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Weighing the risks: The impact of body mass index on postoperative complications in cardiac surgery

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Body mass index;
Cardiac surgery;
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Abstract
Introduction: Body mass index (BMI) is a key determinant of cardiovascular risk and may significantly impact postoperative outcomes. This study aimed to evaluate the relationship between BMI and early postoperative complications in patients undergoing cardiac surgery.
Methods: This retrospective study analyzed data from 555 patients who underwent cardiac surgery at the National Institute of Cardiology from June 2022 to December 2023. Patients were categorized into 4 BMI groups: underweight, normal weight, overweight, and obese. Data on demographics, surgical procedures, postoperative complications, and hemodynamic parameters were collected and analyzed.
Results: Preoperative comorbidities, including chronic heart failure and atrial fibrillation, were more common among underweight patients. This group was also at higher risk of postcardiotomy low output syndrome (univariate OR 3.35, $p = 0.03$), and postoperative atrial fibrillation remained significant in multivariate analysis (OR 1.48, $p = 0.01$), and required increased vasopressor and inotropic support. Obese patients had a significantly increased risk of postoperative mediastinitis in both univariate (OR 2.47, $p = 0.04$) and multivariate analyses (OR 2.12, $p = 0.03$). In-hospital mortality was 14.3 % in underweight vs. 6.1 % in obese patients ($p = 0.52$).
Conclusions: This study highlights the significant impact of BMI on postoperative outcomes in cardiac surgery. Underweight patients exhibited higher rates of postoperative complications and mortality, likely due to underlying comorbidities and limited physiological reserves. While obesity is associated with increased cardiovascular risk, our findings suggest a potential "obesity paradox" in this cohort. Further research is needed to elucidate the underlying mechanisms and refine risk stratification models incorporating BMI and other relevant factors.

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PALABRAS CLAVE
Índice de masa corporal;
Cirugía cardíaca;
Resultados postoperatorios;
Comorbilidades;
Obesidad

Sopesar los riesgos: impacto del índice de masa corporal en las complicaciones postoperatorias en la cirugía cardíaca

Resumen
Introducción: El índice de masa corporal (IMC) representa un factor determinante en la salud cardiovascular y puede influir significativamente en la evolución postoperatoria. El objetivo de este estudio fue analizar la asociación entre el IMC y los desenlaces tempranos en pacientes sometidos a cirugía cardíaca.
Métodos: Este estudio retrospectivo analizó datos de 555 pacientes que se sometieron a cirugía cardíaca en el Instituto Nacional de Cardiología de junio de 2022 a diciembre de 2023. Los pacientes se clasificaron en cuatro grupos de IMC: bajo peso, peso normal, sobrepeso y obesidad. Se recopilaron y analizaron datos demográficos, procedimientos quirúrgicos, complicaciones postoperatorias y parámetros hemodinámicos.
Resultados: Los pacientes con bajo peso presentaron mayor prevalencia de comorbilidades preoperatorias, incluyendo insuficiencia cardiaca crónica y fibrilación auricular. El bajo peso se asoció con un mayor riesgo de síndrome de bajo gasto cardiaco postcardiotomía (análisis univariable OR 3.35, p = 0.03), y la fibrilación auricular postoperatoria se mantuvo significativa en el análisis multivariable (OR 1.48, p = 0.01), requiriendo mayor soporte vasoactivo e inotrópico. Los pacientes obesos mostraron un riesgo significativamente mayor de mediastinitis postoperatoria tanto en el análisis univariable (OR 2.47, p = 0.04) como en el multivariable (OR 2.12, p = 0.03). La mortalidad intrahospitalaria fue de 14.3% en pacientes con bajo peso versus 6.1% en pacientes obesos (p = 0.52).
Conclusiones: Este estudio destaca el impacto significativo del IMC en los resultados postoperatorios en la cirugía cardíaca. Los pacientes con bajo peso exhibieron tasas más altas de complicaciones postoperatorias y mortalidad, probablemente debido a comorbilidades subyacentes y reservas fisiológicas limitadas. Si bien la obesidad se asocia con un mayor riesgo cardiovascular, los hallazgos sugieren una posible "paradoja de la obesidad" en esta cohorte. Se necesita más investigación para dilucidar los mecanismos subyacentes y refinar los modelos de estratificación de riesgo que incorporen el IMC y otros factores relevantes.

Introduction

Background

Body mass index (BMI) is a widely used metric for classifying and assessing body weight in clinical and epidemiological settings. It is calculated by dividing an individual's weight in kilograms by the square of their height in meters (kg/m^2). The World Health Organization defines specific BMI categories to classify individuals based on their weight status, ranging from underweight (BMI < 18.5 kg/m^2) to obesity class 3 (BMI $\geq$ 40 kg/m^2). While BMI serves as a useful tool for detecting and categorizing weight status, its application in clinical practice, particularly in relation to cardiovascular disease (CVD) and surgery outcomes, is a topic of ongoing research.

Obesity is well recognized as a major risk factor for various cardiovascular conditions, including coronary artery disease, heart failure, and stroke. The relationship between obesity and cardiovascular disease is multifactorial, with mechanisms such as hypertension, dyslipidemia, insulin resistance, chronic inflammation, and obstructive sleep apnea contributing to the increased risk.[1] Conversely, underweight individuals (BMI < 18.5 kg/m^2) have been shown to be at increased risk of CVD and mortality due to factors such as muscle depletion, sarcopenia, and a weakened physiological reserve that limits their ability to withstand surgical stress.[2] Given these opposing risks, it is critical to assess how BMI, as a marker of body weight, impacts outcomes in patients undergoing cardiac surgery.

