Original Article

Associations of sarcopenia and malnutrition with 30-day in-hospital morbidity and mortality after cardiac surgery

Takahiro Abe[1], Tasuku Inao[2], Yasushige Shingu[3], Akira Yamada[4], Shingo Takada[5], Arata Fukushima[6], Noriko Oyama-Manabe[7,8], Isao Yokota[2], Satoru Wakasa[3], Shintaro Kinugawa[9,10] & Takashi Yokota[11*]

[1]Department of Rehabilitation, Hokkaido University Hospital, Sapporo, Japan

[2]Department of Biostatistics, Graduate School of Medicine, Hokkaido University, Sapporo, Japan

[3]Department of Cardiovascular Surgery, Faculty of Medicine and Graduate School of Medicine, Hokkaido University, Sapporo, Japan

[4]Department of Cardiovascular Surgery, Teine Keijinkai Hospital, Sapporo, Japan

[5]Department of Lifelong Sport, School of Sports Education, Hokusho University, Ebetsu, Japan

[6]Asabu Heart and Gastrointestinal Clinic, Sapporo, Japan

[7]Department of Diagnostic and Interventional Radiology, Hokkaido University Hospital, Sapporo, Japan

[8]Department of Radiology, Jichi Medical University Saitama Medical Center, Saitama, Japan

[9]Department of Cardiovascular Medicine, Faculty of Medical Sciences, Kyushu University, Fukuoka, Japan

[10]Division of Cardiovascular Medicine, Research Institute of Angiocardiology, Faculty of Medical Sciences, Kyushu University, Fukuoka, Japan

[11]Institute of Health Science Innovation for Medical Care, Hokkaido University Hospital, Sapporo, Japan

Word count: 4,500 words

***Corresponding author:** Dr. Takashi Yokota, Institute of Health Science Innovation for Medical Care, Hokkaido University Hospital, Kita-14 Nishi-5, Kita-Ku, Sapporo 060-8648, Japan. Tel.: +81-11-706-6001; Fax: +81-11-706-7613. Email: t-yokota@med.hokudai.ac.jp

Abstract

Objectives: Sarcopenia and malnutrition often occur simultaneously in adults with cardiovascular diseases. Our objective was to determine the associations of preoperative sarcopenia and malnutrition with major adverse cardiac and cerebral events (MACCE) after cardiac surgery

Methods: We retrospectively analyzed 154 consecutive patients who underwent elective cardiac surgery between January 2015 and June 2018 at two institutions in Japan. Sarcopenia and nutritional status were preoperatively assessed by bilateral psoas muscle volume index (PMVI) using CT scans and the prognostic nutritional index (PNI), respectively.

Results: The median age in the total cohort was 69 years, and 43% were women. Within 30 days after surgery, 20 patients developed in-hospital MACCE and 7 patients died of any cause. Low PMVI (<72.25 cm^3/m^2) and low PNI (<48.15) were each independent predictors of postoperative MACCE occurrence with odds ratios (95% confidence interval) of 3.58 (1.22–10.53) and 3.73 (1.25–11.09) when adjusted for age and sex, and 3.25 (1.07–9.87) and 3.27 (1.08–9.89) when adjusted for preoperative left ventricular ejection fraction, angiotensin-converting enzyme inhibitor or angiotensin-receptor blocker, and anticoagulant. In addition, the combination of low PMVI and low PNI conferred the highest risk of in-hospital MACCE among the 4 groups (i.e., the low PMVI, low PNI, low PMVI+low PNI, and neither low PMVI nor low PNI groups).

Conclusions: Preoperative low PMVI and low PNI were respectively associated with 30-day in-hospital MACCE occurrence after cardiac surgery. Notably, coexistence of these reductions further enhanced the risk of postoperative MACCE.

Keywords: Cardiac surgery, Prognostic nutritional index, Psoas muscle volume, Sarcopenia

Abbreviations

ACE: angiotensin-converting enzyme

ARB: angiotensin-receptor blocker

BMI: body mass index

CI: Confidence interval

CT: Computed tomography

eGFR: Estimated glomerular filtration rate

LVEF: left ventricular ejection fraction

MACCE: Major adverse cardiac and cerebral events

PMAI: Psoas muscle area index

PMVI: Psoas muscle volume index

PNI: Prognostic nutritional index

Introduction

Despite recent advances in surgical procedures and perioperative care, postoperative complications after cardiac surgery remain frequent, leading to prolonged hospital stays, increased medical costs and reduced quality of life [1, 2]. With the increasing aging of the world population, the number of elderly subjects or adults with multiple risk factors who undergo cardiac surgery is increasing. Preoperative risk stratification is important for better patient selection to ensure optimal treatment and prevent serious adverse events after cardiac surgery.

Sarcopenia, which is characterized by muscle loss and muscle dysfunction, is common in elderly people, leading to increased morbidity and mortality [3]. There is a bidirectional link between sarcopenia and cardiovascular diseases in adults [4]. Accumulated evidence suggests that reduced muscle mass increases postoperative risk after various types of surgery, including cancer surgery [5], abdominal surgery [6], and cardiac surgery [7-9]. Measurement of psoas muscle size is one of options to assess sarcopenia. Over the last decade, advances in the visualization and quantitative analysis of 3D imaging have enabled the measurement of psoas muscle volume (PMV) using CT scans [10]. However, most former studies used the psoas muscle area (PMA), a cross-sectional area of axial CT image at the level of the third or fourth lumbar vertebra, for the evaluation of psoas muscle mass, and thus the clinical and prognostic value of PMV in cardiac surgery has remained fully unknown.

Sarcopenia and malnutrition often occur simultaneously in adults with cardiovascular disease. Malnutrition is reported to have harmful effects on postoperative outcomes in cardiac surgery [11]. Recently, the term “malnutrition-sarcopenia syndrome” was proposed, because many older adults clinically present with both conditions, which may accelerate functional impairments and increase the risk of morbidity and mortality [12]. We therefore comparatively investigated the utility of the preoperative PMV index (PMVI: PMV normalized to the squared body height) and prognostic nutritional index (PNI) to assess sarcopenia and malnutrition, respectively, in patients who underwent cardiac surgery, and examined whether sarcopenia and malnutrition were associated with in-hospital morbidity and mortality within 30 days after cardiac surgery.

