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ORIGINAL ARTICLE

Quantification of Sarcopenia using Chest Computed Tomography of the Pectoralis Major Muscle as a Prognostic Tool for Cardiac Surgery Outcomes

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Background and Aim Cardiac surgery is increasingly performed on elderly, frail patients, making objective frailty markers critical for predicting outcomes. Sarcopenia, as defined by the progressive loss of muscle mass and strength, is linked to poorer outcomes after surgery. The pectoralis major (PM) muscle cross-sectional area from chest computed tomography (CT) may offer a novel quantitative method for assessing sarcopenia in cardiac surgery patients.

Methods This study includes data from 237 individuals, who had preoperative chest CT scans and underwent cardiac surgery involving sternotomy from 2019 to 2023 at the Townsville University Hospital, Queensland, Australia. PM muscle area, density, and thickness were measured using chest CT scans. Sarcopenia was defined by the lowest sex-specific quartile in PM area. Demographic data, intra-operative, and postoperative outcomes up to 30 days were collected. Logistic regression analysis assessed the association of sarcopenia with postoperative outcomes. Receiver operating characteristic (ROC) analysis evaluated the clinical value of PM thickness and density in predicting sarcopenia.

Results Cut-off values for PM area were 1,045 mm^2 for males and 609 mm^2 for females, with 59 individuals (25.1%) meeting the criteria for sarcopenia. Sarcopenic patients were significantly older than non-sarcopenic patients ($p<0.001$) and had a lower body mass index ($p=0.008$). Logistic regression showed sarcopenia significantly increased the risk of extended hospital stays (Odds ratio; OR=5.08), longer intensive care unit (ICU) stays (OR=3.16), and prolonged intubation times (OR=2.49; all $p<0.05$). ROC analysis showed high accuracy for muscle thickness (area under the curve; AUC=0.85) in distinguishing sarcopenia, with cut-off values of 12.2 mm for males and 8.1 mm for females. Muscle density had moderate accuracy (AUC=0.64).

Conclusions Our study demonstrates that defining sarcopenia based on the PM cross-sectional area measured from chest CT scans provides a significant predictor of postoperative outcomes in cardiac surgery patients. The established sex-specific cut-off values for muscle area, density and thickness effectively identified sarcopenia, which is associated with prolonged hospitalisation, extended ICU stay, longer intubation time, and an increased risk of postoperative complications.

Keywords Sarcopenia • Frailty • Cardiac surgery • Computed tomography • Pectoralis major

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Introduction

Cardiac surgery has become increasingly prevalent among elderly and frail patients [1]. With an ageing population, there is a growing need to optimise surgical outcomes and identify patients at higher risk for postoperative complications. Frailty, a condition characterised by decreased physiological reserve and increased vulnerability to stressors [2], is a significant predictor of adverse outcomes in this demographic [3]. Among the various markers of frailty, sarcopenia, defined as the progressive loss of skeletal muscle mass and function, has emerged as a critical factor influencing recovery and prognosis following cardiac surgery [4]. Sarcopenia is associated with a range of negative health outcomes, including prolonged hospital stays [4], increased risk of postoperative complications [5], and higher rates of morbidity and mortality [6].

Clinical diagnostic guidelines in sarcopenia have defined sarcopenia based on a combination of muscle function (quality) and muscle mass (quantity). Muscle function is typically assessed through handgrip strength and the Sit-to-Stand test [7–9]. However, because of technical limitations associated with performing pre-operative muscle function assessment, focussing on quantitative muscle mass assessment for detecting sarcopenia has been introduced in several studies. Muscle mass is typically determined using imaging modalities, such as dual-energy X-ray absorptiometry (DEXA), ultrasound, magnetic resonance and computed tomography (CT). Imaging-defined sarcopenia has been previously evaluated in cardiac surgery using CT scans of the psoas muscle, demonstrating its potential as a predictive tool for postoperative outcomes [7,10,11]. This metric can be easily obtained from preoperative chest CT scans, facilitating the integration of sarcopenia assessment into routine clinical practice. This study aims to investigate the utility of quantitative analysis of pectoralis major (PM) mass from pre-operative chest CT scans as a predictor of postoperative outcomes in cardiac surgery patients.

Materials and Methods

Study Design and Setting

The study includes individuals that underwent any cardiac surgery involving sternotomy from 2019 to 2023 at the Townsville University Hospital (TUH), Queensland, Australia. Individuals were recruited through consultation with the Cardiothoracic Surgical Team, and an Indigenous Liaison Officer advised on cultural matters for Indigenous patients. The study was approval by the Townsville Hospital and Health Service human research ethics committee (HREC/QTHS/60962). All patients who underwent cardiac surgery involving sternotomy during the study period had a routine preoperative chest CT scan as part of the standard surgical planning process; therefore, PM measurement was feasible in 100% of cases, with no additional imaging or radiation exposure required. Written informed consent was obtained from all participants prior to inclusion in the study.

Participants

All individuals undergoing cardiac surgery involving sternotomy were considered for inclusion. Exclusion criteria included urgent operations, critical cardiac diseases, and the disapproval of consent to participate in the study. Patient age, gender, height, weight, and body mass inidex (BMI) was calculated, cardiac disease status, diabetes presence, family history of cardiac disease, dyslipidaemia calculated, admission status, preoperative blood results and medications recorded.

