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Original Article

Association of Sarcopenia, as Defined Based on the Skeletal Muscle Index, With Mortality and Morbidity After Cardiac Surgery: A Retrospective Cohort Study

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Objective: To investigate whether "sarcopenia," defined based on the preoperative skeletal muscle index (SMI), can predict major postoperative morbidity and all-cause mortality.
Design: A retrospective observational cohort study.
Setting: At the authors' Department of Critical Care Medicine.
Participants: A total of 986 adult Chinese patients underwent cardiac surgery (coronary artery bypass graft, valve surgery, combined surgery, or aortic surgery) between January 2019 and August 2022.
Measurements and Main Results: The skeletal muscle area at the third lumbar level (L3) was measured via preoperative computed tomography (up to 3 months from the date of imaging to the date of surgery) and normalized to patient height (skeletal muscle index). Sarcopenia was determined based on the skeletal muscle index being in the lowest sex-specific quartile. The primary outcome was all-cause mortality. The secondary outcome was major morbidity. A total of 968 patients were followed for a median of 2.00 years, ranging from 1.06 to 2.90 years. After the follow-up, 76 patients died during the follow-up period. Multivariate Cox proportional analysis showed a relationship between sarcopenia (adjusted hazard ratio 1.80, 95% CI 1.04-3.11; p = 0.034) and all-cause mortality. Kaplan–Meier curves revealed a significantly lower survival rate in the sarcopenia group than in the nonsarcopenia group. Overall, 199 (20.6%) patients had major morbidity. Multivariate analysis showed a significant relationship between sarcopenia (adjusted odds ratio = 2.21, 95% CI 1.52∼3.22, p < 0.001) and major morbidity.
Conclusions: Sarcopenia, defined by the skeletal muscle index, is associated with all-cause mortality and major morbidity after cardiac surgery, thereby suggesting the need for perioperative sarcopenia risk assessment for patients undergoing cardiac surgery to guide the prevention and management of adverse outcomes.

Key Words: sarcopenia; cardiovascular surgery patients; all-cause mortality; morbidity; skeletal muscle index

CARDIOVASCULAR DISEASE is a major global health burden and a leading cause of mortality and morbidity.[1,2] In addition, the aging of the population has led to an increased number of older patients undergoing cardiac surgery, significantly increasing the rate of perioperative adverse events.[3] However, in recent years, improvements in cardiac surgical techniques, anesthesia management, and postoperative care in

Guanglei Fan, Baohe Zang, and Yuhan Qiao contributed equally to the work.

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the intensive care unit have provided various options for preventing and treating adverse postoperative outcomes, making perioperative risk identification more important for physicians. Traditional surgical risk scoring systems, including the Society of Thoracic Surgeons score[4] and the American Society of Anesthesiologists (ASA) class,[5] may lack important information about physiologic status, whereas frailty assessment can provide this information.

Sarcopenia is an age- and disease-related clinical syndrome characterized by a generalized decrease in muscle mass and strength, with or without physical dysfunction, that leads to increased mortality and complication rates in postoperative patients.[6,7] In recent years, there have been more epidemiologic investigations and studies of sarcopenia in the Chinese population, and the data show that the prevalence of sarcopenia in the community-aged population ranges from 8.9% to 38.8%.[8] Sarcopenia is one of the physiologic phenotypes of frailty, and is closely related to frailty.[9] In clinical practice, frailty is often described as a reduction in the physiologic reserve of multiple organ systems,[10] which is a missing factor in current risk models. However, the preoperative assessment of frailty is multifaceted (weight change, decreased mobility, fatigue, muscle strength, activity level, etc),[11] and subjective, time-consuming assessments rarely are performed perioperatively by surgeons. Assessment of sarcopenia is based on preoperative abdominal computed tomography (CT) measurements of the psoas major muscle area or total skeletal muscle area at the level of the third lumbar vertebra (L3), which are objective and easy to obtain.[12]

Sarcopenia has been studied extensively in recent years as a potentially harmful disease or condition associated with increased postoperative mortality, morbidity, and length of hospital stay in patients undergoing major general surgery.[13-15] However, although there have been many studies on the adverse consequences of sarcopenia after cardiac surgery, most of those studies involved a small sample of patients and have focused mostly on heart valve surgery. The aim of this study was to investigate whether sarcopenia in many patients who underwent cardiac surgery could help predict postoperative morbidity and mortality.

Methods

Study Population

The Medical Ethics Committee of the Affiliated Hospital of Xuzhou Medical University approved this registry study (XYFY2023-KL044-01). The study has been filed with the China Clinical Trial Registry (ChiCTR2300072633). The information in this manuscript was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology statement guidelines.

The study authors included consecutive adult patients (≥18 years of age) who underwent cardiac surgery in the cardiovascular surgery unit between January 2019 and August 2022. They did not include patients who did not undergo abdominal CT within 3 months before surgery (preoperative abdominal CT data in this study were obtained from a full aortic CT angiography [CTA] examination because such an examination was not performed for research purposes due to its high risks. Most of those excluded were patients with congenital heart disease, as these patients did not undergo preoperative CTA. Full aortic CTA is needed to determine the need for surgery, as surgeons need to rule out dissecting aneurysms and explore aortic calcification preoperatively to determine surgical feasibility and the appropriate procedures.), patients with preoperative severe liver and kidney dysfunction, patients who underwent preoperative pacemaker implantation, patients with preoperative of infections, and patients who underwent preoperative intra-aortic balloon pump or mechanical ventilation because of circulatory instability were excluded also.