Importance

Cardiac surgery is a crucial intervention for many individuals with severe cardiovascular disease, including those undergoing coronary artery bypass grafting (CABG), valve replacement, or congenital heart defect repair. The relationship between BMI and patient outcomes in cardiac surgery is complex, and there is conflicting evidence on whether obesity leads to worse or better outcomes compared to patients with normal or low BMI. Several studies have suggested an "obesity paradox", where obese patients, despite their higher BMI, may experience better postoperative outcomes compared to those with normal weight[3,4]; however, some authos suggest that the opposite is true.[5] Nevertheless, underweight patients often experience higher mortality and morbidity due to poor nutritional status and other comorbidities that compromise their ability to recover from surgery.[6,7]

Understanding the effects of BMI on postoperative recovery is essential for optimizing patient management. In particular, determining the risks and benefits associated with different BMI categories can guide preoperative assessments, improve surgical outcomes, and refine treatment strategies for patients undergoing cardiac surgery.

Goals of the investigation

The primary goal of this investigation is to explore the association between BMI and early postoperative outcomes in patients undergoing cardiac surgery. Specifically, the study aims to evaluate how different BMI categories affect clinical parameters, such as mediastinal bleeding, low cardiac output syndrome, vasoplegic syndrome, mechanical ventilation time, arrhythmias, and perioperative mortality.

The primary hypothesis is that patients at the extremes of weight (underweight and obese) experience worse postoperative outcomes compared to those with a normal or overweight BMI. To avoid post-hoc exploratory analyses, this hypothesis and the outcome variables, including in-hospital mortality, were defined a priori to ensure a focused and rigorous analysis based on pre-specified clinical endpoints.

This investigation is designed to:

1 Assess the impact of both low and high BMI on early postoperative outcomes in cardiac surgery.
2 Provide insights into how BMI can be incorporated into preoperative risk assessment models to improve patient management and outcomes in cardiac surgery.

By evaluating the relationship between BMI and cardiac surgery outcomes, we hope to contribute valuable information that can guide clinical practice and improve patient care.

Methods

This was an observational, analytical, cross-sectional study based on retrospective data collected between June 1, 2022, and December 31, 2023. The study population comprised 555 non-consecutive patients over 18 years of age who underwent cardiac surgery with extracorporeal circulation and were admitted to the cardiovascular intensive care unit (ICU) at the Ignacio Chávez National Institute of Cardiology during the study period. All patients who met the inclusion criteria were included.

Inclusion criteria were: patients that had undergone cardiac surgery with extracorporeal circulation at the Ignacio Chávez National Institute of Cardiology, aged over 18 years, any gender. Exclusion criteria were: patients who died during the surgical procedure, patients that remained in the cardiovascular ICU for less than 12 h, and patients with incomplete medical records.

Data were collected from a pre-existing database of patients who underwent cardiac surgery with extracorporeal circulation, and included demographics, surgical procedure, hemodynamic values, outcomes, and intrahospital mortality. Medical records, both physical and electronic, were reviewed to collect data on preoperative, intraoperative, and immediate postoperative status. This was a retrospective descriptive study with no experimental interventions, and was therefore classed as minimal risk under Mexico's General Health Law regulations on research involving humans, which applies to studies that use data from routine diagnostic or treatments. All patient data were held confidential.

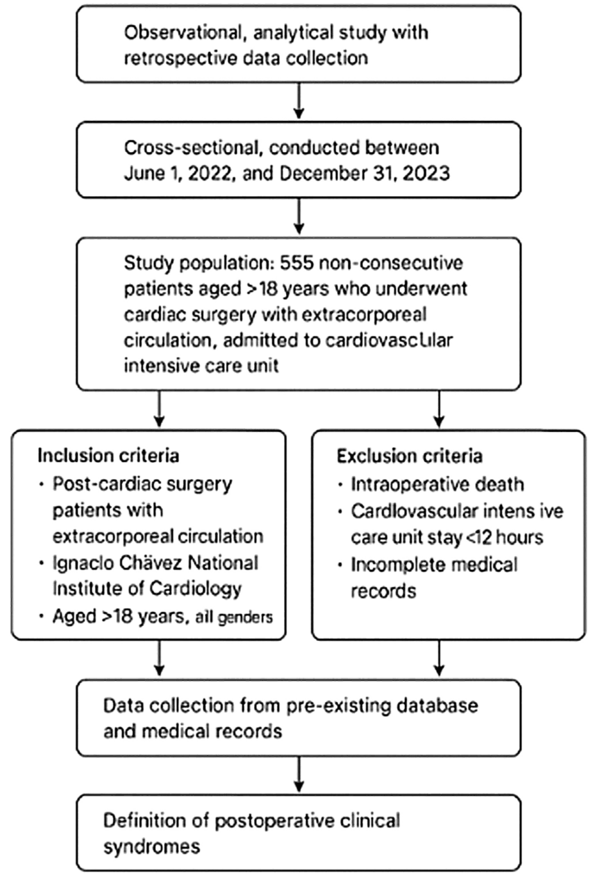

Figure 1 Flow-chart.

The data were collected and the medical records reviewd and analyzed by the authors. The study was performed at the Ignacio Chávez National Institute of Cardiology using data from physical and digital medical records created by medical staff from various departments involved in patient care. The data were entered and analyzed by the authors using their own computer equipment. No financial resources were provided by the Ignacio Chávez National Institute of Cardiology, and the study received no external funding (Fig. 1).

Definition of postoperative clinical syndromes

Low cardiac output syndrome

- Cardiac index < 2.2 l/min/m^2, with systolic blood pressure < 90 mmHg and pulmonary artery occlusion pressure (PAOP) $\geq$ 16 mmHg and/or central venous pressure (CVP) $\geq$ 12 mmHg.