Dyslipidaemia was defined according to established clinical criteria as the presence of one or more of the following abnormalities on fasting lipid profile: total cholesterol >5.2 mmol/L, low-density lipoprotein cholesterol (LDL-C) >3.4 mmol/L, high-density lipoprotein cholesterol (HDL-C) <1.0 mmol/L in men or < 1.3mmol/L in women, or triglycerides (TGs) >1.7 mmol/L. Patients currently receiving lipid-lowering therapy, including statins, were also classified as having dyslipidaemia.

Muscle Mass Assessment

Muscle mass assessment was conducted as per the European Working Group on Sarcopenia in Older People (EWGSOP2) guidelines [12]. Non-contrast chest CT, performed as a routine pre-operative assessment of ascending aortic calcification for cannulation strategy, was used to evaluate PM muscle mass measurements. Importantly, patients did not undergo additional radiation exposure for PM muscle analysis.

Imaging Techniques

All chest CT scans were performed using a spiral 320-detector CT (One Aquilion Toshiba, Japan) with 140 kVp, 100 mA, 1.4 beam pitch, and 1 mm slice thickness. Measurements of PM cross-sectional area, density and thickness were taken at the fourth thoracic vertebra (T4) level. The PM was segmented by drawing a region of interest (ROI) along the edges of the right and left PM, with an attenuation range of 50-90 Hounsfield Units (HU). PM area was measured in cm^2, and PM density was measured in HU and were evaluated using the average attenuation within the ROI. PM thickness was measured as the average of the thickest section of the right and left PM.

Measurement and Analysis

We assessed the utility of CT imaging and PM muscle analysis as a method for assessing sarcopenia in cardiac surgery patients. The PM muscle was assessed in this current study for important reasons. Notably, the PM muscle has been increasingly studied as a potential marker for defining sarcopenia from CT-imaging dimensions [13,14].We assessed the PM muscle as part of routine CT analysis prior to cardiac surgery. The cut-off values for sarcopenia were determined based on the lowest sex-specific quartile for PM area, thickness, and density. Previous studies have used the lowest sex-specific quartile

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methodology in assessing total psoas muscle area for a CT imaging-based definition of sarcopenia [15–18]. Each bilateral measurement of PM area, thickness, and density required approximately 3–5 minutes to complete. All measurements were performed by a senior consultant radiologist with extensive experience in thoracic imaging who was blinded to all clinical and outcome data. Although intra-observer reliability was not formally assessed, the segmentation technique is based on straightforward and reproducible anatomical landmarks, making it easily trainable. Clinicians, radiographers, or research staff with basic CT interpretation skills can be readily trained to perform these measurements with high consistency across centres.

Statistical Analysis

Descriptive statistics were used to summarise patient characteristics. Differences between sarcopenic and non-sarcopenic patients were analysed using t-tests for continuous variables and chi-square tests for categorical variables. Receiver operating characteristic (ROC) analysis was conducted to determine the diagnostic performance of PM measurements. Logistic regression analysis was used to evaluate the association between sarcopenia and postoperative outcomes, adjusting for potential confounders. Significance was recorded when the p-value was less than 0.05.

Results

PM Muscle Area, Density, and Thickness

A representative image showing how the area and thickness values were generated from PM muscle CT imaging is provided in Figure 1. The cut-off values for sarcopenia were determined based on the lowest sex-specific quartile. The average PM area cut-off was 1,045.38 mm^2 for males and 608.95 mm^2 for females and these cut-off values were used to stratify patients into sarcopenic and non-sarcopenic groups. Using these cut-off values, we identified 134 males and 44 females that were non-sarcopenic, and 44 males and 15 females that were sarcopenic. The PM muscle thickness cut-off values were 12.21 mm for males and 8.10 mm for females, while the PM muscle density cut-off values were 31.34 HU for males and 15.67 HU for females.

Preoperative Patient Characteristics

The study consisted of a total of 237 individuals who had pre-operative CT chest scans and underwent cardiac surgery involving sternotomy and are summarised in Table 1. The mean age was 70.47±8.29 years for sarcopenic patients and 61.13±11.48 years for non-sarcopenic patients ($p<0.001$). Weight and BMI were significantly higher in non-sarcopenic patients, compared to sarcopenic patients (p=0.022 and p=0.008, respectively). In addition, peripheral vascular disease (PVD) was more common in patients with sarcopenia (p=0.017) but also paralleled less smokers in the sarcopenic group (p=0.037). Sarcopenic patients had significantly lower cholesterol (3.7 versus 4.5, p=0.005) and TG (1.5 versus 1.8 mmol/L) levels compared to non-sarcopenic patients. No significant differences were observed in creatinine levels (p=0.156) or other blood markers. Regular pre-operative medications were similar between both groups.