Data Collection

General data, including demographic indicators (sex, age, body mass index [BMI], smoking status and alcohol consumption), comorbidities (diabetes mellitus, hypertension, myocardial infarction and heart failure, among others; Supplementary Table S1), laboratory data (hemoglobin, albumin, and creatinine, among others), left ventricular ejection fraction, ASA class, type of surgery, surgical duration, bypass time, and New York Heart Association (NYHA) score, were collected.

Skeletal Muscle Index Measurement

The muscle area was measured and calculated at the third lumbar level (L3) (upper level of the iliac crest) via retrospective analysis of abdominal CT scans using PACS software (up to 3 months from the date of imaging to the date of surgery). At this level, skeletal muscle was identified and quantified by a Hounsfield unit interval of −29 to +150; the skeletal muscle area at the L3 level was measured by freehand mapping techniques (Supplementary Figure S1, which mainly includes the internal oblique, external oblique, transversus abdominis, and rectus abdominis), and height was normalized to obtain the skeletal muscle index (SMI) (cm^2/m^2). Patients were categorized into sex-stratified SMI quartiles, with the lowest quartile defined as sarcopenia. Measurements were performed by a researcher who was blinded to the prognosis of the cardiac patients. The researchers performed independent measurements on a sample of 39 randomly selected scans and assessed interobserver reliability.

Outcome Measures

Patient survival was monitored through August 2023 through telephone interviews or electronic medical records. Survival time was calculated from the date of surgery to the most recent follow-up visit or date of death.

For this study, all-cause mortality was the primary outcome, and the time to the endpoint was calculated as the number of days from the surgery date to the event (all-cause mortality refers to the total number of deaths from all causes over a given period). The secondary outcome was major morbidity during postoperative hospitalization. Major morbidity included acute kidney injury, reexploration for bleeding, acute heart failure, new stroke, pulmonary infection, sepsis, and deep sternal wound infection (Supplementary Table S2).[16,17]

Statistical Analysis

The normality of the data was assessed via visual inspection of histograms and by Shapiro-Wilk's W test. All normally distributed and skewed continuous variables are presented as mean (SD) or median (IQR). Categorical variables are presented as frequencies (%). Continuous variables were compared between groups with the Student's *t* test or the Mann−Whitney *U* test depending on the normality of the distribution, whereas the Fisher exact test was used to compare categorical variables.

The intraclass correlation coefficient for observer agreement with respect to the SMI was calculated, and an intraclass correlation coefficient >0.75 indicated high reliability. In addition, the Bland-Altman agreement was used to analyze the agreement between the 2 measurements, and the mean difference between the 2 indices, and the 95% limits of agreement were calculated.

The study authors included factors with a p value < 0.05 and clinical significance in the one-way regression analysis. Cox proportional hazards regression models were used to estimate the association between sarcopenia and all-cause mortality. The authors used logistic regression to investigate the associations between sarcopenia and major morbidity. Variables with a p value < 0.1 in the univariate analysis were entered into the multivariate regression analysis. Potential multicollinearity was tested using the variance inflation factor, with a variance inflation factor ≥5 indicating the presence of multicollinearity. The associations between the SMI and mortality risk were examined using a Cox regression model adjusted for age, hemoglobin, type of surgery, surgical duration, emergent surgery, and ASA class with spline functions. The principle of 10 events per variable in multivariate analysis was not violated. Long-term survival was estimated via the Kaplan-Meier method, and comparisons between the 2 groups were performed with the log-rank test. The area under the receiver operating characteristic curve was used to assess predictive validity. Subgroup analyses were performed using stratified Cox proportional hazards models. The modifications and interactions of the subgroups were inspected by likelihood ratio tests. To assess the robustness of the results, sensitivity analyses were performed using different statistical methods and outcomes. First, the authors adjusted for confounding factors using a propensity-score matching (PSM) approach; second, they considered patients who died from noncardiac causes as having no outcome event. Kaplan−Meier curves were plotted after PSM, and group comparisons were performed using the adjusted log-rank test.

Because the percentage of missing data was low (0%-6%), no imputation was performed. A p value < 0.05 (2-sided) was considered to indicate statistical significance. R4.1.2 (R Foundation for Statistical Computing) and SPSS 26.0 (IBM SPSS, Inc) statistical software were used for analysis.

Results

Population Characteristics

Of the 968 patients enrolled (Fig 1), 242 (25.0%) had sarcopenia. Preoperative patient characteristics and operative data are shown in Table 1. When the authors categorized the patients into sarcopenia and non-sarcopenia groups, there were more smokers and older patients in the sarcopenia group than in the non-sarcopenia group. In addition, there were more patients with heart failure and NYHA class III disease in the sarcopenia group than in the nonsarcopenia group. However, the number of hypertensive patients and BMI were lower in the sarcopenia group. Tests and examinations indicated that N-terminal prohormone of brain natriuretic peptide levels were significantly higher in the sarcopenia group than in the nonsarcopenia group. In contrast, the serum albumin concentration, hemoglobin level, and left ventricular ejection fraction were significantly lower in the sarcopenia group than in the nonsarcopenia group.