Patients and Methods

Patients

We retrospectively analyzed the patients who underwent elective cardiac surgery (open-heart surgery) between January 2015 and June 2018 at Hokkaido University Hospital and Teine Keijinkai Hospital, when they were 20 years of age or older. In these hospitals, preoperative whole-body CT (including abdominal CT) scan was routinely performed. Patients were excluded *i)* if they underwent emergent cardiac surgery, *ii)* if they had not undergone abdominal CT scan within 30 days before cardiac surgery, or *iii)* if their blood lymphocyte counts and serum albumin levels had not been measured within 7 days before cardiac surgery. The study was approved by the respective ethics committees of Hokkaido University Hospital (approval no. 021-0027) and Teine Keijinkai Hospital (approval no. 2-021202-00), and the investigation conformed to the principles outlined in the Declaration of Helsinki.

Clinical and laboratory data

All the data, including demographic and laboratory data (which were evaluated within 7 days before cardiac surgery), medical history, medication (recorded at hospital admission), type of cardiac surgery, duration of mechanical ventilation after surgery, and length of hospital stay were collected from each institution's medical records. The estimated glomerular filtration rate (eGFR) was calculated from the serum creatinine values and the patient's age with the use of the Japanese equation [13]: eGFR = 194 × (serum creatinine, mg/dL)$^{-1.094}$ × (age, yrs)$^{-0.287}$ × (0.739 if female). The left ventricular ejection fraction (LVEF) was measured using the biplane method of disks by echocardiography.

Sarcopenia assessment using CT scanning

To assess sarcopenia, we evaluated bilateral PMV by CT scans using 3D Slicer version 4.5

(**Figure 1A**), which is a free, open-source extensible software application for medical image computing and visualization, as described [10]. CT scans were acceptable *i)* if performed within 30 days prior to the surgery and *ii)* if sections included the whole psoas muscle. We also evaluated cross-sectional bilateral PMA at the fourth lumbar (L4) level with a single axial CT image using 3D Slicer (**Figure 1B**), as described [14]. Finally, we determined the PMVI and the PMA index (PMAI) by normalization of the PMV and the PMA to squared body height (m^2), respectively. The assessment of PMA and PMV was conducted in a blind manner regarding the outcomes.

Nutritional assessment

The nutritional status of each patient was assessed by the PNI, which was calculated as 10 × serum albumin (g/dL) + 0.005 × total lymphocyte count (per mm^3), as described [11].

Outcome measures

Postoperative in-hospital outcomes included all-cause and cardiac death, major adverse cardiac and cerebral events (MACCE), any complications possibly related to surgery, and reoperation that occurred within 30 days after cardiac surgery. The primary study endpoint was MACCE, which comprised all-cause death, nonfatal myocardial infarction, stroke or transient ischemic attack, and emergent coronary revascularization, and the secondary study endpoints were all-cause death, cardiac death, any complications, and reoperation. These outcomes were assessed from each institute's medical records.

Potential variables as confounders

Multivariable analysis was performed to investigate the prognostic impact of various parameters on the in-hospital MACCE occurrence after cardiac surgery. Each of the following variables was included in the analysis before model selection: age, sex, body mass index (BMI), LVEF, hypertension, diabetes, dyslipidemia, heart failure, preoperative atrial fibrillation, history of stroke, prior cardiac surgery, medication, type of surgical procedures, white blood cell counts, hemoglobin, eGFR, PMVI, and PNI.

Statistical analysis

Continuous variables were expressed as the median (1st–3rd quartile), and categorical variables were expressed as number (percentage). The Spearman's correlation test was used to check the correlation between PMVI and PMAI or PNI in the total cohort. We divided the total cohort into two groups based on the median values of PMVI and PNI. The mean differences and corresponding 95% confidence intervals (CIs) between the male and female groups were estimated assuming that these differences are normally distributed. Cumulative event rates of in-hospital MACCE after cardiac surgery were evaluated by means of the

Kaplan-Meier method. To check the prognostic impact of PMVI and PNI on occurrence of in-hospital MACCE after cardiac surgery, we prepared the bootstrap samples (1,000 replications) and specified some models based on the global score chi-square statistics [15]. Among the various models including potential variables that can be confounders, we finally selected the two best models (model-1: age and sex; model-2: left ventricular ejection fraction, angiotensin-converting enzyme [ACE] inhibitor or angiotensin-receptor blocker [ARB], and anticoagulant) from the viewpoint of the Akaike information criterion (AIC) of the models and clinical interpretation. Logistic regression analyses were used to estimate the odds ratios and corresponding 95% CIs for occurrence of in-hospital MACCE after surgery. Analyses to calculate AIC were implemented using proc surveyselect and proc logistic in the SAS software program (version 9.4; SAS Institute, Cary, NC). Other analyses were performed using R software (version 4.2.3; R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria).

Results

Initially, we enrolled 430 patients in our study. Subsequently, we excluded 246 patients either because they underwent emergent cardiac surgery, or because they had no measurable CT imaging (used for evaluation of psoas muscle size) performed within 30 days before surgery, or no measurement of blood lymphocyte counts (used for evaluation of PNI value) within 7 days before surgery. Finally, a total of 154 patients who underwent elective cardiac surgery were included and were followed up at each hospital within 30 days after surgery. The flow diagram of this study is shown in **Figure 2**.

Patient characteristics

The median age of the total cohort was 69 years, and 67 patients (43%) were women. Only 9 patients (6%) had a prior history of cardiac surgery. The most common type of cardiac surgery was valve surgery (53%) and 14% of the total patients underwent combined surgery including coronary-artery bypass grafting and valve surgery. The median values (1st–3rd quartile) of bilateral PMAI, bilateral PMVI, and PNI were 6.25 (4.91–7.33) cm^2/m^2, 72.25 (55.26–81.88) cm^3/m^2, and 48.15 (42.42–51.35), respectively, in the total cohort. Characteristics of the low PMVI, the high PMVI, the low PNI, and the high PNI groups as well as the total cohort are shown in **Table 1**. We also divided the total cohort into another 4 groups (the high PMVI/high PNI, the low PMVI/high PNI, the high PMVI/low PNI, and the low PMVI/low PNI groups), and characteristics of these groups are shown in **Supplementary Material, Table S1**.

Correlation of PMVI with PMAI or PNI

There was no significant correlation between bilateral PMVI and PMAI at the L4 level measured using CT scans in patients who underwent cardiac surgery (Spearman's r = 0.03) (**Supplementary Material, Figure S1A**). In addition, bilateral PMVI was not significantly correlated with PNI in these patients (Spearman's r = -0.06) (**Supplementary Material, Figure S1B**).

Sex difference in psoas muscle size

Male patients had larger PMV than female patients with mean difference (95% CI) of 29.21 (11.31 to 47.10) (**Supplementary Material, Figure S2A**). However, the PMVI was comparable between male and female patients with mean difference (95% CI) of -1.42 (-8.40 to 5.56) (**Supplementary Material, Figure S2B**).