Operative Data

Intraoperatively, no significant differences were noted in surgery type or pump time between the sarcopenic and non-sarcopenic patient groups. Sarcopenic patients had a

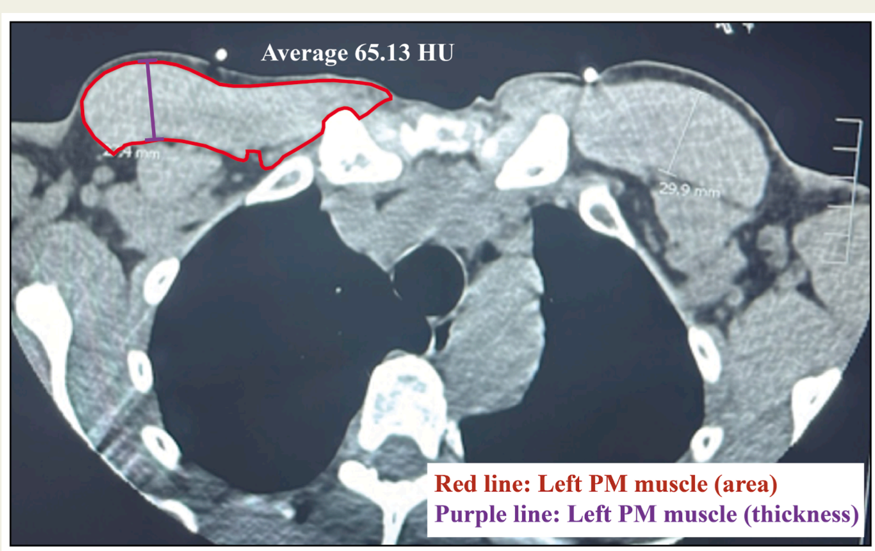

Figure 1 Representative CT scan image of PM muscle. The PM muscle is indicated (red line). PM area (red line = 2,184 mm^2), thickness (purple line =27.4 mm) and density (65.13 HU) were calculated for each patient chest CT scan. The numbers above relate to the representative image provided.
Abbreviations: CT, computed tomography; HU, Hounsfield units; PM, pectoralis major.

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Table 1 Preoperative characteristics including associated cardiovascular risk factors, blood marker levels and medications for all patients.