SMI Measurements

The ICC for the measurement of the skeletal muscle indices between the 2 observers was 0.980 (95% CI 0.964-0.989) for the validation sample. The Bland-Altman analysis is shown in Supplementary Figure S2. The bias for the SMI was 0.965 cm^2/m^2 (95% CI 0.562-1.369), and the upper and lower limits of agreement were 3.405 cm^2/m^2 and −1.475 cm^2/m^2, respectively. The mean SMI was 47.2 cm^2/m^2, 41.5 cm^2/m^2 for women, and 50.4 cm^2/m^2 for men. Sarcopenia was diagnosed if the SMI was in the lowest sex-specific quartile, and subjects were categorized as having sarcopenia if their SMI was <36.1 cm^2/m^2 for women and 45.3 cm^2/m^2 for men (Supplementary Figure S3).

Associations of Sarcopenia With Mortality

A total of 968 patients were followed for a median of 2.00 years, ranging from 1.06 to 2.90 years, whereas a total of 14 patients were lost to follow-up. During the follow-up period, 76 patients died (Table 2). According to the univariate Cox proportional analysis, age, hemoglobin level, type of surgery, NYHA score, surgical duration, bypass time, ASA class, and sarcopenia were significantly associated with all-cause mortality. According to the multivariate Cox proportional analysis, age (adjusted hazard ratio [aHR] = 1.05, 95% CI 1.02-1.08; p = 0.002), heart valve surgery (aHR = 2.17, 95% CI 1.26-3.74; p = 0.005), surgical duration (aHR = 1.26, 95% CI 1.11-1.41. p < 0.001), ASA class (aHR = 1.83, 95% CI 1.15-2.9; p = 0.011), and sarcopenia (aHR 1.80, 95% CI 1.04-3.11; p = 0.034) were associated with all-cause mortality (Table 3).

Kaplan−Meier curves revealed that the survival rate was significantly lower in the sarcopenia group than in the nonsarcopenia group (log-rank test, p < 0.001; Fig 2). Similarly, the 90-day and 1-year survival rates were lower in patients with

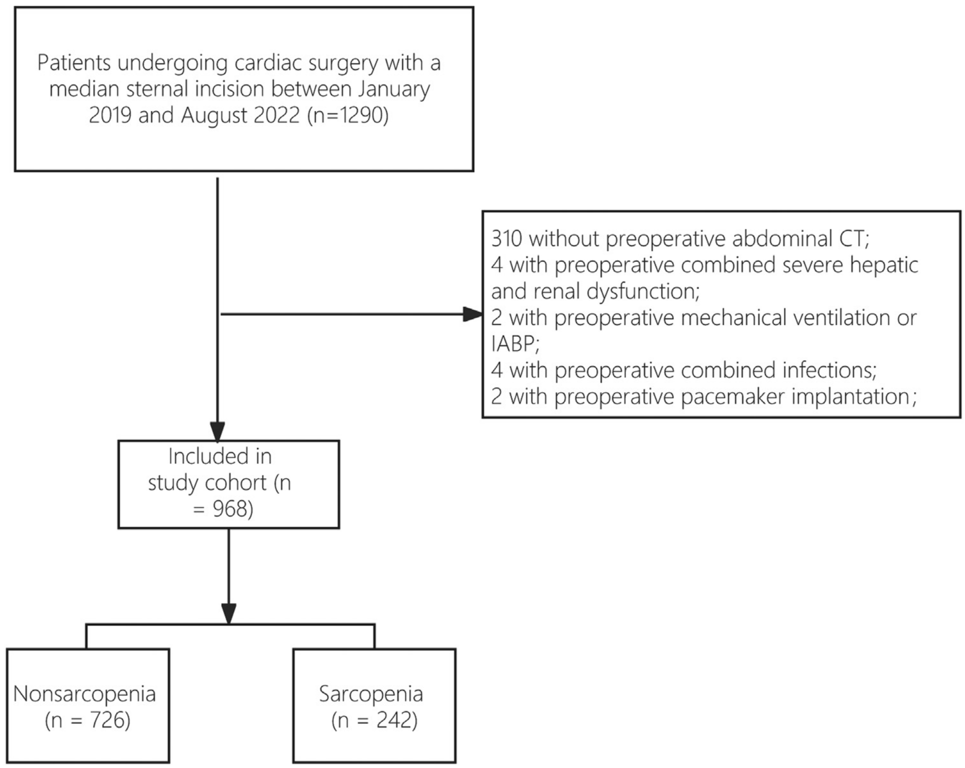

Fig 1. Flow diagram of the study population. CT, computed tomography; IABP, intra-aortic balloon pump.

sarcopenia than in those without sarcopenia (Table 2; Supplementary Figure S4).

To assess the predictive accuracy of sarcopenia status (SMI), ASA class, and age for postoperative all-cause mortality, the authors generated receiver operating characteristic curves and calculated the area under the curve (AUC). ASA + age + SMI had the largest AUC, and there was a statistically significant difference between the AUC predicted by ASA + age and the AUC predicted by ASA + age + SMI (p = 0.024, Z = 2.26). Therefore, the addition of muscle sarcopenia status (SMI) to the traditional risk assessment model (ASA + age) improved the predictive power of postoperative all-cause mortality, with an AUC ranging from 0.655 to 0.718 (Fig 3).