Outcomes

With respect to the primary endpoint, 20 patients (13%) in the total cohort experienced MACCE after cardiac surgery within 30 days of their hospital stay. MACCE occurred in 15 patients with low PMVI and 5 patients with high PMVI. Similarly, 15 patients with low PNI and 5 patients with high PNI experienced MACCE after surgery. With respect to the secondary endpoints, 7 patients (5%) in the total cohort died of any cause and 6 (4%) died of cardiac causes after surgery, but none of the patients with high PNI died of any cause and only one patient with high PMVI died of cardiac causes. A total of 86 patients (56%) had one or some complications after surgery and 26 patients (17%) underwent reoperation. In-hospital outcomes within 30 days after cardiac surgery are shown in **Table 2**. In addition, outcomes of the high PMVI/high PNI, the low PMVI/high PNI, the high PMVI/low PNI, and the low PMVI/low PNI groups are shown in **Supplementary Material, Table S2**.

Predictors of MACCE

After accounting for age and sex, low PMVI and low PNI were independent predictors of in-hospital MACCE occurrence within 30 days after cardiac surgery, with odds ratios (95% CI) of 3.58 (1.22–10.53) and 3.73 (1.25–11.09), respectively. Even after adjustment for preoperative left ventricular ejection fraction, ACE inhibitor or ARB, and anticoagulant, low PMVI and low PNI were independent predictors of in-hospital MACCE occurrence after surgery with odds ratios (95% CI) of 3.25 (1.07–9.87) and 3.27 (1.08–9.89), respectively. In addition, the combination of low PMVI and low PNI was also an independent predictor of postoperative MACCE occurrence with odds ratios (95% CI) of 4.91 (1.81–13.35) after adjustment for age and sex and 4.51 (1.58–12.75) after adjustment for preoperative left ventricular ejection fraction, ACE inhibitor or ARB, and anticoagulant. **Table 3** shows the results of the multivariable logistic regression analysis of variables impacting MACCE occurrence over the 30-day in-hospital stay after surgery. The cumulative incidence rate of in-hospital MACCE within 30 days after cardiac surgery was the highest in the low PMVI/low PNI group compared to the other 3 groups (**Figure 3**).

Discussion

This retrospective study in patients who underwent elective cardiac surgery found that preoperative sarcopenia, defined by low PMVI, and malnutrition, defined by low PNI, were respectively independent predictors of the occurrence of in-hospital MACCE within 30 days after surgery. In addition, patients with both low PMVI and low PNI had a higher risk of 30-day MACCE after cardiac surgery compared to those with only low PMVI or low PNI, and those with neither predictor.

Sarcopenia is a well-recognized predictor of postoperative mortality and morbidity after cardiac surgery [16]. Although the measurement of psoas muscle mass for sarcopenia quantification before cardiac surgery has recently drawn attention in clinical practice, most of the relevant previous studies evaluated the cross-sectional area of the psoas muscle using axial CT images [7-9]. To our knowledge, our study is the first to show the prognostic impact of low PMVI on morbidity and mortality after open-heart cardiac surgery. Unexpectedly, there was no correlation between PMVI and PMAI in our population. Theoretically, PMV could be calculated as the sum of the cross-sectional areas of the psoas muscle from the proximal to the distal ends. However, our findings indicate that a single cross-sectional area of the psoas muscle may not necessarily reflect the total volume of the psoas muscle.

The psoas muscle, a main hip flexor muscle, plays a pivotal role in walking, standing from a seated position, and maintaining an upright posture with balance, all of which are essential for daily living [17]. It has been reported that age-related muscle atrophy is likely to initiate at the fifth decade in the psoas muscle, which is earlier than in other trunk muscles [18]. Although the underlying mechanism that connects preoperative psoas muscle sarcopenia (i.e., low PMVI) and high incidence of major cardiovascular complications after cardiac surgery has yet to be clarified, one possible explanation is that physical inactivity due to the patient's illness or sedentary lifestyle may cause sarcopenia with reduced muscle strength and function, resulting in increased postoperative morbidity and mortality. Indeed, a systematic review and meta-analysis has shown that lack of moderate-to-vigorous physical activity is associated with sarcopenia in older adults [19].

In the present study, malnutrition and psoas muscle sarcopenia were each independently associated with increased rate of MACCE occurrence within 30 days of the hospital stay after cardiac surgery. Notably, we demonstrated for the first time that the combination of malnutrition and sarcopenia increased the risk of MACCE occurrence after open-heart cardiac surgery compared to the risk in patients with malnutrition alone, sarcopenia alone, or neither malnutrition nor sarcopenia. The sarcopenia phenotype is associated with malnutrition and reduced muscle mass and has recently been proposed as part of the definition of malnutrition [20]. Many adults are at high risk of malnutrition due to factors such as decreased appetite or food intake, poor dentition, severity of disease condition, social and economic challenges, and cognitive decline [12]. It has been reported that low PNI is associated with poor clinical outcomes after open-heart cardiac surgery [11], which is consistent with our findings. However, there was no correlation between PNI and PMVI in our population, suggesting that we need to take care of both malnutrition and sarcopenia, and neither of them can be ignored in the risk management of cardiac surgery.

In the present cohort, we had some sarcopenic patients whose nutritional status was normal or high. Recently, sarcopenic obesity has drawn attention to clinicians because coexistence of sarcopenia and obesity may amplify the risk of morbidity and mortality compared to sarcopenia or obesity alone in older people [21]. A previous study showed that sarcopenic obesity was associated with increased occurrence of infection after cardiac surgery [22]. However, in the present study, the median value (1st–3rd quartile) of BMI in the low PMVI/high PNI group was 23.9 (19.9–26.6), indicating that most patients in this group were not obese. Although we could not confirm detailed mechanism of sarcopenia alone, reduced exercise rather than undernutrition might affect lowered psoas muscle mass in these patients.

Our study has some limitations. First, our registry captures only in-hospital outcomes, and future studies with longer-term outcomes after hospital discharge are needed. Second, since our participating institutions were one of the largest hospitals in Japan, more complicated and higher risk patients might be included compared to general population undergoing cardiac surgery. Considering that this is a retrospective study conducted in only 2 institutions, prospective multicenter clinical trials are further needed to investigate clinical impact of preoperative sarcopenia and malnutrition on the risk after open-heart cardiac surgery. Third, we did not evaluate functional capacity of the skeletal muscle, which may also be an important factor of sarcopenia or frailty. Finally, we did not have information on the physical activity or dietary intake of participants, both of which may influence psoas muscle mass and nutritional status.