Variable	Sarcopenia (n=59)				Non-Sarcopenia (n=178)				p-value
	Non-Indigenous n=50	Indigenous n=9	p-value	Total	Non-Indigenous n=133	Indigenous n=45	p-value	Total	
Age, years, mean±SD	70.90±8.45	68.11±7.32	*0.357	70.47±8.29	63.7±10.9	53.6±9.9	*<0.001	61.13±11.48	*<0.001
Gender, female, n (%)	11 (22.0)	4 (44.4)	***0.213	15 (25.4)	26 (19.5)	18 (40.0)	**0.006	44 (24.7)	**0.914
Height, mean±SD	169.1±9.7	167.1±11.7	*0.573	168.8±9.97	171.9±8.98	169.9±7.87	*0.191	171.4±8.73	*0.05
Weight, mean±SD	80.9±15.6	74.58±19.45	*0.282	84.0±16.2	89.9±18.7	85.5±19.4	*0.184	88.8±18.9	*0.022
BMI, mean±SD	28.1±4.9	26.8±7.1	*0.524	27.9±5.2	30.3±5.9	29.8±6.0	*0.596	30.2±5.9	*0.008
LVEF, %, mean±SD	53.6±12.5	57.4±11.1	*0.427	54.1±12.3	55.4±10.7	50.3±14.1	*0.041	54.1±11.8	*0.988
COPD, n (%)	7 (14.0)	2 (22.2)	***0.615	9 (15.3)	15 (11.3)	5 (11.1)	*0.976	20 (11.2)	**0.414
Diabetes, n (%)	24 (48.0)	5 (55.6)	***0.731	29 (49.2)	44 (33.3)	30 (66.7)	**<0.001	74 (41.8)	**0.325
HTN, n (%)	35 (70.0)	8 (88.9)	***0.421	43 (72.9)	78 (59.1)	32 (71.1)	**0.151	110 (62.1)	**0.135
PVD, n (%)	6 (12.0)	0 (0.0)	***0.577	6 (10.2)	2 (1.5)	2 (4.4)	***0.263	4 (2.2)	***0.017
Stroke, n (%)	8 (16.0)	1 (11.1)	***>0.99	9 (15.3)	9 (6.8)	3 (6.8)	***>0.99	12 (6.8)	**0.052
FH of IHD, n (%)	3 (6.0)	2 (22.2)	***0.163	5 (8.5)	25 (18.9)	10 (22.2)	**0.633	35 (19.8)	**0.055
Dyslipidaemia, n (%)	18 (36.0)	7 (77.8)	***0.029	25 (42.4)	72 (54.5)	31 (68.9)	**0.092	103 (58.2)	**0.065
NYHA class			***0.119				**0.899		**0.365
I	4 (21.1)	2 (100.0)		6 (28.6)	23 (46.0)	8 (40.0)		31 (44.3)	
II	10 (52.6)	0 (0.0)		10 (47.6)	20 (40.0)	9 (45.0)		29 (41.4)	
III	5 (26.3)	0 (0.0)		5 (23.8)	7 (14.0)	3 (15.0)		10 (14.3)	
Angina, n (%)	21 (42.2)	5 (55.6)	***0.488	26 (25.5)	57 (43.2)	19 (42.2)	**0.911	76 (42.9)	**0.879
SOB, n (%)	26 (52.0)	5 (55.6)	***>0.99	31 (52.5)	56 (42.4)	19 (42.2)	**0.981	75 (42.4)	**0.174
Admission with ACS, n (%)	17 (34.0)	6 (66.7)	***0.134	23 (39.0)	43 (32.6)	20 (44.4)	**0.151	63 (35.6)	**0.639
Admission with HF, n (%)	6 (12.0)	2 (22.2)	***0.595	8 (13.6)	18 (13.6)	8 (17.8)	**0.498	26 (14.7)	**0.831
Active smoker, n (%)	4 (8.0)	2 (22.2)	***0.224	6 (11.5)	22 (16.7)	18 (40.0)	**0.001	40 (22.6)	**0.037
Ex-smoker, n (%)	29 (58.0)	4 (44.4)	***0.488	26 (44.1)	75 (56.8)	24 (53.3)	**0.684	99 (55.9)	**>0.99
Preoperative blood results									
Hb, g/L	130 (118–137)	139 (109–147)	0.316	130 (118–139)	137 (128–149)	134 (120–150)	0.314	136 (126–148)	0.059****
Creatinine, µmol/L	90 (77–110)	104 (83–386)	0.129	91 (77–114)	87 (75–102)	92 (63–112)	0.704	88 (74–106)	0.156****
HbA1c, %	6.3 (5.6–7.0)	5.8 (5.5–6.17)	0.348	6.2 (5.6–6.8)	5.8 (5.4–7.0)	6.9 (6.1–8.7)	<0.001	6.1 (5.6–7.7)	0.773****
Cholesterol, mmol/L	3.6 (3.2–5.1)	4.3 (3.1–5.5)	0.569	3.7 (3.2–5.2)	4.5 (3.5–5.4)	4.4 (3.6–5.3)	0.844	4.5 (3.5–5.4)	0.005****
LDL, mmol/L	1.9 (1.20–3.07)	2.8 (1.4–3.5)	0.375	1.95 (1.2–3.1)	2.40 (1.5–3.4)	2.5 (1.8–3.4)	0.508	2.45 (1.6–3.4)	0.056****
HDL, mmol/L	1.0 (0.8–1.4)	0.95 (0.6-–1.5)	0.480	1.0 (0.8–1.4)	1.0 (0.8–1.3)	0.9 (0.8–1.1)	0.054	1.0 (0.8–1.20)	0.531****
TG, mmol/L	1.50 (1.0–2.2)	1.60 (1.3–2.2)	0.724	1.5 (1.1–2.2)	1.7 (1.2–2.5)	1.9 (1.4–2.8)	0.373	1.8 (1.3–2.6)	0.038****
Preoperative medications									
ACEi, n (%)	19 (22.9)	8 (88.9)	***0.008	27 (26.5)	53 (40.2)	26 (57.8)	**0.040	79 (44.6)	0.880
ARB, n (%)	11 (22.0)	0 (0.0)	***0.141	11 (18.6)	25 (18.9)	6 (13.3)	**0.393	31 (17.5)	0.844
Beta-blocker, n (%)	30 (60.0)	5 (55.6)	***>0.99	35 (59.3)	63 (47.7)	30 (66.7)	**0.028	93 (52.5)	0.365
Statins, n (%)	34 (68.0)	6 (66.7)	***>0.99	40 (67.8)	87 (65.9)	32 (71.1)	**0.521	119 (67.2)	0.936

Table 1. (continued).

Variable	Sarcopenia (n=59)				Non-Sarcopenia (n=178)				p-value
	Non-Indigenous n=50	Indigenous n=9	p-value	Total	Non-Indigenous n=133	Indigenous n=45	p-value	Total	
Oral hypoglycemic, n (%)	17 (34.0)	3 (33.3)	***>0.99	20 (33.9)	34 (25.8)	20 (44.4)	****0.019**	54 (30.5)	0.627
Insulin, n (%)	10 (20.0)	0 (0.0)	0.333	10 (16.9)	13 (9.8)	8 (17.8)	**0.155	21 (11.9)	0.317

Comparisons were made between Indigenous and non-Indigenous patients among sarcopenic and non-sarcopenic groups and between all sarcopenic and non-sarcopenic patients. The number of patients and the percentage of patients for each variable is provided as n (%). Bolded p-values represent those with statistical significance.

*Independent sample t-test, **Chi square test, ***Fisher exact test, ****Mann–Whitney U test.

Abbreviations: ACEi, angiotensin-converting enzyme inhibitors; ACS, acute coronary syndrome; ARB, angiotensin receptor blocker; BMI, body mass index; COPD, chronic obstructive pulmonary disease; FH, family history; Hb, haemoglobin; HbA1C, haemoglobin A1C; HDL, high-density lipoprotein; HF, heart failure; HTN, hypertension; IHD; ischaemic heart disease; LDL, low-density lipoprotein; LVEF, left ventricle ejection fraction; NYHA, New York Heart Association; PVD, peripheral vascular disease; SD, standard deviation; SOB, shortness of breath; TG, triglyceride.

median cross-clamp time of 81 mins (IQR: 53-103), versus 71 mins (IQR: 54-95) for non-sarcopenic patients (p=0.534) (Table 2).