The restricted cubic spline (RCS) showed a linear and negative correlation (p for nonlinearity = 0.181) between SMI and all-cause mortality (Supplementary Fig S5). Exploratory subgroup analyses included age, sex, BMI, hypertension, diabetes status, hemoglobin, and albumin concentration. Multivariate Cox regression was adjusted for age, type of surgery, surgical duration, hemoglobin, emergent surgery, and ASA class. There was no interaction between these variables and all-cause mortality (Fig 4).

Sensitivity Analysis

To adjust for the mismatch between the limited number of events and the large number of confounders, the authors performed a PSM analysis (Fig 2). The differences in the variables after PSM are shown in Supplementary Table S3. After PSM, sarcopenia was associated with all-cause mortality (HR = 2.35, 95% CI 1.12 ∼ 4.96; p = 0.024; Table 4). In addition, the authors considered patients who died from noncardiac causes as having no outcome event, and showed that sarcopenia was an independent risk factor for postoperative all-cause mortality (HR = 1.83, 95% CI 1.05-3.17; p = 0.032; Table 4).

Associations of Sarcopenia With Morbidity

Overall, 199 (20.6%) patients had major morbidity (Table 2). Factors associated with major diseases are shown in Supplementary Table S4. In multivariate analysis, age (adjusted odds ratio [aOR] 1.03, 95% CI 1.01-1.06; p < 0.004), percutaneous coronary intervention (aOR 2.01, 95% CI 1.16-3.49; p = 0.013), ASA class (aOR 2.00, 95% CI 1.41-2.85; p < 0.001), emergency surgery (aOR = 6.14, 95% CI 1.15-32.85; p = 0.034), surgical duration (aOR = 1.33, 95% CI 1.19-1.48; p < 0.001), valve surgery (aOR = 1.75, 95% CI 1.11- 2.77; p = 0.017), valve surgery combined with coronary bypass artery grafting (aOR = 2.71, 95% CI 1.29∼5.68; p = 0.009), and sarcopenia (aOR = 2.21, 95% CI 1.52∼3.22; p < 0.001) were significantly associated with major morbidity.

Discussion

This study showed that sarcopenia (defined as having an SMI in the lowest sex-stratified quartile) was independently associated with all-cause mortality after cardiac surgery. It was also associated with the development of major morbidity. Muscle mass as a new marker of frailty has the advantage that it can be measured easily with good reproducibility and

Table 1
Patient and Operative Characteristics According to Sarcopenia Status

Variables	Total (n = 968)	Nonsarcopenia (n = 726)	Sarcopenia (n = 242)	p Value
Age, mean ± SD, y	62.4 ± 9.3	61.7 ± 9.2	64.4 ± 9.3	< 0.001
Female sex, n (%)	344 (35.5)	254 (35)	90 (37.2)	0.535
BMI, mean ± SD, kg/m^2	24.7 ± 3.5	25.6 ± 3.2	21.9 ± 2.8	< 0.001
Alcohol abuse, n (%)	158 (16.3)	127 (17.5)	31 (12.8)	0.088
Smoking, n (%)	211 (21.8)	170 (23.4)	41 (16.9)	0.035
History, n (%)				
Diabetes	209 (21.6)	153 (21.1)	56 (23.1)	0.499
Hypertension	449 (46.4)	361 (49.7)	88 (36.4)	< 0.001
Heart failure	102 (10.5)	63 (8.7)	39 (16.1)	0.001
MI	134 (13.8)	94 (12.9)	40 (16.5)	0.162
PCI	86 (8.9)	67 (9.2)	19 (7.9)	0.514
Atrial fibrillation	132 (13.6)	94 (12.9)	38 (15.7)	0.279
Stroke	194 (20.0)	136 (18.7)	58 (24)	0.078
COPD	7 (0.7)	5 (0.7)	2 (0.8)	1
CKD	40 (4.2)	25 (3.5)	15 (6.2)	0.063
Hemoglobin, mean ± SD, g/dL	135.7 ± 27.2	137.8 ± 29.3	129.5 ± 18.2	< 0.001
HsTnT, mean ± SD, ng/L	48.6 ± 360.0	43.5 ± 386.2	63.9 ± 268.3	0.452
NT-proBNP, median (IQR), pg/mL	334.0 (116.0-917.5)	286.0 (101.0-831.0)	513.4 (177.5-1419.0)	< 0.001
Albumin, mean ± SD, g/L	42.4 ± 5.0	42.7 ± 4.9	41.6 ± 5.4	0.005
Creatinine, mean ± SD, μmol/L	69.7 ± 33.3	69.5 ± 35.4	70.1 ± 26.3	0.807
ALT, median (IQR), U/L	22.0 (17.0-32.0)	22.0 (17.0-32.0)	23.0 (17.0-33.2)	0.651
AST, median (IQR), U/L	23.0 (16.0-36.0)	23.0 (17.0-37.8)	24.0 (15.0-34.0)	0.418
LVEF, mean ± SD, %	57.5 ± 7.8	57.9 ± 7.5	56.4 ± 8.7	0.007
ASA class				0.092
2	164 (16.9)	130 (17.9)	34 (14)	
3	650 (67.1)	490 (67.5)	160 (66.1)	
4	154 (15.9)	106 (14.6)	48 (19.8)	
NYHA				0.042
2	752 (77.7)	577 (79.5)	175 (72.3)	
3	176 (18.2)	119 (16.4)	57 (23.6)	
4	40 (4.1)	30 (4.1)	10 (4.1)	
Type of surgery				0.328
CABG	544 (56.2)	420 (57.9)	124 (51.2)	
Valve	340 (35.1)	244 (33.6)	96 (39.7)	
CABG + valve	44 (4.5)	33 (4.5)	11 (4.5)	
Aortic	40 (4.1)	29 (4)	11 (4.5)	
Emergent surgery	22 (2.3)	18 (2.5)	4 (1.7)	0.455
Off-pump surgery	372 (38.4)	289 (39.8)	83 (34.3)	0.127
Bypass time, median (IQR), min	70.5 (0.0-125.0)	70.0 (0.0-120.0)	80.0 (0.0-130.0)	0.057
Surgical duration, mean ± SD, h	5.0 ± 1.8	5.0 ± 1.7	4.9 ± 1.9	0.63