Conclusion

Our work identified that low PMVI and low PNI were both important preoperative risk factors of in-hospital MACCE after cardiac surgery. Moreover, the coexistence of low PMVI and low PNI enhanced the risk of MACCE occurrence after cardiac surgery compared to the risk in patients with low PMVI alone, low PNI alone, or neither low PMVI nor low PNI. In preoperative risk assessment, clinicians (including physicians, physiotherapists, and dietitians) need to take care of both sarcopenia and malnutrition in patients undergoing cardiac surgery.

Funding

The study was supported by a Grant-in-Aid for Scientific Research from KAKENHI (no. 21K08020).

Conflict of interest

None declared.

Data availability

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

Author contribution

Takahiro Abe: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing—original draft. **Tasuku Inao**: Data curation; Formal analysis; Methodology; Visualization; Writing—original draft. **Yasushige Shingu**: Conceptualization; Supervision; Investigation; Writing—review & editing. **Akira Yamada**: Conceptualization; Investigation; Writing—review & editing. **Shingo Takada**: Conceptualization; Investigation; Writing—review & editing. **Arata Fukushima**: Conceptualization; Investigation; Writing—review & editing. **Noriko Oyama-Manabe**: Data curation; Methodology; Supervision; Visualization; Writing—review & editing. **Isao Yokota**: Data curation; Formal analysis; Methodology; Supervision; Writing—review & editing. **Satoru Wakasa**: Conceptualization; Investigation; Supervision; Writing—review & editing. **Shintaro Kinugawa**: Conceptualization; Supervision; Writing—review & editing. **Takashi Yokota**: Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Project administration; Writing—original draft.

References

[1] Brown PP, Kugelmass AD, Cohen DJ, Reynolds MR, Culler SD, Dee AD *et al. The frequency and cost of complications associated with coronary artery bypass grafting surgery: results from the United States Medicare program*. Ann Thorac Surg 2008;**85**:1980-6.

[2] Patel AS, Bergman A, Moore BW, Haglund U. *The economic burden of complications occurring in major surgical procedures: a systematic review*. Appl Health Econ Health Policy 2013;**11**:577-92.

[3] Beaudart C, Zaaria M, Pasleau F, Reginster JY, Bruyere O. *Health outcomes of sarcopenia: a systematic review and meta-analysis*. PLoS One 2017;**12**:e0169548.

[4] Gao K, Cao LF, Ma WZ, Gao YJ, Luo MS, Zhu J *et al. Association between sarcopenia and cardiovascular disease among middle-aged and older adults: Findings from the China health and retirement longitudinal study*. EClinicalMedicine 2022;**44**:101264.

[5] Xiao J, Caan BJ, Cespedes Feliciano EM, Meyerhardt JA, Peng PD, Baracos VE *et al. Association of low muscle mass and low muscle radiodensity with morbidity and mortality for colon cancer surgery*. JAMA Surg 2020;**155**:942-49.

[6] Hajibandeh S, Hajibandeh S, Jarvis R, Bhogal T, Dalmia S. *Meta-analysis of the effect of sarcopenia in predicting postoperative mortality in emergency and elective*

abdominal surgery. Surgeon 2019;**17**:370-80.

[7] Hawkins RB, Mehaffey JH, Charles EJ, Kern JA, Lim DS, Teman NR *et al. Psoas muscle size predicts risk-adjusted outcomes after surgical aortic valve replacement*. Ann Thorac Surg 2018;**106**:39-45.

[8] Okamura H, Kimura N, Mieno M, Yuri K, Yamaguchi A. *Preoperative sarcopenia is associated with late mortality after off-pump coronary artery bypass grafting*. Eur J Cardiothorac Surg 2020;**58**:121-29.

[9] Yamashita M, Kamiya K, Matsunaga A, Kitamura T, Hamazaki N, Matsuzawa R *et al. Prognostic value of psoas muscle area and density in patients who undergo cardiovascular surgery*. Can J Cardiol 2017;**33**:1652-59.

[10] Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin JC, Pujol S *et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network*. Magn Reson Imaging 2012;**30**:1323-41.

[11] Gucu A, Ozluk OA, Sunbul SA, Engin M, Seker IB, Sunbul A. *Prognostic nutritional index as a marker of mortality: an observational cohort study of patients undergoing cardiac surgery*. Rev Cardiovasc Med 2021;**22**:499-503.

[12] Vandewoude MF, Alish CJ, Sauer AC, Hegazi RA. *Malnutrition-sarcopenia syndrome: is this the future of nutrition screening and assessment for older adults?* J Aging Res 2012;**2012**:651570.

[13] Matsuo S, Imai E, Horio M, Yasuda Y, Tomita K, Nitta K *et al. Revised equations for estimated GFR from serum creatinine in Japan*. Am J Kidney Dis 2009;**53**:982-92.

[14] Hsu J, Krishnan A, Lin CT, Shah PD, Broderick SR, Higgins RSD *et al. Sarcopenia of the psoas muscles is associated with poor outcomes following lung transplantation*. Ann Thorac Surg 2019;**107**:1082-88.

[15] Furnival GM, Willson RW. *Regression by leaps and bounds*. Technometrics 1974;**16**:499-511.

[16] Ansaripour A, Arjomandi Rad A, Koulouroudias M, Angouras D, Athanasiou T, Kourliouros A. *Sarcopenia adversely affects outcomes following cardiac surgery: a systematic review and meta-analysis.* J Clin Med 2023;**12**:5573

[17] Lifshitz L, Bar Sela S, Gal N, Martin R, Fleitman Klar M. *Iliopsoas the hidden muscle: anatomy, diagnosis, and treatment.* Curr Sports Med Rep 2020;**19**:235-43.

[18] Naruse M, Fountain WA, Claiborne A, Finch WH, Trappe S, Trappe TA. *Muscle group-specific skeletal muscle aging: a 5-yr longitudinal study in septuagenarians*. J Appl Physiol 2023;**134**:915-22.

[19] Sanchez-Sanchez JL, He L, Morales JS, de Souto Barreto P, Jimenez-Pavon D, Carbonell-Baeza A *et al. Association of physical behaviours with sarcopenia in older adults: a systematic review and meta-analysis of observational studies*. Lancet Healthy

Longev 2024;**5**:e108-e19.

[20] Cederholm T, Jensen GL, Correia M, Gonzalez MC, Fukushima R, Higashiguchi T *et al. GLIM criteria for the diagnosis of malnutrition - A consensus report from the global clinical nutrition community*. Clin Nutr 2019;**38**:1-9.