- Urine output < 0.5 ml/kg/h, central venous oxygen saturation < 60%, lactate > 3 mmol/l.
- Postoperative use of inotropes and/or ventricular assist devices for at least 12 h.
- Real or relative hypovolemia ruled out or managed; no predictors of fluid responsiveness

Vasoplegic syndrome

- Hypotension:
  - o Systolic blood pressure < 80 mmHg.
  - o Mean arterial pressure < 50 mmHg.
- Vasodilation:
  - o Systemic vascular resistance < 800 dyn/s/cm^{-5}.
  - o CVP > 5 mmHg.
  - o PAOP > 10 mmHg.
- Cardiac index > 2.2 l/min/m^2.
- Use of vasopressors:
  - o Norepinephrine > 0.3 mcg/kg/min.
- Real or relative hypovolemia ruled out or managed; no predictors of fluid responsiveness

Mediastinal bleeding

- > 300 ml in the first hour after surgery.
- > 200 ml per hour for more than 2 h.
- > 100 ml per hour for more than 3 h.

For statistical analysis, the Shapiro-Wilk normality test was used to evaluate the distribution of continuous variables. Variables were recorded as mean ± standard deviation if normally distributed, or as median and interquartile range (IQR) in the case of non-parametric data. Continuous variables were compared using the Mann-Whitney U test, while categorical variables were expressed as frequencies and percentages, with comparisons made using the chi-square test or Fisher's exact test, as appropriate. A logistic regression model adjusted for age and sex was used to identify variables that predict adverse postoperative outcomes. Statistical significance was set at $p < 0.05$. Data analyses were performed using STATA version 14.

Model validation and adjustment for multiple comparisons

To ensure the robustness of our findings, we performed logistic regression analyses adjusting for potential confounders, particularly age, (given the significantly younger age of the underweight group), sex, previous cardiac surgery, and high surgical risk, defined as a logistic EuroSCORE > 5%. Model performance was assessed using goodness-of-fit statistics and multicollinearity diagnostics to ensure the stability and interpretability of the regression coefficients. Discrimination was evaluated using the C-statistic (area under the ROC curve), while calibration was assessed with the Hosmer-Lemeshow goodness-of-fit test. Collinearity among independent variables was examined using the variance inflation factor (VIF), with values greater than 5 indicating significant multicollinearity. Due to the large number of endpoints evaluated across BMI strata—including clinical characteristics, hemodynamic parameters, vasoactive drug use, and postoperative complications—the risk of type I error from multiple comparisons could not be ruled out. Consequently, p-values were interpreted cautiously, and findings were contextualized using effect sizes and 95% confidence intervals. Where appropriate, the Bonferroni correction was considered for exploratory outcomes, although it was not applied across the board due to the observational nature of the study and the risk of inflating type II errors.

As an internal validation strategy, we performed a sensitivity analysis excluding the underweight group (BMI < 18.5 kg/m^2) due to its small size and demographic imbalance. This subgroup was not only significantly younger but also exhibited disproportionate rates of comorbidities and complications, which could have biased our estimations. Exclusion of this group did not materially alter the direction or magnitude of the main associations observed, so this confirmed the consistency and internal validity of our results.

Ethics approval

The study was exempt from approval by the research ethics committee. The registry was retrospective and approved prior to the analysis. Data were obtained from the Cardiovascular Critical Care Unit database. No additional intervention was performed on the patients beyond their routine clinical management, and the study was considered to pose minimal risk.

Consent for publication

The patient or their legally authorized representative provided written informed consent for patient information and images to be published.

This research was reported in accordance with the STROBE recommendations for cohort studies.[8]

Results

Baseline characteristics

The study population had a gender distribution of 43.2% women and 53.3% men. The median age was 57 years, although underweight patients (BMI < 18.5 kg/m^2) were significantly younger, with a median age of 29 years compared to 57–58 years in other BMI categories ($p < 0.001$). A history of previous cardiac surgery was more common in underweight individuals (33.3%) than in other BMI groups ($p = 0.03$). Most patients were classified as NYHA functional class II (61.2%), followed by class III (21.8%), class I (13.7%), and class IV (3.2%). Comorbidities such as hypothyroidism (10.4%), chronic kidney disease (5.6%), cerebrovascular disease (5.6%), and COPD (0.7%) were relatively infrequent. Prior myocardial infarction occurred only in patients with obesity (15.3%); heart failure (26.7%) and atrial fibrillation (53.3%) were more frequent in the underweight group. Diabetes mellitus and arterial hypertension were both significantly associated with BMI ($p < 0.001$). Diabetes was more prevalent in overweight and obese patients (27.8% and

Table 1 Baseline characteristics.

Variable	Total (n = 555)	BMI < 18.5 (kg/m^2) (n = 15)	BMI 18.5–24.9 (kg/m^2) (n = 201)	BMI 25–29.9 (kg/m^2) (n = 241)	BMI > 30 (kg/m^2) (n = 98)	p
Women, n (%)	240 (43.2)	8 (53.3)	85 (42.3)	91 (45.3)	42 (42.9)	0.70
Men, n (%)	315 (56.8)	7 (46.7)	116 (57.7)	150 (62.2)	56 (57.1)	
Previous cardiac surgery, n (%)	66 (11.9)	5 (33.3)	26 (12.9)	22 (9.1)	13 (13.3)	0.03
Hypothyroidism, n (%)	58 (10.4)	2 (13.3)	25 (12.4)	22 (9.1)	9 (9.2)	0.66
Previous myocardial infarction, n (%)	63 (11.3)	0	18 (9.0)	30 (12.4)	15 (15.3)	0.18
Diabetes mellitus, n (%)	125 (22.5)	1 (6.7)	31 (15.4)	67 (27.8)	26 (26.5)	0.00
Chronic obstructive pulmonary disease n (%)	4 (0.7)	0	2 (1.0)	1 (0.4)	1 (1.0)	0.85
Chronic kidney disease n (%)	31 (5.6)	0	2 (1.0)	1 (0.4)	8 (8.2)	0.44
Hypertension, n (%)	230 (41.4)	2 (13.3)	68 (33.8)	107 (44.4)	53 (54.1)	0.00
Heart failure, n (%)	151 (27.2)	8 (53.3)	53 (26.4)	65 (27.0)	25 (25.5)	0.14
Atrial fibrillation, n (%)	100 (18.0)	4 (26.7)	44 (21.9)	42 (17.4)	10 (10.2)	0.07
Cerebrovascular disease, n (%)	31 (5.6)	1 (6.7)	0 (0.0)	1 (0.4)	4 (4.1)	0.77
NYHA functional class						
I	76 (13.7)	1 (6.7)	22 (10.9)	37 (15.4)	16 (16.3)	0.40
II	339 (61.2)	8 (53.3)	128 (63.7)	147 (61.2)	56 (57.1)	
III	121 (21.8)	6 (40.0)	41 (20.4)	50 (20.8)	24 (24.5)	
IV	18 (3.2)	0	10 (5.0)	6 (2.5)	2 (2.0)	
Age (years), median (IQR)	57 (45–65)	29 (23–43)	58 (42–65)	57 (46–65)	57 (46–67)	0.00