Postoperative outcomes revealed that sarcopenic patients had a longer ICU stay (median 3 days versus 2 days, $p<0.001$), longer hospital stays (median 9 days versus 6 days, $p<0.001$), and a greater intubation time (1.57 ± 2.77 versus 1.14 ± 2.01, p=0.020) when compared to non-sarcopenic patients. Sarcopenic patients were also more likely to experience postoperative complications including atrial fibrillation (AF), acute kidney injury (AKI), stroke, sternal wound infection, pulmonary infection and return to theatre (p=0.002) (Table 3).

Diagnostic Performance

ROC analysis demonstrated that PM thickness had a greater area under the curve (AUC=0.85, $p<0.001$) compared to PM density (AUC=0.64, p=0.001) for predicting sarcopenia, with a cut-off value of 11.28 mm providing 80.0% sensitivity and 70.0% specificity (Figure 2 and Table 4). Importantly, correlation analysis revealed a strong positive correlation between PM area and thickness (r=0.91, $p<0.001$), while the correlation between PM area and density was weaker and not statistically significant (r=0.38, p=0.565). There was no significant correlation between PM density and thickness (r=0.063, p=0.334) (Table 5).

Logistic Regression Analysis

Logistic regression analysis (Table 6) showed that sarcopenia significantly associated with an increased risk of extended hospital stay (adjusted OR=5.08, 95% CI: 2.35–10.96, $p<0.001$), a longer stay in ICU (adjusted OR=3.16, 95% CI: 1.54–6.50, p=0.002), and prolonged intubation (adjusted OR=2.49, 95% CI: 1.09–5.67, p=0.031), after adjusting for age, sex, BMI, smoking status, and PVD.

Discussion

The present study demonstrates that the presence of sarcopenia, as detected through chest CT scan quantification of PM muscle cross-sectional area, is a significant independent predictor of postoperative outcomes in patients undergoing cardiac surgery. In addition, we find that the defined PM muscle thickness cut-off point strongly correlated with PM cross-sectional area, suggesting that muscle thickness, may also be a feasible muscle dimension to define sarcopenia. Importantly, longer hospitalisation, ICU stay, and postoperative complications were noted in sarcopenic patients after adjustment for associated risk factors. Additionally, sarcopenic patients were found to be older with a lower BMI, and more likely to have comorbidities such as peripheral vascular disease. Surprisingly, we find that sarcopenic patients compared to non-sarcopenic patients, have lower levels of cholesterol and TG. This aligns with a growing body of literature suggesting lower lipid levels may underscore a catabolic state instead of a favourable metabolic profile

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Table 2 **Intraoperative patient data.**

Variable	Sarcopenia				Non-Sarcopenia				p-value
	Non-Indigenous	Indigenous	p-value	Total	Non-Indigenous	Indigenous	p-value	Total	
Redo-operation	1 (2.0)	0 (0.0)	*>0.99	1 (1.7)	5 (3.8)	1 (2.2)	*>0.99	6 (3.4)	*0.684
Type of surgery			*0.615				***0.010**		*0.277
Aorta	2 (4.0)	0 (0.0)		2 (3.4)	7 (5.3)	1 (2.2)		8 (4.5)	
AVR	3 (6.0)	0 (0.0)		3 (5.1)	21 (15.9)	1 (2.2)		22 (12.4)	
CABG	26 (52.0)	7 (77.8)		33 (55.9)	76 (57.6)	30 (66.7)		106 (59.9)	
Concomitant	15 (30.0)	1 (11.1)		16 (27.1)	18 (23.1)	13 (28.9)		31 (17.5)	
MV repair/ replacement	4 (8.0)	1 (11.1)		5 (8.5)	8 (6.1)	0 (0.0)		8 (4.5)	
Other	0 (0.0)	0 (0.0)		0 (0.0)	2 (1.5)	0 (0.0)		2 (1.1)	
Intra-operative data									
Pump time-isolated procedure, min, median (IQR)	111 (76–151)	81 (76–142)	**0.607	109 (76-146)	99 (81–129)	95 (75–139)	**0.740	99 (81–131)	**0.411
Cross clamp time-isolated procedure, min, median (IQR)	82 (52–103)	60 (53–107)	**0.693	81 (53–103)	72 (55–96)	69 (54–99)	**0.758	71 (54–95)	**0.534

Operation type as well as cross clamp time and pump time in isolated procedures are shown. Comparisons were made between Indigenous and non-Indigenous patients among sarcopenic and non-sarcopenic groups and between all sarcopenic and non-sarcopenic patients. Mean values are provided ± SD, n (%). Bolded p-values represent those with statistical significance.

*Independent sample t-test, **Chi square test.

Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft; IQR, interquartile range; MV, mitral valve; SD, standard deviation.