The values are presented as numbers and percentages (%) for categorical variables and means (SDs) or medians (IQRs) as appropriate for continuous variables.
Abbreviations: ALT, alanine transaminase; ASA, American Society of Anesthesiologists; AST, aspartate aminotransferase; BMI, body mass index; CABG, coronary artery bypass graft; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; HsTnT, high sensitive troponin T; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NT-proBNP, N-terminal prohormone of brain natriuretic peptide; NYHA, New York Heart Association; PCI, percutaneous coronary intervention.

objectivity from available clinical CT data, regardless of the patient's disease status or physical mobility.

In this single-center retrospective observational study, the study authors assessed sarcopenia using the sum of all muscle areas on the L3 level section of preoperative abdominal CT. This approach may be more accurate and comprehensive than using the psoas region alone. The most appropriate threshold for sarcopenia may vary by race, sex, and age group, making it difficult to provide a universal definition of sarcopenia based on current literature. Therefore, based on the study population of the present cohort, as in previous studies,[13-15] the authors chose the SMI in the lowest quartile by sex as the threshold, resulting in SMI thresholds <45.3 cm^2/m^2 and <36.1 cm^2/m^2 for men and women, respectively; these values were similar to those found in articles published by researchers in Japan and South Korea,[18,19] but much lower than the thresholds found in Western articles on sarcopenia and cancer cachexia.[14,20]

In recent years, an increasing number of studies have shown that skeletal muscle mass is an important indicator of physiologic reserve, and plays a very important role in the body's immunity, inflammation, and exercise tolerance.[21-23] Sarcopenia has been identified as an independent predictor of major morbidity, poor survival, and high hospitalization costs after surgery for malignant tumors.[13-15,20] However, relatively little is known about the impact of sarcopenia on adverse outcomes after cardiac surgery. Okamura et al. showed that sarcopenia,

Table 2
Outcomes by Sarcopenia Status

Variables	Total (n = 968)	Nonsarcopenia (n = 726)	Sarcopenia (n = 242)	p Value
ICU stay, median (IQR), h	17.0 (17.0-18.0)	17.0 (17.0-18.0)	17.0 (17.0-40.0)	< 0.001
Length of stay, median (IQR), d	11.0 (9.0-14.0)	11.0 (9.0-14.0)	12.0 (10.0-14.0)	< 0.001
Prolonged ventilation, n (%)	70 (7.2)	38 (5.2)	32 (13.2)	< 0.001
Reintubation, n (%)	33 (3.4)	15 (2.1)	18 (7.4)	< 0.001
Pulmonary infection, n (%)	101 (10.4)	60 (8.3)	41 (16.9)	< 0.001
Sepsis, n (%)	45 (4.6)	23 (3.2)	22 (9.1)	< 0.001
Sternal wound infection, n (%)	24 (2.5)	19 (2.6)	5 (2.1)	0.633
AKI, n (%)	87 (9.0)	47 (6.5)	40 (16.5)	< 0.001
Reexploration for bleeding, n (%)	29 (3.0)	19 (2.6)	10 (4.1)	0.231
AHF, n (%)	81 (8.4)	38 (5.2)	43 (17.8)	< 0.001
IABP, n (%)	9 (0.9)	3 (0.4)	6 (2.5)	0.01
New stroke, n (%)	14 (1.4)	10 (1.4)	4 (1.7)	0.758
Discharge to facility, n (%)	26 (2.7)	16 (2.2)	10 (4.1)	0.108
Major morbidity, n (%)	199 (20.6)	123 (16.9)	76 (31.4)	< 0.001
In-hospital mortality, n (%)	27 (2.8)	16 (2.2)	11 (4.5)	0.055
90-day mortality, n (%)	54 (5.6)	30 (4.1)	24 (9.9)	< 0.001
1-year mortality, n (%)	59 (6.1)	32 (4.4)	27 (11.2)	< 0.001
All-cause mortality, n (%)	76 (7.9)	43 (5.9)	33 (13.6)	< 0.001

The values are presented as the number (proportion) or median (IQR).
Abbreviations: AHF, acute heart failure; AKI, acute kidney injury; ICU, intensive care unit; IABP, intra-aortic balloon pump.

as defined based on the psoas muscle area, had an effect on the long-term survival of patients who underwent heart valve surgery.[24] However, in their study, the population was 70 years or older, and the only surgery type was heart valve surgery; therefore, their conclusions have limited applicability. Yamashita et al. showed that sarcopenia, as defined based on the psoas major index, was not an independent risk factor for long-term all-cause mortality after cardiac surgery,[25] probably because they used the psoas muscle area rather than the total skeletal muscle area, which does not allow for a comprehensive assessment of the patient's muscle mass. In addition, the diagnostic threshold for sarcopenia in this study was set at a high level, resulting in 50% of patients diagnosed with sarcopenia, which was much higher than the prevalence of sarcopenia in the Asian population (5.5%-25.7%),[26] thus reducing its ability to identify preoperative risk.