BMI: Body Mass Index: **NYHA:** New York Heart Association; **IQR:** interquartile range.

26.5%, respectively), while hypertension was more common in the obese group (54.1%) (Table 1).

Surgical characteristics

The most frequent procedures were aortic valve replacement (28.6%), coronary artery bypass grafting (15.7%), and mitral valve replacement (9.7%). Combined mitral and tricuspid valve replacement (4.9%), mitral and aortic valve replacement (7.4%), and the Bentall-Bono procedure (31.5%) were also performed. While the underweight group underwent a relatively higher proportion of surgeries, no statistically significant differences in cardiopulmonary bypass time (median 145 min) or aortic cross-clamp time (median 99 min) were observed across BMI groups. However, surgical risk according to EuroSCORE was significantly higher in underweight patients (median 3.9) compared to obese patients (median 2.1) (Table 2).

Postoperative outcomes

Postoperative low cardiac output syndrome was significantly more frequent in the underweight group (33.3%) vs normal weight (13.9%), overweight (12.9%), and obese (11.2%) patients (p = 0.13); this association was confirmed by logistic regression analysis (OR 3.35; 95% CI 1.11–10.11). Although not statistically significant, underweight patients also had the highest in-hospital mortality rate (14.3%) compared to rates of 5.5%, 6.2%, and 6.1% in normal weight, overweight, and obese patients, respectively. These patients also had longer hospital stays (median 14 days) compared to 10–11 days in other groups (Table 3).

Hemodynamic parameters and use of vasoactive agents

Hemodynamic support requirements differed markedly across BMI groups. Underweight patients required norepinephrine more frequently at 6 h postoperatively (80%, p = 0.01), and received significantly higher doses at 6 h (median 0.14 mcg/kg/min, p = 0.02). Although the difference at 24 h (median 0.23 mcg/kg/min) was not statistically significant, it remained elevated. Dobutamine was used at significantly higher doses in the underweight group at 24 h (median 9 mcg/kg/min, p = 0.03). Milrinone was also more frequently used at 24 h in underweight patients, with significantly higher doses (median 0.98 mcg/kg/min, p = 0.02). Steroid use was more common in the underweight group at 6 h (13.3%, p = 0.04), suggesting a heightened inflammatory response (Table 4).

Logistic regression analysis

In the univariate logistic regression analysis, BMI < 18.5 kg/m^2 was significantly associated with postcardiotomy low cardiac output syndrome (OR 3.35, 95% CI 1.11–10.11, p = 0.03). Other outcomes such as mediastinal hemorrhage (OR 1.73, 95% CI 0.47–6.30, p = 0.40), hepatic dysfunction (OR 1.95, 95% CI 0.53–7.12, p = 0.31), postoperative atrial fibrillation (OR 2.59, 95% CI 0.86–7.76, p = 0.08), and in-hospital mortality (OR

Table 2 Surgical characteristics.

Variable	Total (n = 555)	BMI < 18.5 (kg/m^2) (n = 15)	BMI 18.5—24.9 (kg/m^2) (n = 201)	BMI 25—29.9 (kg/m^2) (n = 241)	BMI > 30 (kg/m^2) (n = 98)	p
Aortic valve replacement, n (%)	159 (28.6)	3 (20.0)	51 (25.4)	68 (28.2)	37 (37.8)	0.13
Coronary artery bypass grafting, n (%)	87 (15.7)	1 (6.7)	23 (11.4)	46 (19.1)	17 (17.3)	0.11
Mitral valve replacement n (%)	54 (9.7)	1 (6.7)	21 (10.4)	30 (12.4)	2 (2.0)	0.03
Mitral valve replacement + tricuspid valve replacement, n (%)	27 (4.9)	1 (6.7)	12 (6.0)	11 (4.6)	3 (3.1)	0.71
Aortic valve replacement + mitral valve replacement, n (%)	41 (7.4)	3 (20.0)	12 (6.0)	19 (7.9)	7 (7.1)	0.24
CABG + aortic valve replacement, n (%)	23 (4.1)	0	9 (4.5)	9 (3.7)	5 (5.1)	0.79
Bentall-De Bono procedure, n (%)	31 (5.6)	1 (6.7)	16 (8.0)	7 (2.9)	7 (7.1)	0.11
Other surgeries, n (%)	136 (24.5)	5 (33.3)	59 (29.3)	51 (21.2)	21 (21.4)	0.16
Cardiopulmonary bypass time (minutes), median (IQR)	145 (112—187)	123 (98—190)	145 (111—195)	144 (109—180)	151 (116—189)	0.64
Aortic cross-clamp time (minutes), median (IQR)	99 (76—126)	92 (62—156)	104 (79—130)	97 (77—124)	90 (70—122)	0.51
EuroSCORE, median (IQR)	1.9 (1—3.7)	3.9 (1.4—7.9)	2.0 (1—3.8)	1.8 (1—3.6)	2.1 (1—3.9)	0.17

BMI: body mass index: **IQR:** interquartile range.