[19,20]. Studies showed that modestly higher triglycerides, and total cholesterol were independently associated with a lower risk of sarcopenia, highlighting the potential role of lipids in protecting against muscle depletion [19,20]. These findings suggest lower lipid levels in sarcopenic individuals may represent impaired physiological reserve, systemic catabolism, subclinical malnutrition, or unmasked sustained exposure to chronic diurnal resource scarcity.

Our study is consistent with previous research showing that sarcopenia predicts post cardiac surgery outcomes [4,21–26]. Okamura et al. [25] recently reported that preoperative sarcopenia defined from the psoas muscle area, associated with a greater risk of long-term mortality and major adverse cardio-cerebrovascular events in elderly patients undergoing cardiac valve surgery.

Interestingly, our analysis revealed differences in sarcopenia prevalence between Australian Indigenous and non-Indigenous patients, with Indigenous patients showing a lower prevalence of sarcopenia despite having higher rates of comorbidities (Table 1). This finding contrasts with previous studies that associate Indigenous status with higher frailty and sarcopenia risk [24,26,27]. This suggests that being Indigenous may not be an isolated factor contributing to sarcopenia, and highlight the need for further research to explore the complex interplay between ethnicity, sarcopenia, and other health determinants in this group.

Overall, results from our current study and others support incorporating sarcopenia assessment into preoperative evaluations, with the goal of enhancing prognosis and improving the management of patients undergoing cardiac surgery, particularly in diverse populations. Beyond its prognostic value, CT-defined sarcopenia may also serve as a practical tool for prospectively identifying patients at increased perioperative risk. In elective or non-urgent cardiac surgery cases, where time allows for preoperative optimisation, recognising reduced muscle mass could guide targeted interventions such as nutritional support and resistance-based prehabilitation programs. Integrating such assessment into standard pre-surgical evaluation may help refine clinical decision-making and surgical timing, particularly in older and frail patients, ultimately improving postoperative recovery and long-term outcomes.

The exact mechanism connecting preoperative sarcopenia to increased postoperative morbidity risks is still not fully

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Table 3 Postoperative patient data.

Variable	Sarcopenia				Non-Sarcopenia				p-value
	Non-Indigenous	Indigenous	p-value	Total	Non-Indigenous	Indigenous	p-value	Total	
Postoperative data									
Day of extubation, mean±SD	1.65±2.99	1.11±0.78	**0.821	1.57±2.77	1.05±1.86	1.38±2.41	**0.322	1.14±2.01	****0.020**
ICU stay, days, median (IQR)	3 (2-4)	3 (2.0–5.5)	**0.583	3 (–4)	2 (1–3)	2 (1–4)	**0.160	2 (1–3)	**<**0.001**
Hospital stay, days, median (IQR)	9 (7–12)	9 (8–11)	**0.882	9 (7–12)	6 (5–9)	7 (5 –11.5)	**0.145	6 (5–9)	**<**0.001**
Postoperative complications			*0.338				***0.001**		***0.002**
AF	18 (36.0)	5 (22.6)		23 (39.0)	33 (28.1)	4 (8.9)		37 (20.9)	
AKI	2 (4.0)	1 (11.1)		3 (5.1)	2 (1.5)	1 (2.2)		3 (1.7)	
Stroke	2 (4.0)	0 (0.0)		2 (3.4)	5 (3.8)	1 (2.2)		6 (3.4)	
Sternal wound infection	2 (4.0)	1 (11.1)		3 (5.1)	0 (0.0)	3 (6.7)		3 (1.7)	
Pulmonary infection	1 (2.0)	0 (0.0)		1 (1.7)	1 (0.8)	4 (8.9)		5 (2.8)	
Return to theatre	4 (8.0)	0 (0)		4 (6.8)	1 (0.8)	2 (4.4)		3 (1.7)	
Others	2 (4.0)	1 (11.1)		3 (5.1)	21 (15.9)	5 (11.1)		26 (14.7)	
Mortality	1 (2.0)	0 (0.0)	*>0.990	1 (1.7)	4 (3.0)	1 (2.2)	*>0.990	5 (2.6)	*>0.990

Postoperative duration of intubation, ICU stay, and total hospital stay as well as post-operative complications are shown. Comparisons were made between Indigenous and non-Indigenous patients among sarcopenic and non-sarcopenic groups and between all sarcopenic and non-sarcopenic patients. n (%). Bolded p-values represent those with statistical significance.
*Extended Fisher test, **Mann–Whitney U test.
Abbreviations: AF, atrial fibrillation; AKI, acute kidney injury; ICU, intensive care unit; IQR, interquartile range; SD, standard deviation.

understood. Nonetheless, previous studies indicate that patients with sarcopenia may have a reduced capacity for recovery after major surgery, possibly due to altered protein metabolism or a lower physiological reserve to manage surgical stress [28].

Lim et al. [29] explored the influence of sarcopenia on outcomes following minimally invasive cardiac surgery (MICS). They found comparable perioperative outcomes and survival between sarcopenic and non-sarcopenic patients, suggesting that MICS might mitigate the adverse effects of sarcopenia. In contrast, our study observed significant differences in short-term outcomes between sarcopenic and non-sarcopenic patients undergoing sternotomy. This difference may highlight the potential benefits of MICS in elderly, frail patients, suggesting an area for further research and potential clinical practice adjustments.