Table 3
Cox Proportional Hazards Analysis for Independent Risk Factors for All-Cause Mortality

Variable	Univariate Analysis		Multivariate	
	HR (95% CI)	p Value	Adjusted HR (95% CI)	Adjusted p Value
Age	1.05 (1.02∼1.08)	< 0.001	1.05 (1.02∼1.08)	0.002
BMI	0.94 (0.88∼1.01)	0.071	0.99 (0.91∼1.07)	0.723
Stroke	1.26 (0.74∼2.14)	0.391		
Diabetes	1.04 (0.61∼1.79)	0.878		
Hypertension	1.26 (0.81∼1.97)	0.313		
CKD	2.18 (0.89∼5.38)	0.09		
Hemoglobin	0.99 (0.97∼1)	0.034	1 (0.99∼1.01)	0.718
Albumin	1.01 (0.97∼1.06)	0.663		
LVEF, %	0.98 (0.95∼1.01)	0.108		
Type of surgery				
CABG	Reference		Reference	
Valve	1.23 (0.74∼2.04)	0.417	2.17 (1.26∼3.74)	0.005
CABG + valve	2.25 (0.95∼5.35)	0.066	2.05 (0.8∼5.23)	0.136
Aortic	4.1 (1.97∼8.54)	< 0.001	2.77 (0.82∼9.31)	0.100
Bypass time	1.006 (1.004∼1.008)	< 0.001		
Surgical duration	1.31 (1.19∼1.45)	< 0.001	1.24 (1.1∼1.41)	< 0.001
Off-pump surgery	0.69 (0.42∼1.12)	0.131		
Emergency surgery	4.38 (1.9∼10.08)	< 0.001	0.57 (0.12∼2.69)	0.481
NYHA	1.82 (1.3∼2.54)	< 0.001		
ASA class	2.49 (1.68∼3.69)	< 0.001	1.83 (1.15∼2.9)	0.011
Sarcopenia	2.28 (1.45∼3.58)	< 0.001	1.8 (1.04∼3.11)	0.034

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; CABG, coronary artery bypass graft; CKD, chronic kidney disease; HR, hazard ratio; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

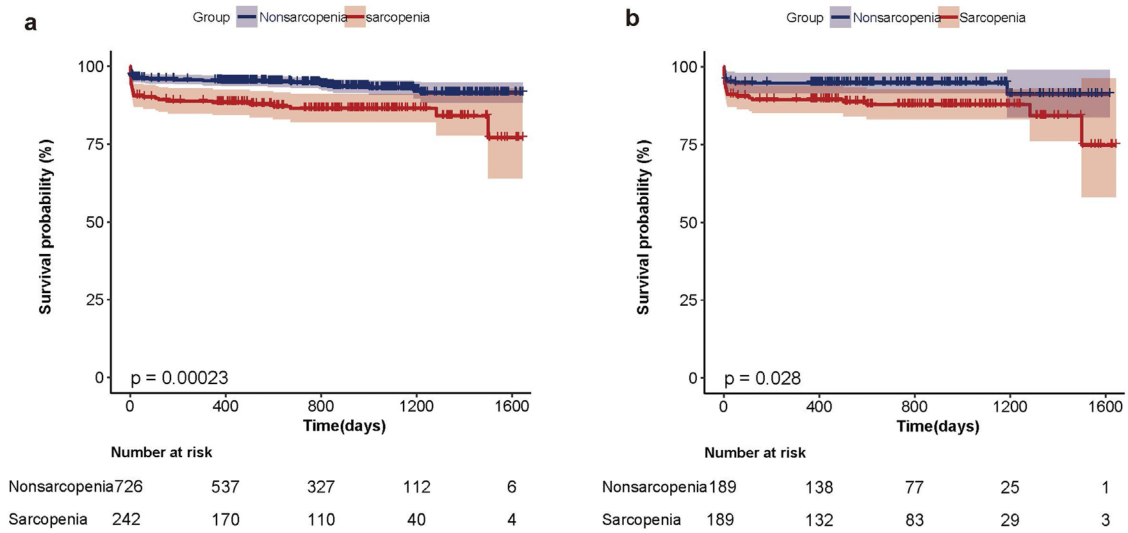

Fig 2. Kaplan−Meier curves of the survival rates of patients who underwent cardiac surgery with or without sarcopenia (with 95% CIs). (A) Unadjusted analysis. (B) Propensity-score matching adjusted analysis.