Table 3 Outcomes.

Variable	Total (n = 555)	BMI < 18.5 (kg/m^2) (n = 15)	BMI 18.5—24.9 (kg/m^2) (n = 201)	BMI 25—29.9 (kg/m^2) (n = 241)	BMI > 30 (kg/m^2) (n = 98)	p
Mediastinal hemorrhage, n (%)	71 (12.8)	3 (20.0)	32 (15.9)	27 (11.2)	9 (9.2)	0.24
Low cardiac output syndrome, n (%)	75 (13.5)	5 (33.3)	28 (13.9)	31 (12.9)	11 (11.2)	0.13
Vasoplegic syndrome, n (%)	39 (7.0)	1 (6.7)	14 (7.0)	18 (7.5)	6 (6.1)	0.97
Hypovolemia, n (%)	201 (36.2)	4 (26.7)	75 (37.3)	96 (39.9)	26 (26.5)	0.2
Delirium, n (%)	68 (12.2)	2 (13.3)	24 (11.9)	34 (14.2)	8 (8.2)	0.49
Cerebrovascular event, n (%)	21 (3.8)	0	4 (2.0)	10 (4.2)	7 (7.2)	0.15
In-hospital pneumonia n (%)	57 (10.3)	0	18 (9.0)	29 (12.1)	10 (10.3)	0.48
Mediastinitis, n (%)	24 (4.3)	0	4 (2.0)	12 (5.0)	6 (6.1)	0.27
Transfusion, n (%)	292 (52.6)	10 (66.7)	111 (55.2)	123 (51.2)	48 (49.5)	0.51
Acute kidney injury n (%)	168 (30.4)	3 (20.0)	62 (30.8)	77 (32.1)	26 (26.5)	0.63
Renal replacement therapy, n (%)	33 (6.0)	1 (6.7)	12 (6.0)	12 (5.0)	8 (8.2)	0.6
Hepatic dysfunction, n (%)	64 (11.5)	3 (20.0)	24 (11.9)	31 (12.9)	6 (6.1)	0.17
Mesenteric ischemia n (%)	1 (0.2)	0	0	0	1 (1.0)	0.2
Postoperative atrial fibrillation, n (%)	92 (16.6)	5 (33.3)	28 (13.9)	46 (19.2)	13 (13.4)	0.11
In-hospital mortality n (%)	34 (6.1)	2 (14.3)	11 (5.5)	15 (6.2)	6 (6.1)	0.52
Postoperative ICU stay (days), median (IQR)	3 (2—4)	3 (2—4)	3 (2—4)	3 (2—4)	2 (2—3)	0.02
Days on mechanical ventilation, median (IQR)	1 (1—1)	1 (1—1)	1 (1—1)	1 (1—1)	1 (1—1)	0.98
Hospital length of stay (days), median (IQR)	10 (7—17)	14 (6—20)	10 (7—17)	10 (8—20)	11 (7—18)	0.47
SOFA Score at 24 h median (IQR)	5 (3—7)	5 (3—8)	5 (3—7)	5 (3—7)	5 (3—7)	0.68
SOFA Score at 72 h median (IQR)	3 (2—5)	4 (3—5)	3 (2—5)	3 (2—5)	3 (2—5)	0.7

BMI: body mass index: **IQR:** interquartile range.

Table 4 Hemodynamic parameters and vasoactive drugs.

Variable	Total (n = 555)	BMI < 18.5 (kg/m^2) (n = 15)	BMI 18.5–24.9 (kg/m^2) (n = 201)	BMI 25–29.9 (kg/m^2) (n = 241)	BMI > 30 (kg/m^2) (n = 98)	p
6 h						
Cardiac index (l/min/m^2), median (IQR)	2.0 (1.6–2.5)	2.16 (1.6–2.6)	2.2 (1.7–2.7)	2 (1.5–2.5)	2 (1.5–2.4)	0.08
Central venous pressure (mmHg), median (IQR)	9 (8–11)	9 (6–12)	9 (8–11)	9 (8–11)	10 (8–12)	0.004
Systemic vascular resistance index (dynes-s/cm^5/m^2), median (IQR)	2527 (1964–3193)	2506 (2111–3246)	2391 (1897–3056)	2643.5 (2024–3368)	2531 (1989–3108)	0.06
Mixed venous O_2 saturation (%), median (IQR)	69 (62.2–76)	67.9 (55.2–77)	70 (64–77)	69 (62–75)	68 (61.2–74)	0.1
O_2 extraction ratio (%), median (IQR)	30 (24–36)	32 (23–45)	30 (24–34)	30 (24–37)	31 (25–38)	0.33
Venous-to-arterial CO_2 pressure difference (mmHg), median (IQR)	7 (4.5–9)	7 (4–11)	6.5 (4–9)	7 (4–9)	7 (5–8)	0.77
Venous-arterial CO_2 to arterial-venous O2 content difference ratio, median (IQR)	1.5 (1.07–2.04)	1.46 (1.2–2.1)	1.5 (1.1–2.1)	1.5 (1.04–2)	1.4 (1.1–1.9)	0.77
Lactate, median (IQR)	2.5 (1.7–3.9)	2.6 (1.7–6.3)	2.6 (1.8–4.1)	2.4 (1.7–3.8)	2.5 (1.9–4.1)	0.52
Norepinephrine, n (%)	331 (60.1)	12 (80)	127 (63.8)	127 (53.1)	65 (66.3)	0.01
Dose of norepinephrine, median (IQR)	0.08 (0.05–0.15)	0.14 (0.08–0.35)	0.07 (0.04–0.12)	0.09 (0.05–0.16)	0.08 (0.05–0.15)	0.02
Dobutamine, n (%)	172 (32.2)	8 (53.3)	70 (35.2)	70 (29.3)	24 (24.5)	0.06
Dose of dobutamine, median (IQR)	3.6 (2.6–5)	5.5 (3.5–8.5)	4 (3–7)	3 (2.5–5)	4 (2.7–5)	0.09
Vasopressin, n (%)	128 (23.2)	7 (46.7)	45 (22.6)	52 (21.8)	24 (24.5)	0.16
Dose of vasopressin, median (IQR)	0.05 (0.03–0.06)	0.06 (0.02–0.16)	0.05 (0.03–0.06)	0.04 (0.02–0.06)	0.06 (0.04–0.08)	0.12
Levosimendan n (%)	101 (18.3)	5 (33.3)	37 (18.6)	45 (18.8)	14 (14.3)	0.33
Dose of levosimendan, median (IQR)	0.1 (0.05–0.1)	0.1 (0.05–0.1)	0.1 (0.05–0.1)	0.1 (0.07–0.1)	0.1 (0.1–0.1)	0.92
Milrinone, n (%)	15 (2.7)	1 (6.7)	7 (3.5)	5 (2.0)	2 (2.0)	0.59
Dose of milrinone, median (IQR)	0.3 (0.2–0.5)	0.49 (0–0.9)	0.3 (0.2–0.4)	0.3 (0.1–0.5)	0.5 (0.5–0.5)	0.83
Methylene blue, n (%)	19 (3.4)	1 (6.7)	6 (3.0)	7 (2.9)	5 (5.1)	0.66
Steroids, n (%)	17 (3.1)	2 (13.3)	3 (1.5)	7 (2.9)	5 (5.1)	0.04