Several studies have assessed the cross-sectional area of the psoas muscle using abdominal CT scans to diagnose sarcopenia (15-17). Additionally, Kiriya et al. [30] assessed sarcopenia in cardiac surgery patients using the total psoas muscle index (TPI), which is the sum cross-sectional area of both psoas muscles (mm^2) normalised to height (m^2), and the intra-muscular adipose tissue content (IMAC) from abdominal CT scans. Their findings indicated higher complication rates in patients with low TPI and high IMAC, underscoring the prognostic value of both muscle quantity and quality. Further work has examined the relationship between measures of skeletal muscle mass at L3 and T12 segments [22,23,25]. From these studies it has been proposed that assessing muscle mass using chest CT scans at the T12 level could serve as a diagnostic tool for sarcopenia [22,23,25], supporting chest CT analysis as a valid approach to diagnose sarcopenia.

In this study we used a novel opportunistic chest CT scan approach to assess for sarcopenia using the PM muscle. Importantly, as chest CT scans are routinely performed on almost all patients undergoing cardiac surgery, this approach provides the opportunity to assess for sarcopenia without the need for additional X-ray exposure. Additionally, our study further determined sex-specific PM muscle cut-off values for sarcopenia detection based on the lowest sex-specific quartile. This approach has proven validity,

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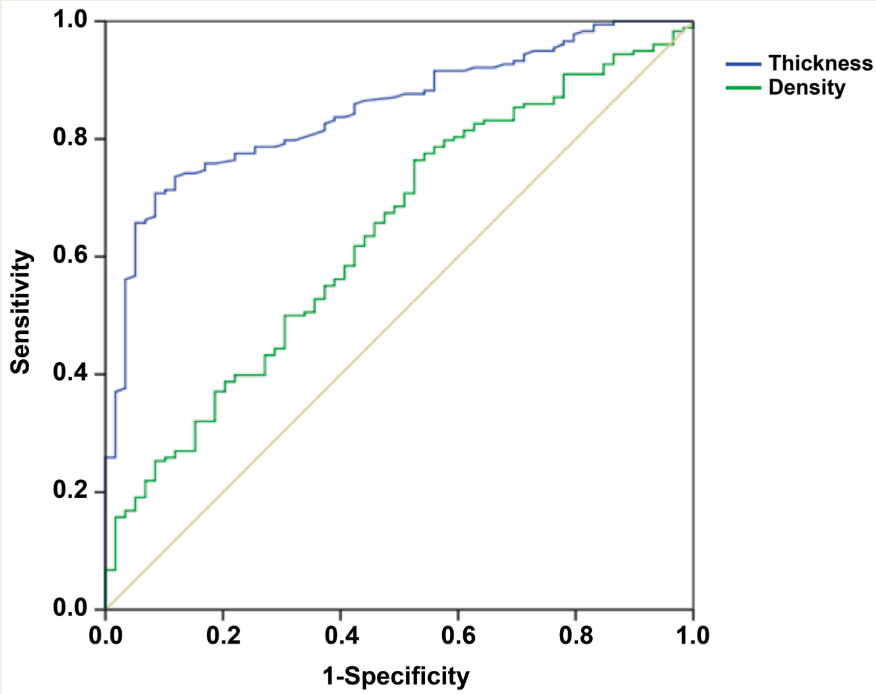

Figure 2 ROC analysis of PM thickness and density in predicting sarcopenia. Graph showing ROC curves with AUC analysis. ROC analysis was used to define cut-off values as well as sensitivity and specificity in predicting sarcopenia from PM muscle thickness and PM muscle density based on our pre-defined PM muscle cross-sectional area cut-off value. Analysis of PM thickness (blue line; AUC=0.85; cut-off: 11.28; sensitivity 80%, specificity 70%) and PM density (green line, AUC=0.64; cut-off: 31.59; sensitivity: 70%; specificity: 50%) are shown. The reference (taupe line) is also indicated. Abbreviations: AUC, area under the curve; PM, pectoralis major; ROC, receiver operating characteristic.

having been previously used to calculate psoas muscle cut-off values for identifying sarcopenia in cardiac surgery patients [25].

Although CT imaging is widely regarded as the gold standard for non-invasive muscle mass assessment, there are no current consensus cutoff values for diagnosing sarcopenia. In this regard, studies employing CT images have used a wide range of different cut-off values for sarcopenia diagnosis [31]. This highlights a major gap in the field and further underscores the requirement for consensus CT cut-off values for muscle mass assessment to diagnose sarcopenia.

From a feasibility standpoint, the integration of CT-defined sarcopenia assessment into preoperative workflows appears highly practical. Chest CT imaging is routinely performed prior to cardiac surgery, allowing PM muscle analysis to be completed on existing datasets within minutes and without any additional cost or patient exposure. The minimal time requirement and absence of added procedural burden make this technique well suited for incorporation into routine clinical practice. The measurement approach is straightforward and reproducible, enabling clinicians, radiographers, or research staff with basic CT interpretation experience to be easily trained to

Table 4 Diagnostic performance of thickness and density indexes.