This study further demonstrated that age and ASA class are independent risk factors for mortality and morbidity in addition to sarcopenia. These metrics are commonly used perioperatively by surgeons to assess surgical risk. This finding suggested that clinicians can incorporate sarcopenia into traditional risk assessment indicators (ASA class + age), which could provide a better understanding of a patient's risk of surgical and anesthetic injuries and thus help to individualize perioperative management strategies preemptively. For example, surgeons can use minimally invasive surgical approaches such as thoracoscopy or intervention to reduce stress[27,28]; additionally, anesthesiologists and critical care physicians can optimize intraoperative monitoring and postoperative care planning throughout the process, with special emphasis on critical organ protection via lung-protective ventilation strategies,[29] cerebral oxygen saturation monitoring,[30] goal-directed fluid therapy,[31] and multimodal analgesia.[32] However, for patients of various ASA classes and ages, which are often unchangeable, the research focus should be variable factors, and sarcopenia has attracted a great deal of interest. The reserve of muscle function can be increased by strengthening nutritional support[33] and functional rehabilitation exercises,[34,35] mainly including supplementing branch-chain amino acids, strengthening pulmonary physical therapy, and functional exercise before and after surgery. Waite et al. showed that providing preoperative rehabilitation to frail patients improved physical mobility and shortened the length of hospital stay in patients who underwent coronary artery bypass grafting or valvular surgery.[36] Overall, sarcopenia is a reversible physiologic state, and its management is an ongoing process throughout the perioperative period that requires the collaboration of a multidisciplinary team and timely interventions to facilitate postoperative recovery and improve patient prognosis.

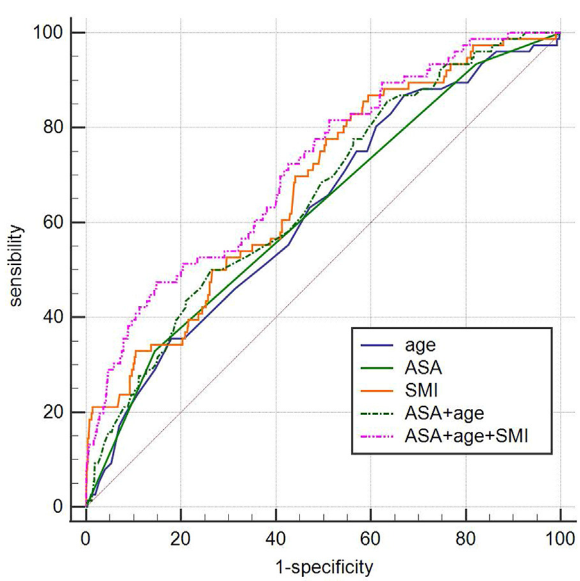

Fig 3. Preoperative risk assessment models for predicting long-term mortality after cardiac surgery. The areas under the curve for American Society of Anesthesiologists (ASA), age, skeletal muscle index, ASA + age, and ASA + age + skeletal muscle index were 0.624 (95% CI, 0.592-0.654), 0.624 (95% CI, 0.593-0.655), 0.676 (95% CI, 0.646-0.706), 0.655 (95% CI, 0.688-0.746), and 0.718 (95% CI, 0.688-0.746). ASA, American Society of Anesthesiologists; SMI, skeletal muscle index.

Strengths and Limitations

Compared with those of previous studies, the strengths of this study included a larger sample size, more types of cardiac surgery, and a wider age range. In addition, this was the first study to examine the association between sarcopenia and morbidity and mortality after cardiac surgery in a Chinese population, and the diagnosis of sarcopenia was based on a more comprehensive skeletal muscle index rather than the psoas index.

This study had several limitations. This was a single-center retrospective study with many unknown confounders, and the conclusions drawn need to be validated by a multicenter,