[21] Benz E, Pinel A, Guillet C, Capel F, Pereira B, De Antonio M *et al. Sarcopenia and sarcopenic obesity and mortality among older people*. JAMA Netw Open 2024;**7**:e243604.

[22] Visser M, van Venrooij LM, Vulperhorst L, de Vos R, Wisselink W, van Leeuwen PA *et al. Sarcopenic obesity is associated with adverse clinical outcome after cardiac surgery*. Nutr Metab Cardiovasc Dis 2013;**23**:511-8.

Table 1. Baseline characteristics in patients who underwent cardiac surgery with and without sarcopenia or malnutrition

Characteristic	Total (n=154)	PMVI		PNI	
		Low (n=77)	High (n=77)	Low (n=77)	High (n=77)
Age (years)	69 (61–75)	67 (59–73)	71 (65–77)	70 (66–77)	67 (58–75)
Female	67 (44%)	32 (42%)	35 (45%)	34 (44%)	32 (42%)
Height (cm)	160.1 (152.7–167.2)	163.0 (154.6–169.0)	158.1 (151.2–166.0)	159.3 (150.3–166.3)	160.8 (153.8–168.4)
BMI (kg/m^2)	23.3 (20.2–25.6)	22.3 (19.7–25.5)	23.5 (21.2–25.9)	22.4 (19.8–25.2)	24 (21.3–26.6)
LVEF (%)	61 (42–68)	62 (40–69)	59 (44–66)	57 (39–66)	63 (47–70)
Medical history:					
Hypertension	88 (57%)	41 (53%)	47 (61%)	43 (56%)	45 (58%)
Diabetes	55 (36%)	19 (25%)	36 (47%)	26 (34%)	29 (38%)
Dyslipidemia	77 (50%)	33 (43%)	44 (57%)	33 (43%)	44 (57%)
Heart failure	57 (37%)	34 (44%)	23 (30%)	35 (46%)	22 (29%)
Atrial fibrillation[a]	33 (21%)	12 (16%)	21 (27%)	23 (30%)	10 (13%)
Stroke	42 (27%)	19 (25%)	23 (30%)	26 (34%)	16 (21%)
Prior cardiac surgery	9 (6%)	6 (8%)	3 (4%)	7 (9%)	2 (3%)
Medication[b]					
ACE inhibitor or ARB	77 (50%)	45 (58%)	32 (42%)	39 (51%)	38 (49%)
β-blocker	67 (44%)	32 (42%)	35 (45%)	34 (45%)	33 (42%)
Diuretics	72 (47%)	37 (48%)	35 (45%)	42 (55%)	30 (38%)
Statin	76 (49%)	34 (44%)	42 (55%)	35 (46%)	41 (53%)
Insulin	23 (15%)	7 (9%)	16 (21%)	12 (16%)	11 (14%)
Anticoagulant	43 (28%)	21 (27%)	22 (29%)	25 (33%)	18 (23%)
Antiplatelet	65 (42%)	25 (32%)	40 (52%)	34 (45%)	31 (40%)
Surgery:					
CABG	50 (33%)	15 (20%)	35 (46%)	24 (31%)	26 (34%)
Valve surgery	82 (53%)	48 (62%)	34 (44%)	37 (48%)	45 (58%)
CABG + valve surgery	22 (14%)	14 (18%)	8 (10%)	16 (21%)	6 (8%)
Laboratory data:					
WBC (10^3/μL)	5.9 (4.7–6.9)	5.8 (4.7–6.8)	5.9 (4.7–6.9)	5.3 (4.3–6.6)	6.0 (5.2–6.9)
Lymphocyte count (10^3/μL)	1.4 (0.9–1.9)	1.3 (1.0–1.8)	1.4 (0.9–2.0)	1.0 (0.7–1.3)	1.8 (1.5–2.1)
Hemoglobin (g/dL)	12.7 (11.5–13.5)	12.7 (11.6–13.8)	12.6 (11.4–13.5)	12.0 (10.5–13.2)	13.0 (12.4–14.2)
Serum albumin (g/dL)	4.1 (3.7–4.3)	4.1 (3.8–4.4)	4.0 (3.7–4.2)	3.8 (3.5–4.0)	4.3 (4.1–4.5)

eGFR (mL/min/1.73 m^2)	59.4 (41.0–75.6)	57.4 (40.5–74.5)	60.9 (42.3–77.7)	47.8 (25.4–62.8)	70.4 (56.4–83.1)
PMAI at L4 (cm^2/m^2)	6.25 (4.91–7.33)	6.24 (5.09–7.30)	6.28 (4.68–7.47)	6.19 (4.47–7.20)	6.51 (5.33–7.56)
PMVI (cm^3/m^2)	72.25 (55.26–81.88)	55.20 (39.39–66.09)	82.06 (77.89–94.44)	74.26 (55.45–83.64)	71.14 (55.20–80.64)
PNI	48.15 (42.42–51.35)	48.90 (43.20–52.10)	46.90 (42.40–50.40)	42.40 (39.80–45.60)	51.40 (50.10–53.50)
Length of hospital stay (days)	32 (23-54)	35 (24-56)	30 (23-50)	38 (24-58)	31 (17-46)
Duration of mechanical ventilation:					
≤ 2 days	102 (66%)	45 (58%)	57 (74%)	43 (57%)	59 (76%)
> 2 days	52 (34%)	32 (42%)	20 (26%)	33 (43%)	19 (24%)

Data are median (1st–3rd quartile) or number (%). ACE, angiotensin-converting enzyme; ARB, angiotensin-receptor blocker; BMI, body mass index; CABG, coronary-artery bypass grafting; COPD, chronic obstructive pulmonary disease; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; PMAI, psoas muscle area index; PMVI, psoas muscle volume index; PNI, prognostic nutritional index; WBC, white blood cell count. a) Preoperative atrial fibrillation was identified by 12-lead electrocardiogram within 7 days before cardiac surgery. b) The timing of medication is on the day of hospital admission before cardiac surgery. The total cohort was divided into high PMVI (≥72.25 cm^3/m^2) and low PMVI (<72.25 cm^3/m^2) groups by the median value of PMVI, and it was divided into high PNI (≥48.15) and low PNI (<48.15) groups by the median value of PNI.

