org/10.3390/nu13082764.

[4] Rasheedy D, El-Kawaly WH. The accuracy of the Geriatric Nutritional Risk Index in detecting frailty and sarcopenia in hospitalized older adults. Aging Clinical and Experimental Research. 2020; 32: 2469–2477. https://doi.org/10.1007/s40520-020-01492-5.

[5] Bihari S, Bannard-Smith J, Bellomo R. Albumin as a drug: its biological effects beyond volume expansion. Critical Care and Resuscitation. 2020; 22: 257–265. https://doi.org/10.1016/S1441-2772(23)00394-0.

[6] Gürbak İ, Güner A, Güler A, Şahin AA, Çelik Ö, Uzun F, *et al*. Prognostic influence of objective nutritional indexes on mortality after surgical aortic valve replacement in elderly patients with severe aortic stenosis (from the nutrition-SAVR trial). Journal of Cardiac Surgery. 2021; 36: 1872–1881. https://doi.org/10.1111/jocs.15434.

[7] Lu H, Claggett BL, Minamisawa M, Ostrominski JW, Foà A, Pabón MA, *et al*. Prognostic Significance of Nutritional Scores in Patients With Heart Failure: Insights From the PARAGON-HF Trial. Journal of the American Heart Association. 2025; 14: e038872. https://doi.org/10.1161/JAHA.124.038872.

[8] Anzaki K, Kanda D, Ikeda Y, Takumi T, Tokushige A, Ohmure K, *et al*. Impact of Malnutrition on Prognosis and Coronary Artery Calcification in Patients with Stable Coronary Artery Disease. Current Problems in Cardiology. 2023; 48: 101185. https://doi.org/10.1016/j.cpcardiol.2022.101185.

[9] Naganuma M, Kudo Y, Suzuki N, Masuda S, Nagaya K. Effect of malnutrition and frailty status on surgical aortic valve replacement. General Thoracic and Cardiovascular Surgery. 2022; 70: 24–32. https://doi.org/10.1007/s11748-021-01667-5.

[10] Pavone N, Cammertoni F, Bruno P, Cutrone G, Chiariello GA, Calabrese M, *et al*. Does a Poor Preoperative Nutritional Status Impact outcomes of Heart Valve Surgery? The Journal of Frailty & Aging. 2024; 13: 501–506. https://doi.org/10.14283/jfa.2024.54.

[11] Luo P, Shi K, Luo Y, Ren HB. Prognostic value of the Geriatric Nutritional Risk Index in patients undergoing cardiac surgery: a systematic review and meta-analysis. Frontiers in Nutrition. 2025; 12: 1628671. https://doi.org/10.3389/fnut.2025.1628671.

[12] Yan D, Shen Z, Zhang S, Hu L, Sun Q, Xu K, *et al*. Prognostic values of geriatric nutritional risk index (GNRI) and prognostic nutritional index (PNI) in elderly patients with Diffuse Large B-Cell Lymphoma. Journal of Cancer. 2021; 12: 7010–7017. https://doi.org/10.7150/jca.62340.

[13] Nakamura T, Haraguchi Y, Matsumoto M, Ishida T, Momomura SI. Prognostic impact of malnutrition in elderly patients with acute myocardial infarction. Heart and Vessels. 2022; 37: 385–391. https://doi.org/10.1007/s00380-021-01922-y.

[14] STARSurg Collaborative, EuroSurg Collaborative. Impact of postoperative cardiovascular complications on 30-day mortality after major abdominal surgery: an international prospective cohort study. Anaesthesia. 2024; 79: 715–724. https://doi.org/10.1111/anae.16220.

[15] Hicks KA, Mahaffey KW, Mehran R, Nissen SE, Wiviott SD, Dunn B, *et al*. 2017 Cardiovascular and Stroke Endpoint Definitions for Clinical Trials. Circulation. 2018; 137: 961–972. https://doi.org/10.1161/CIRCULATIONAHA.117.033502.

[16] Khan MS, Usman MS, Van Spall HGC, Greene SJ, Baqal O, Felker GM, *et al*. Endpoint adjudication in cardiovascular clinical trials. European Heart Journal. 2023; 44: 4835–4846. https://doi.org/10.1093/eurheartj/ehad718.

[17] Seoudy H, Al-Kassou B, Shamekhi J, Sugiura A, Frank J, Saad M, *et al*. Frailty in patients undergoing transcatheter aortic valve replacement: prognostic value of the Geriatric Nutritional Risk Index. Journal of Cachexia, Sarcopenia and Muscle. 2021; 12: 577–585. https://doi.org/10.1002/jcsm.12689.

[18] Koseki K, Yoon SH, Kaewkes D, Koren O, Patel V, Kim I, *et al*. Impact of the Geriatric Nutritional Risk Index in Patients Undergoing Transcatheter Aortic Valve Implantation. The American Journal of Cardiology. 2021; 157: 71–78. https://doi.org/10.1016/j.amjcard.2021.07.016.

[19] Verwijmeren L, Noordzij PG, Daeter EJ, Emmelot-Vonk MH, Vernooij LM, van Klei WA, *et al*. Preoperative frailty and one-year functional recovery in elderly cardiac surgery patients. The Journal of Thoracic and Cardiovascular Surgery. 2023; 166: 870–878.e6. https://doi.org/10.1016/j.jtcvs.2022.01.032.