Table 4 (*Continued*)

Variable	Total (n = 555)	BMI < 18.5 (kg/m^2) (n = 15)	BMI 18.5–24.9 (kg/m^2) (n = 201)	BMI 25–29.9 (kg/m^2) (n = 241)	BMI > 30 (kg/m^2) (n = 98)	p
24 h						
Cardiac index (l/min/m^2), median (IQR)	2.13 (1.8–2.5)	2.2 (1.7–2.8)	2.2 (1.9–2.6)	2.1 (1.7–2.5)	2 (1.6–2.4)	0.02
Central venous pressure (mmHg), median (IQR)	10 (9–12)	11 (8–12)	10 (9–12)	10 (9–12)	10 (10–12)	0.55
Systemic vascular resistance index (dynes-s/cm^5/m^2), median (IQR)	2433 (2058–3029)	2267 (1766–2633)	2365 (1942–2898)	2426.5 (2058–3173)	2572 (2219.5–3162)	0.02
Mixed venous O_2 saturation (%), median (IQR)	68.1 (63–73)	65.4 (60–76)	68.7 (63–73)	68 (62.7–73)	70 (64–73.3)	0.59
O_2 extraction ratio (%), median (IQR)	30 (25–35)	34.5 (22–39)	30 (25–35)	30 (25–36)	28 (25–33)	0.14
Venous-to-arterial CO_2 pressure difference (mmHg), median (IQR)	6 (4–7)	6.5 (4–8)	5 (4–7)	6 (3–7)	5 (4–8)	0.69
Venous-arterial CO_2 to arterial-venous O2 content difference ratio, median (IQR)	1.39 (0.9–1.8)	1.3 (1.2–2.1)	1.4 (0.9–1.9)	1.4 (0.9–1.8)	1.4 (1–2)	0.66
Lactate, median (IQR)	1.9 (1.5–2.6)	1.8 (1.3–2)	2 (1.5.2.6)	1.9 (1.4–2.6)	2 (1.6–2.8)	0.28
Norepinephrine, n (%)	113 (20.9)	3 (21.4)	39 (20)	52 (21.9)	19 (20.2)	0.91
Dose of norepinephrine, median (IQR)	0.08 (0.03–0.2)	0.23 (0.14–2.5)	0.08 (0.02–0.2)	0.08 (0.03–0.18)	0.05 (0.04–0.18)	0.21
Dobutamine, n (%)	83 (15.4)	3 (21.4)	30 (15.4)	36 (15.2)	14 (13.9)	0.93
Dose of dobutamine, median (IQR)	3 (2.5–5)	9 (3–24)	4.3 (2.5–5.3)	3 (2.5–5)	2.5 (1.1–3.5)	0.03
Vasopressin, n (%)	63 (11.7)	3 (21.4)	24 (12.3)	25 (10.5)	11 (11.7)	0.64
Dose of vasopressin, median (IQR)	0.04 (0.03–0.06)	0.09 (0.01–0.1)	0.04 (0.02–0.06)	0.06 (0.04–0.07)	0.03 (0.02–0.06)	0.09
Levosimendan, n (%)	71 (13.1)	4 (28.6)	23 (11.8)	31 (13.1)	13 (13.8)	0.35
Dose of levosimendan, median (IQR)	0.1 (0.05–0.1)	0.07 (0.03–0.1)	0.1 (0.1–0.1)	0.1 (0.05–0.1)	0.1 (0.05–0.1)	0.76
Milrinone, n (%)	9 (1.7)	1 (7.1)	4 (2)	4 (1.7)	0 (0)	0.22
Dose of milrinone, median (IQR)	0.5 (0.1–0.6)	0.98 (0.9–0.9)	0.2 (0–0.3)	0.5 (0.5–0.6)	0 (0)	0.02
Methylene blue, n (%)	5 (0.9)	0 (0)	2 (1)	1 (0.4)	2 (2.1)	0.51
Steroids, n (%)	11 (2)	1 (7.1)	4 (2)	3 (1.3)	3 (3.2)	0.36

BMI: body mass index: **IQR:** interquartile range.