Table 2. In-hospital outcomes within 30 days after cardiac surgery

Outcome	Total (n=154)	PMVI Low (n=77)	PMVI High (n=77)	PNI Low (n=77)	PNI High (n=77)
Primary endpoint:					
MACCE	20 (13%)	15 (20%)	5 (7%)	15 (20%)	5 (7%)
Secondary endpoints:					
All-cause death	7 (5%)	6 (8%)	1 (1%)	7 (9%)	0 (0%)
Cardiac death	6 (4%)	5 (7%)	1 (1%)	6 (8%)	0 (0%)
Any complications:	86 (56%)	47 (61%)	39 (51%)	49 (64%)	37 (48%)
Acute coronary syndrome	5 (3%)	2 (3%)	3 (4%)	3 (4%)	2 (3%)
Stroke or transient ischemic attack	4 (3%)	2 (3%)	2 (3%)	3 (4%)	1 (1%)
New onset of atrial fibrillation	41 (27%)	25 (32%)	16 (21%)	21 (27%)	20 (26%)
Heart failure	4 (3%)	2 (3%)	2 (3%)	3 (4%)	1 (1%)
Infection	29 (19%)	17 (22%)	12 (16%)	13 (17%)	16 (21%)
Major bleeding	21 (14%)	10 (13%)	11 (14%)	14 (18%)	7 (9%)
Cardiac tamponade	9 (6%)	6 (8%)	3 (4%)	6 (8%)	3 (4%)
Renal replacement therapy due to AKI	14 (9%)	10 (13%)	4 (5%)	8 (11%)	6 (8%)
Permanent pacemaker implantation	3 (2%)	2 (3%)	1 (1%)	3 (4%)	0 (0%)
Reoperation	26 (17%)	17 (22%)	9 (12%)	17 (22%)	9 (12%)

Data are number (%). AKI, acute kidney injury; MACCE, major adverse cardiac and cerebral events (all-cause death, nonfatal myocardial infarction, stroke or transient ischemic attack, and emergent coronary revascularization); PMVI, psoas muscle volume index; PNI, prognostic nutritional index.

Table 3. Logistic regression analysis for occurrence of in-hospital MACCE within 30 days after cardiac surgery according to sarcopenia (low PMVI) and/or malnutrition (low PNI)

Variable	Odds ratio	95% confidence interval
Model-1 (adjusted for age and sex):		
Low PMVI (vs. high PMVI)	3.58	1.22–10.53
Low PNI (vs. high PNI)	3.73	1.25–11.09
Low PMVI/low PNI (vs. others[a])	4.91	1.81–13.35
Model-2 (adjusted for preoperative LVEF, ACE inhibitor or ARB, and anticoagulant):		
Low PMVI (vs. high PMVI)	3.25	1.07–9.87
Low PNI (vs. high PNI)	3.27	1.08–9.89
Low PMVI/low PNI (vs. others[a])	4.51	1.58–12.75

ACE, angiotensin-converting enzyme; ARB, angiotensin-receptor blocker; LVEF, left ventricular ejection fraction; MACCE, major adverse cardiac and cerebrovascular events; PMVI, psoas muscle volume index; PNI, prognostic nutritional index. a) high PMVI/high PNI, high PMVI/low PNI, or low PMVI/high PNI.

Figure legends

Central Image. CI, confidence interval; MACCE, major adverse cardiac and cerebrovascular events; OR, odds ratio; PMVI, psoas muscle volume index; PNI, prognostic nutritional index.

Figure 1. Representative CT images of psoas muscle volume and psoas muscle area measured using 3D Slicer. (A) Psoas muscle volume measurement example: extracting the psoas muscles shown in red in the CT coronal section for volume measurement. (B) Psoas muscle area measurement example: extracting the psoas muscles shown in red in the CT axial cross-section for area measurement.

Figure 2. Flowchart of the study.

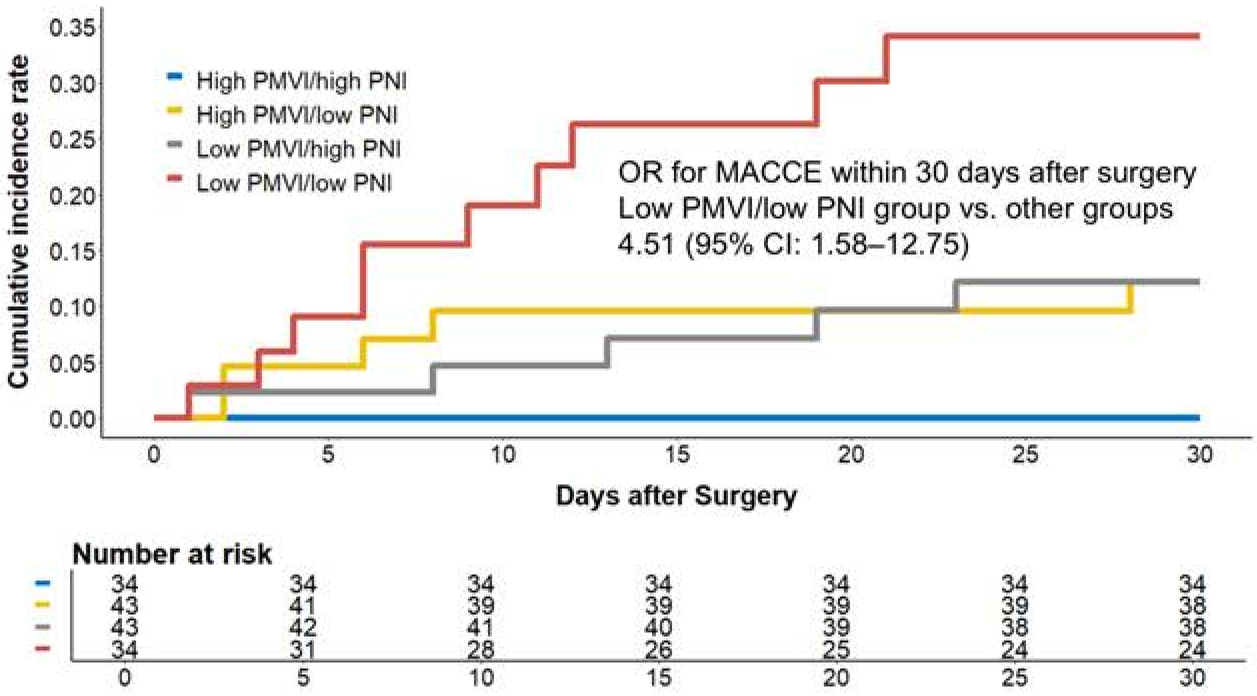
Figure 3. Cumulative incidence rate of in-hospital MACCE within 30 days after cardiac surgery. PMVI, psoas muscle volume index; PNI, prognostic nutritional index.