Feature	AUC (95% CI)	Cut-off point	Sensitivity (%)	Specificity (%)
Thickness	0.85 (0.80–0.90), p<0.001	11.28	80.0	70.0
Density	0.64 (0.56–0.72), p=0.001	31.59	70.0	50.0

Data from ROC and AUC analysis for defining cut-off values as well as sensitivity and specificity in predicting sarcopenia from pectoralis major thickness and density based on pre-defined cross-sectional area cut-off value. The AUC values are provided with 95% CIs.
Abbreviations: AUC, area under the curve; CI, confidence interval; ROC, receiver operating characteristic.

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Table 5 **Correlation of pectoralis major area, density, and thickness.**

Variable	Mean thickness	Mean density
Mean area	r=0.911	r=0.38
	p<0.001	p=0.565
Mean thickness	-	r=0.063
		p=0.334

The analysis of the linear relationship between pectoralis major muscle area, density, and thickness is shown. The correlation coefficient "r" values are provided, and the bolded p-value represents statistical significance.

perform the analysis with consistent accuracy across centres. Moreover, the method lends itself to future automation through AI-based muscle segmentation tools, which would further streamline analysis and support large-scale clinical implementation and cost-effectiveness evaluation.

A strength of this study is the use of objective measurements of the PM muscle from chest CT scans, which minimises inter-observer variability and enhances reproducibility. Additionally, the inclusion of a relatively large sample size and the use of a single radiologist for muscle measurements further strengthen the reliability of our findings. A key strength of this study is the inclusion of a considerable proportion of Indigenous Australian patients, a group that remains under-represented in cardiovascular and frailty research. This representation enhances the relevance and generalisability of our findings and highlights the importance of continuing to explore imaging-based frailty markers within diverse populations.

There are limitations to consider related to the current study. First, the study was conducted at a single centre, which may limit the generalisability of the findings to other populations or settings. Second, the use of PM muscle measurements as a proxy for overall muscle mass might not fully capture the complexity of sarcopenia, which also involves muscle strength and function. Future studies should incorporate comprehensive sarcopenia assessments, that in addition to imaging assessment of PM muscle mass, adopt a sarcopenia questionnaire, such as SARC-F, which have shown utility in detecting sarcopenia [32], together with functional testing including assessment of handgrip strength, gait speed and Sit-to-Stand capabilities. Moreover, further studies are required to determine which measurement level or area and what cut-off value is the best predictor of outcomes following cardiac surgery.

Given the significant impact of sarcopenia on post-operative outcomes, as demonstrated by our study, future research should focus on the development and validation of sarcopenia screening protocols that incorporate the quantification of the PM muscle area from chest CT scans. Additionally, interventions aimed at mitigating sarcopenia, such as preoperative nutritional supplementation and resistance exercise training, should be explored in the context of these specific sarcopenia measures to determine their efficacy in improving surgical outcomes.

Conclusions

This study provides compelling evidence that sarcopenia, as determined by PM cross-sectional area from chest CT scans, is a valuable predictor of postoperative outcomes in cardiac surgery patients. PM cut-off values for sarcopenia via chest CT is a feasible, easy to use and reliable criteria as part of pre-cardiac surgery assessment. Incorporating sarcopenia assessment into routine preoperative evaluations can aid in identifying high-risk surgical patients and tailoring pre-operative strategies to improve surgical outcomes in vulnerable populations.

Table 6 **Logistic regression analysis to test the predictor role of sarcopenia for hospital stay, ICU stay and days of intubation.**

Variable	Crude OR (95% CI)	p-value	*Adjusted OR (95% CI)	p-value
Hospital stay length				
Sarcopenia	5.58 (2.88–10.82)	**<0.001**	5.08 (2.35–10.96)	**<0.001**
ICU stay				
Sarcopenia	2.90 (1.58–5.33)	**0.001**	3.16 (1.54–6.50)	**0.002**
Days of intubation				
Sarcopenia	2.34 (1.16–4.73)	**0.017**	2.49 (1.09–5.67)	**0.031**

Summary of the association of sarcopenia with length of hospital stay, ICU, and days of intubation. Bolded p-values represent those with statistical significance.
*Data adjusted for age, gender, body mass index, smoking and peripheral vascular disease.
Abbreviations: CI, confidence interval; ICI, intensive care unit; OR, Odds ratio.

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Declaration of Competing Interests

The authors declare that they have no conflicts of interest relevant to this work.

Author Contributions

P.N.: Conceptualisation, Methodology, Validation, Formal analysis, Investigation, Resources, data curation, Writing - Original Draft, Writing - Review & Editing, Visualisation; P.S.: Conceptualisation, Investigation, Resources, Writing - Review & Editing; Supervision, Project administration, Funding acquisition; J.R.: Conceptualisation, Investigation, Resources, Writing - Review & Editing; Supervision, Project administration, Funding acquisition; L.H.: Conceptualisation, Resources, Writing - Review & Editing, Supervision, Funding acquisition; N.D.: Methodology, Investigation, Resources, Writing - Review & Editing, Project administration; C.M.: Conceptualisation, Methodology, Writing - Review & Editing, Visualisation, Supervision, Project administration, Funding acquisition.

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