2.64, 95% CI 0.57–4.71, p = 0.20) did not reach statistical significance in this group. Mediastinitis was significantly associated with BMI > 30 kg/m^2, (OR 2.47, 95% CI 1.02–5.95, p = 0.04).

In the multivariate logistic regression model, BMI > 30 kg/m^2 remained significantly associated with mediastinitis (OR 2.12, 95% CI 1.36–2.88, p = 0.03). Although the association between BMI < 18.5 kg/m^2 and postcardiotomy low output syndrome (OR 1.11, 95% CI 0.51–1.71, p = 0.06) and mediastinal hemorrhage (OR 1.52, 95% CI 0.81–2.23, p = 0.11) showed trends, they did not reach statistical significance. Hepatic dysfunction in the low BMI group showed an OR of 1.71 (95% CI 1.05–2.36, p = 0.17). Postoperative atrial fibrillation was significantly associated with BMI < 18.5 kg/m^2 in the multivariate analysis (OR 1.48, 95% CI 0.87–2.09, p = 0.01). No significant association was observed between BMI < 18.5 kg/m^2 and in-hospital mortality (OR 1.29, 95% CI 0.44–2.14, p = 0.13). The model demonstrated good discriminatory ability (C-statistic = 0.82; 95% CI: 0.77–0.87) and acceptable calibration (Hosmer-Lemeshow p = 0.43). No evidence of multicollinearity was observed, as all VIF values were below 2 (Table 5).

Discussion

This study emphasizes the potential role of BMI as a predictor of clinical outcomes in the immediate postoperative period in patients undergoing cardiac surgery. A higher proportion of individuals with low weight had a history of prior cardiac surgery and were diagnosed with atrial fibrillation, with a median age of 23–43 years, representing a relatively young population. Additionally, higher rates of chronic heart failure (53.3%) were observed in this group, particularly in NYHA functional classes II and III. The low BMI group underwent the highest proportion of double valve replacement surgeries, including 6.7% of mitral/tricuspid and 20% of aortic/mitral replacements. This group also exhibited higher EuroSCORE surgical risk stratification scores, with a median ranging from 1.4 to 7.9.

The overweight group demonstrated a heightened cardiovascular risk profile, with 26.5% diagnosed with diabetes and 54.1% with systemic hypertension - values that are significantly higher than those in other BMI groups. The overweight patients were older (46–67 years), which aligns with the natural course of chronic degenerative diseases, especially metabolic disorders that are known precursors of coronary artery disease, degenerative valve disease, and aortopathy. These findings support previously published evidence confirming that the obese population has higher comorbidity rates compared to other BMI groups, including higher rates of prior coronary syndromes, hypertension, diabetes, chronic kidney disease, and chronic pulmonary disease. Patients with BMI > 30 kg/m^2 tend to develop atherosclerotic and valvular disease earlier, requiring surgical intervention due to their high comorbid burden. Notably, patients in the overweight and obese groups had the highest incidence of CABG surgeries (19.1% and 17.3%, respectively), and the highest percentage of isolated aortic valve replacement (37.8%) and combined valve replacement plus coronary artery bypass surgery (5.1%) occured in the obese group. This group also exhibited longer (up to 189 min) extracorporeal circulation times.

Regarding perioperative complications, the low BMI group (BMI < 18.5 kg/m^2) had a higher frequency of mediastinal hemorrhage (20%). This finding is likely linked to a lower circulating blood volume, which increases the risk for bleeding and transfusion requirements compared to other BMI groups, insofar as 66.7% of low-weight patients required transfusion support. Increased hemodilution due to higher extracorporeal circulation volumes, coupled with lower hepatic reserve, predisposes this group to acute liver failure (20%). Furthermore, anticoagulant use due to the higher rates of preoperative atrial fibrillation (26.7%) may have contributed to this outcome. Postoperatively, the low BMI group had a higher incidence of atrial fibrillation (33.3%) compared to the other groups, likely associated with preoperative structural heart disease and congenital heart conditions, given the median age of 29 years (IQR 23–43 years). Additionally, this group experienced a higher incidence of low cardiac output syndrome (33.3%),[9] with increased vasopressor and inotropic support contributing to its development. Accordingly, patients with BMI < 18.5 kg/m^2 had higher in-hospital mortality rates (14.3%) and longer hospital stays (median 14 days) compared to other groups. These findings corroborate those of previous studies which suggest that low-weight patients experience higher mortality and postoperative complications due to factors such as frailty, sarcopenia/cachexia, and low energy-metabolic reserves that weaken their physiological response to surgical stress.[10]

In contrast, patients in the overweight and obese groups exhibited lower rates of mediastinal hemorrhage (11.2% and 9.2%), low cardiac output syndrome (12.9% and 11.2%), transfusion requirements (51.2% and 49.5%), acute hepatic injury (12.9% and 6.2%), and postoperative atrial fibrillation (19.2% and 13.4%). However, the obese group showed a significantly higher incidence of mediastinitis compared to the other groups (8.2%). This complication was associated with diabetes mellitus, chronic obstructive pulmonary disease (COPD), and particularly the CABG surgical technique, in which the use of both internal mammary arteries can reduce blood flow to the sternum by up to 90%. This finding refutes the hypothesis that low-weight patients would experience higher rates of postoperative infection. Notably, obesity is a significant risk factor for deep sternal wound infections after CABG, which are associated with higher morbidity.[11] Perioperative cerebrovascular events were more common in obese patients (7.2%), reflecting the higher burden of cardiovascular and metabolic diseases (hypertension, diabetes, chronic coronary syndrome, chronic renal disease). There were no differences in the duration of mechanical ventilation between the BMI groups, contrasting with some reports suggesting that morbidly obese and low-weight patients have longer durations of mechanical ventilation post-surgery, particularly those with BMI > 40 kg/m^2, who are more likely to develop atelectasis and significant gas exchange abnormalities.