Associations of sarcopenia and malnutrition with 30-day in-hospital morbidity and mortality after cardiac surgery

Summary

- Participants: 154 patients who underwent elective cardiac surgery
- Exposure: PMVI (i.e., skeletal muscle mass) and PNI (i.e., nutritional status)
- Primary outcome: in-hospital MACCE
- Main findings: Coexistence of low PMVI and low PNI enhanced the risk of in-hospital MACCE occurrence after cardiac surgery compared to the risk in patients with low PMVI alone, low PNI alone, or neither low PMVI nor low PNI.

Cumulative incidence rate of in-hospital MACCE within 30 days after cardiac surgery



CI, confidence interval; MACCE, major adverse cardiac and cerebrovascular events; OR, odds ratio; PMVI, psoas muscle volume index; PNI, prognostic nutritional index.

Figure 1

A

Psoas muscle volume

B

Psoas muscle area at L4 level

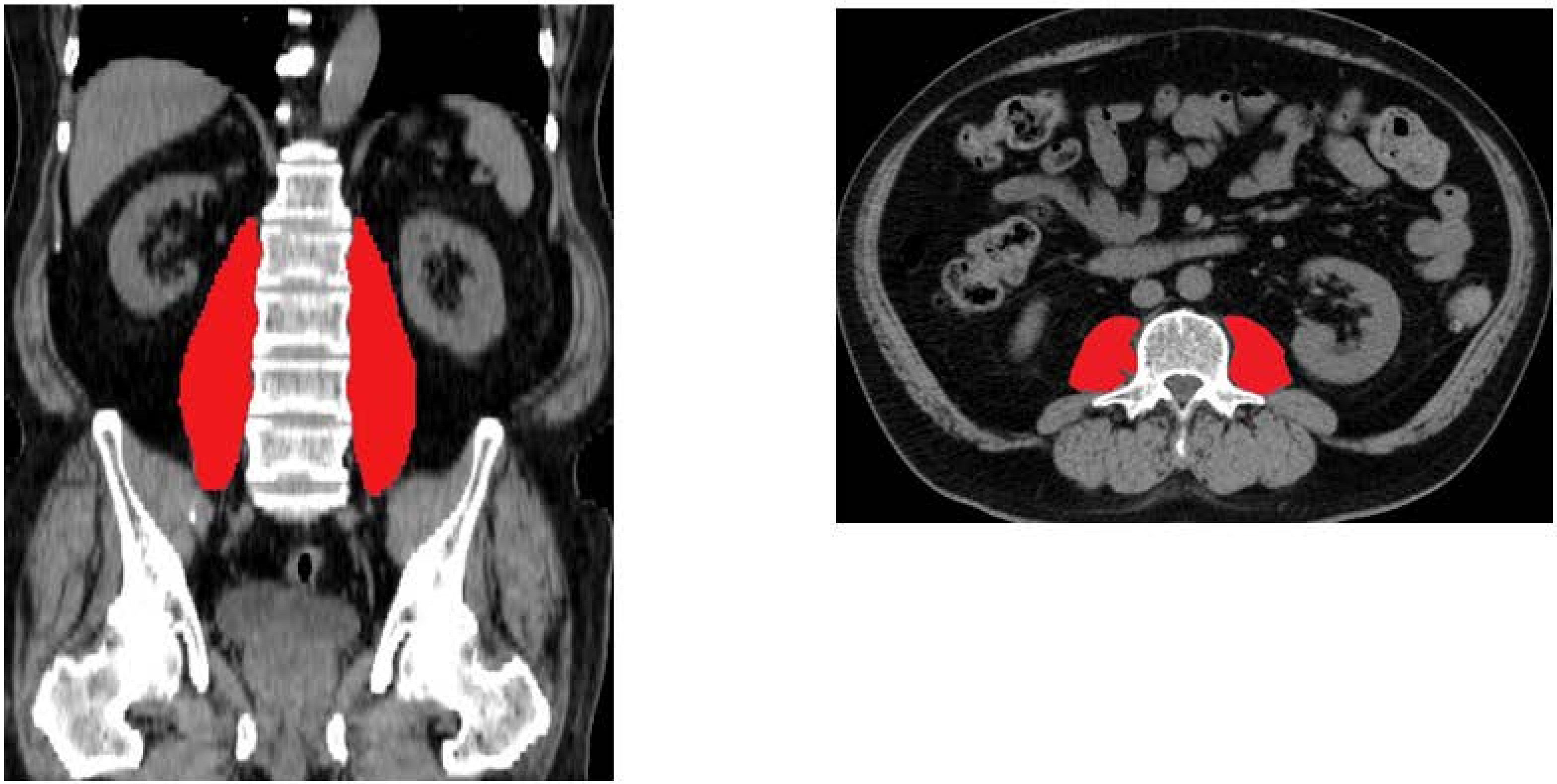


Figure 2

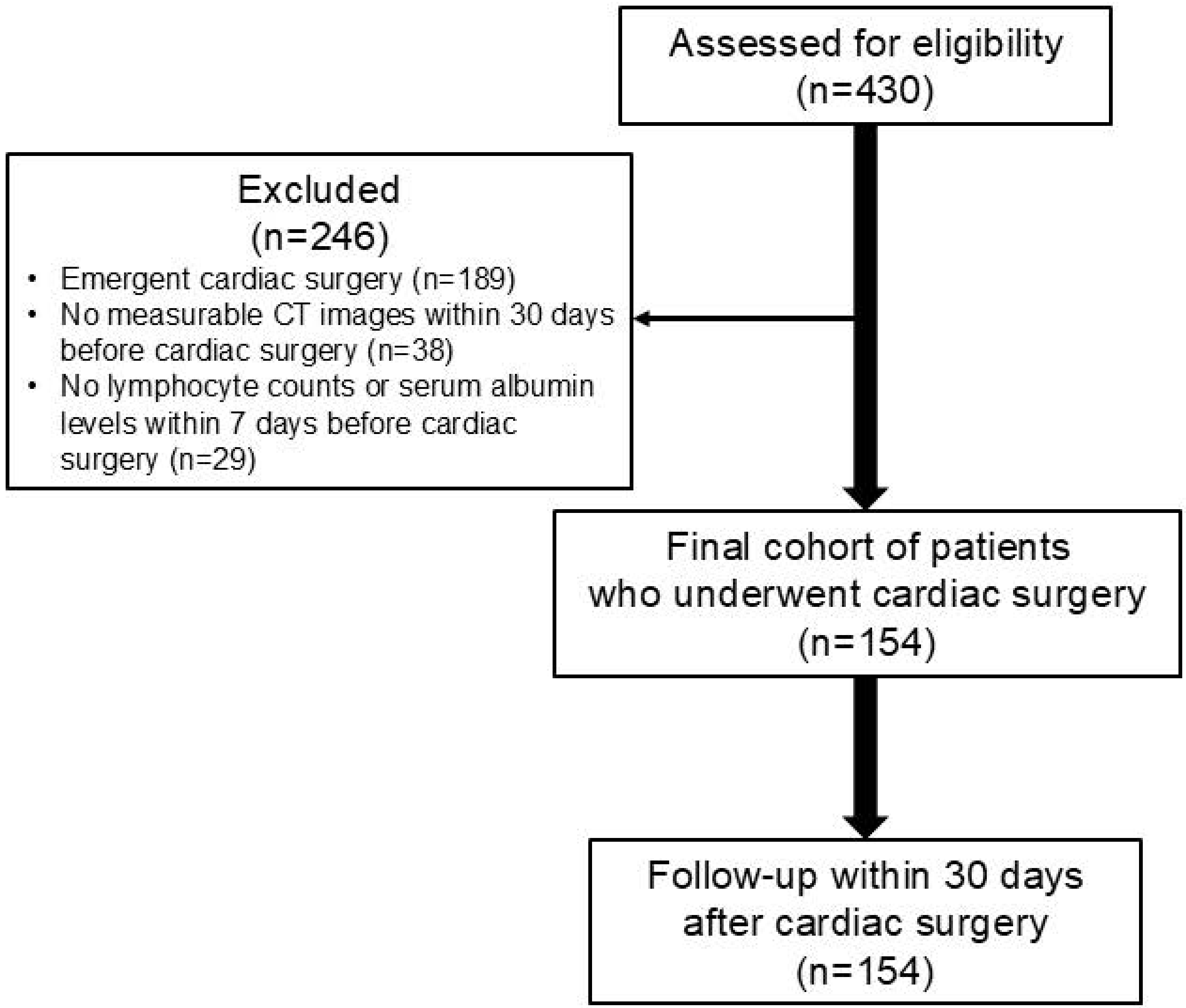
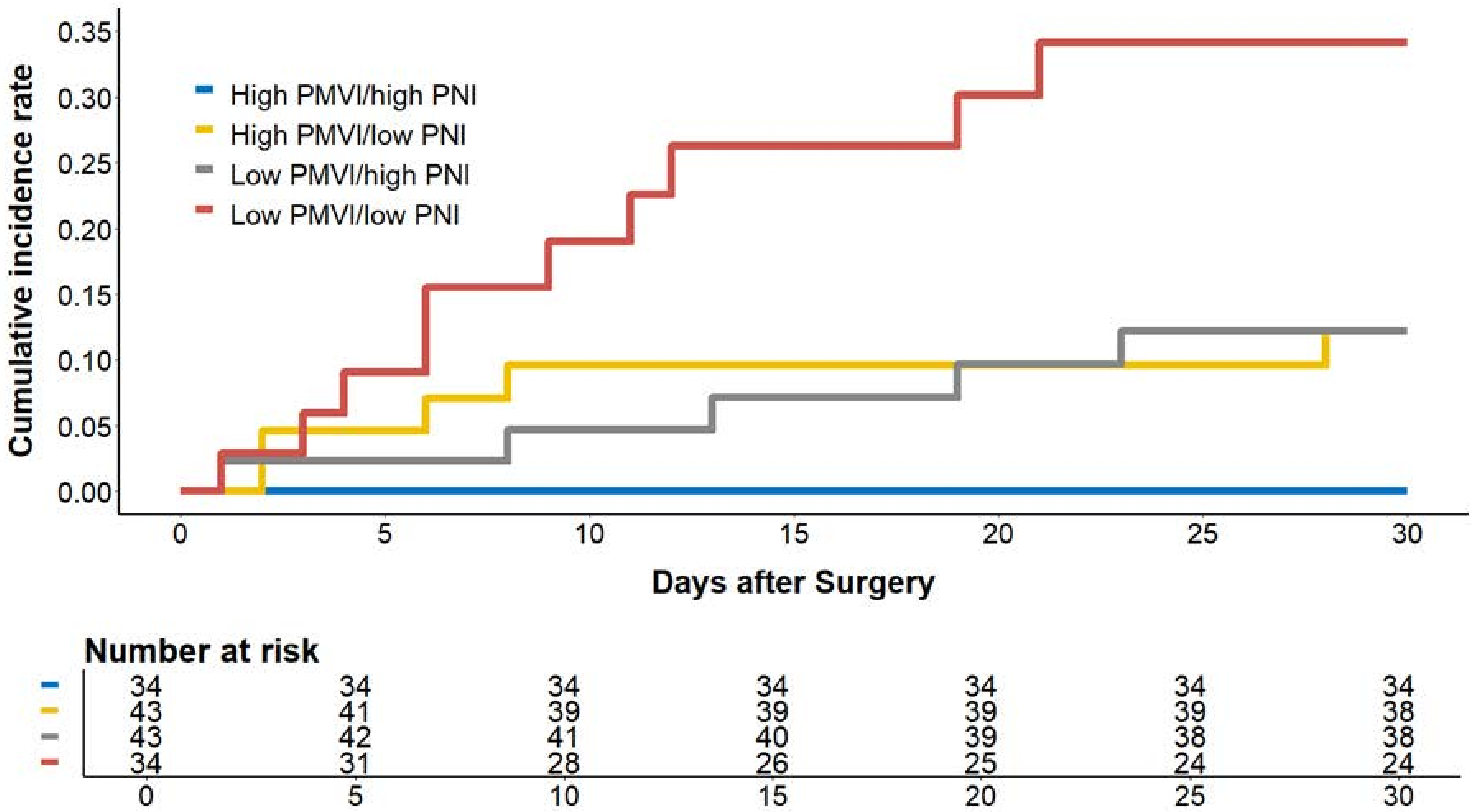

Assessed for eligibility
(n=430)
Excluded
(n=246)
• Emergent cardiac surgery (n=189)
• No measurable CT images within 30 days before cardiac surgery (n=38)
• No lymphocyte counts or serum albumin levels within 7 days before cardiac surgery (n=29)
Final cohort of patients who underwent cardiac surgery
(n=154)
Follow-up within 30 days after cardiac surgery
(n=154)

Figure 3



0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Cumulative incidence rate
High PMVI/high PNI
High PMVI/low PNI
Low PMVI/high PNI
Low PMVI/low PNI
0
5
10
15
20
25
30
Days after Surgery
Number at risk
34 34 34 34 34 34 34
43 41 39 39 39 39 38
43 42 41 40 39 38 38
34 31 28 26 25 24 24
0 5 10 15 20 25 30