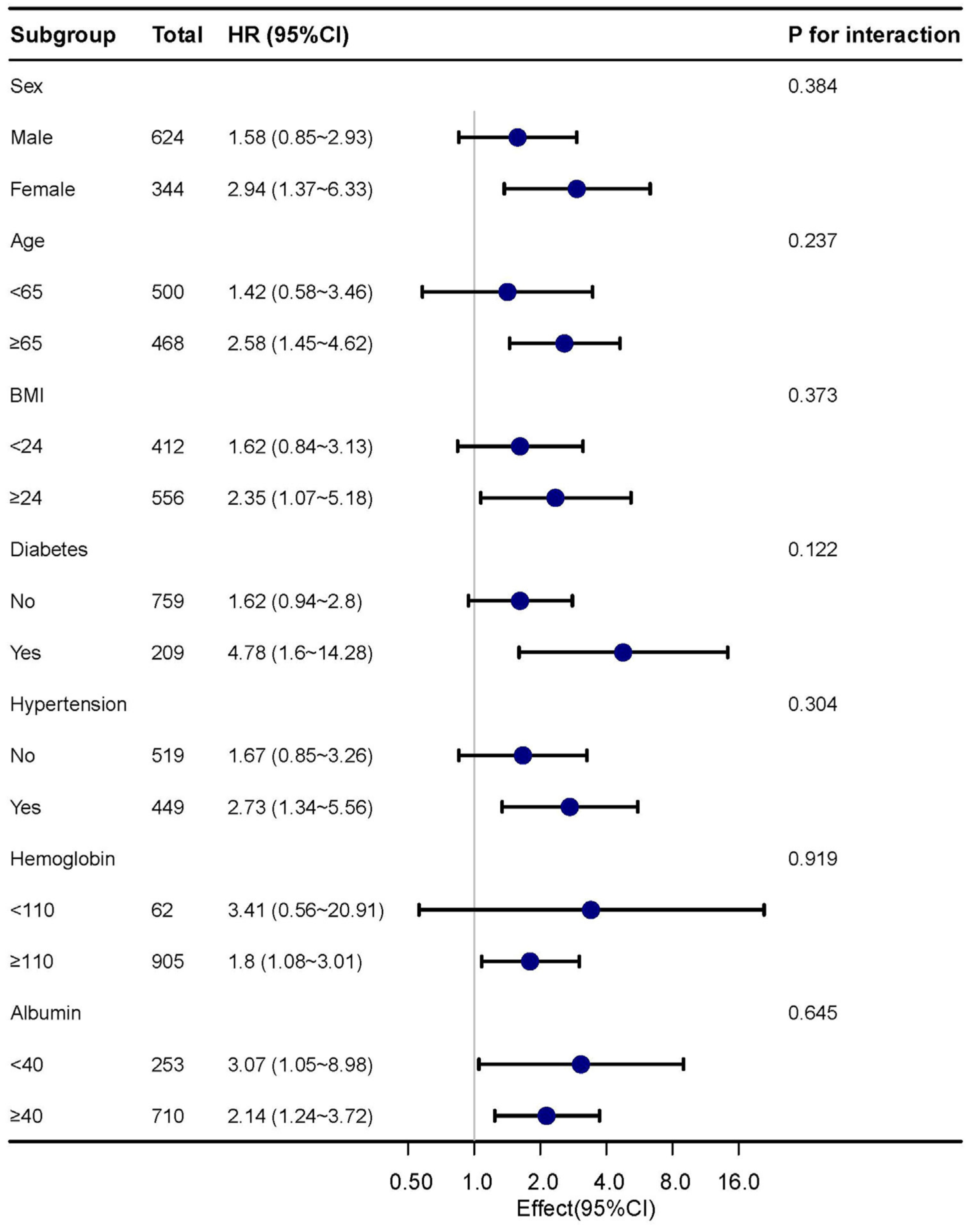

Fig 4. Results of the subgroup and interaction analyses. Multivariate Cox regression was adjusted for age, type of surgery, surgical duration, hemoglobin level, emergency surgery, and American Society of Anesthesiologists class. BMI, body mass index; HR, hazard ratio.

large-sample prospective study in the future. Second, this study assessed only the patient's muscle mass and did not include the assessment of muscle function and physical function. In contrast, the most recent diagnostic criterion for sarcopenia developed by the Asian Sarcopenia Working Group defines sarcopenia as a geriatric syndrome characterized by age-related loss of muscle mass, muscle strength, and/or physical function.[26] Third, this study defined the cutoff for "sarcopenia" as the lowest quartile, which was similar to the findings of previous studies. There is no universally accepted definition of sarcopenia because the skeletal muscle index threshold for defining sarcopenia may vary by race, region, and age group. This limits the generalizability of the findings of this study, and additional research is needed in the future to determine the most accurate threshold for identifying sarcopenia. Fourth, the pathogenesis of sarcopenia is not fully understood and may be related to oxidative stress, malnutrition, endocrine metabolism, and genetic factors.[6,15] Future studies are needed to determine the underlying mechanisms of sarcopenia and poor prognosis.

Table 4
Sensitivity Analysis

Variable		PSM		Sensitivity Analysis	
	N	HR (95% CI)	p Value	HR (95% CI)	p Value
Sarcopenia					
No	726	Reference		Reference	
Yes	242	2.35 (1.12∼4.96)	0.024	1.83 (1.05∼3.17)	0.032

Abbreviations: HR, hazard ratio; PSM, propensity-score matching.

Additionally, there are no interventional studies on preoperative sarcopenia and postoperative outcomes, and sarcopenia may be a substitute for another disease; additional studies are needed in the future to shed light on these issues. Fifth, the relatively low prevalence of chronic obstructive pulmonary disease in this study, which is strongly associated with sarcopenia, may have been related to the retrospective nature of the study and the fact that the population included young adults. Sixth, mortality peaked at 90 days in the population studied in this study so that sarcopenia may have a more pronounced effect on the short-term prognosis, and future follow-up data from many patients over a long period are needed to further validate the effect of sarcopenia on the long-term prognosis. Finally, 310 (24%) patients were excluded due to missing preoperative abdominal CT scans. This may have contributed to selection bias and reduced the generalizability of the preoperative assessment of sarcopenia using the skeletal muscle index. As shown in Supplementary Table S5, the 310 patients who were excluded had higher rates of alcohol consumption and heart failure than the 968 patients. There were no other differences.

Conclusions

In conclusion, sarcopenia, as defined based on the skeletal muscle index, is an independent risk factor for all-cause mortality and morbidity in patients undergoing cardiac surgery. Future studies are needed to define diagnostic thresholds for muscle mass in cardiac populations and to investigate the impact of different interventions on the postoperative recovery of sarcopenia patients. Such studies will help promote the inclusion of skeletal muscle measurements in perioperative risk assessments to guide the development of appropriate interventions to improve perioperative body composition in cardiovascular patients with poor physiologic reserve and, where possible, reverse adverse outcomes.

Declaration of competing interest

None.

CRediT authorship contribution statement

Baohe Zang: Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yuhan Qiao:** Data curation, Conceptualization. **Tianchi Shan:** Data curation, Conceptualization. **Shuyang Fu:** Methodology, Investigation. **Wei Xu:** Investigation, Data curation. **Wen Cai:** Methodology, Conceptualization. **Yaning Jiang:** Formal analysis, Conceptualization. **Yali Chao:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Wenjing Zhao:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2024.01.016.

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