Interestingly, the mortality rate was lower in the obese group (6.1%) compared to the low-weight group (14.3%). While this observation could suggest a possible protective effect of obesity, these findings should be interpreted with caution. The concept of the "obesity paradox" remains con-

Table 5 Logistic regression model for outcomes.

Univariate analysis

Variable	OR	95% CI	p
BMI < 18.5 (kg/m²)			
Mediastinal hemorrhage	1.73	0.47–6.30	0.4
Postcardiotomy low cardiac output syndrome	3.35	1.11–10.11	0.03
Hepatic dysfunction	1.95	0.53–7.12	0.31
Postoperative atrial fibrillation	2.59	0.86–7.76	0.08
In-hospital mortality	2.64	0.57–4.71	0.2
BMI > 30 kg/m²			
Mediastinitis	2.47	1.02–5.95	0.04

Multivariate analysis.

Variable	OR	95% CI	p
BMI < 18.5 (kg/m²)			
Mediastinal hemorrhage	1.52	0.81–2.23	0.11
Postcardiotomy low cardiac output syndrome	1.11	(0.51–1.71)	0.06
Hepatic dysfunction	1.71	1.05–2.36	0.17
Postoperative atrial fibrillation	1.48	0.87–2.09	0.01
In-hospital mortality	1.29	0.44–2.14	0.13
BMI > 30 kg/m²			
Mediastinitis	2.12	1.36–2.88	0.03

BMI: body mass index; **OR:** odds ratio; **CI:** confidence interval.

troversial, and many of the differences observed in our study lack statistical significance. These apparent advantages might be influenced by selection bias, confounding factors, or the limitations of BMI as a surrogate for nutritional or metabolic status. BMI does not differentiate between lean and fat mass or account for adipose tissue distribution, and this may explain some of these unexpected findings.[12,13]

The hemodynamic evolution of patients was analyzed at 6 and 24 h post-surgery. The low-weight population showed a higher tendency to require vasopressor and inotropic agents at both time points. Significant differences were found in norepinephrine and vasopressin use compared to other BMI groups, with at least 80% and 46.7% of low-weight patients requiring these medications at 6 h, respectively. This trend persisted at 24 h, with higher median doses compared to the other groups. The higher use of vasopressors correlated with increased hemorrhagic complications (mediastinal hemorrhage) and hypovolemic shock. Additionally, this group required more inotropic support, with 53.3% receiving dobutamine, 33.3% receiving levosimendan, and 6.7% receiving milrinone at 6 h. These findings persisted at 24 h, with higher doses of dobutamine (median 9 mcg/kg/min) and milrinone (median 0.98 mcg/kg/min). These results are linked to the higher frequency of post-cardiotomy low cardiac output syndrome (33.3%) and its progression to cardiogenic shock in low BMI patients. Furthermore, this group showed a higher frequency of methylene blue (6.7%) and steroid (13.3%) usage at 6 h, with steroid use maintaining this trend at 24 h (7.1%).[14]

While BMI is widely used as a simple and accessible measure of body composition, it has notable limitations when used as the sole marker in surgical risk assessment. BMI does not differentiate between lean mass, fat mass, or fat distribution, all of which influence postoperative outcomes differently. Mariscalco et al.[15] demonstrated that BMI may inadequately reflect true risk, particularly in patients with high muscle mass or sarcopenia, where BMI values can be misleading. They call for more precise methods of assessing body composition and predicting surgical prognosis, such as bioimpedance analysis or imaging techniques.

Furthermore, visceral adiposity, which is not captured by BMI, plays a critical role in systemic inflammation and postoperative recovery. Therefore, future studies should go beyond BMI and incorporate more specific assessments of body composition to refine risk stratification. Overall, while BMI remains a useful initial tool, its limitations call for cautious interpretation and highlight the need for multidimensional evaluation in cardiac surgery patients.

Study limitations

This was a single-centre retrospective study, a design that limits the generalizability of the findings and underscores the need for replication at other centers to assess the reproducibility of our results. The small sample size, particularly of the underweight group, which also had a significantly younger median age, compromises the statistical power and the comparability between groups. Additionally, the study focused on a specific subpopulation—postoperative cardiac surgery patients—so the results may not be applicable to all critical care patients. Other important limitations include the lack of data on visceral fat and musculoskeletal composition and the absence of long-term follow-up, which restricts the understanding of prolonged outcomes.

Conclusions

In conclusion, our findings suggest that patients with a BMI < 18.5 kg/m^2 undergoing cardiac surgery may face higher risks, including increased mortality rates and adverse early postoperative outcomes, compared to other BMI groups. BMI is an important marker to consider in preoperative risk assessment for cardiac surgery. However, due to its limitations—such as an inability to differentiate between lean mass, fat mass, and the distribution of adipose tissue—future studies should explore alternative indices that better reflect body composition, optimise risk stratification models, and establish a clearer relationship between weight and surgical risk.

CRediT authorship contribution statement

AAPD: data collection, writing the original draft. **RGN**: methodology, analysis. **GRV**: review. **DMS**: original idea, methodology, analysis and writing the original draft, review and editing.

Ethical approval and consent to participate

The local research and institutional ethics committees waived approval for this study.

Consent for publication

Written informed consent for the publication of patient information and images was obtained either from the patient or a legally authorized representative.

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Data availability

The data supporting the findings of this study are available upon request from the corresponding author [DMS].

Declaration of competing interest

The authors declare that there are no conflicts of interest to disclose.

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