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Impact of Body Mass Index on Outcomes in Cardiac Surgery



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Objectives: Body mass index (BMI) commonly is used in obesity classification as a surrogate measure, and obesity is associated with a cluster of risk factors for cardiovascular disease. The aim of this study was to investigate the impact of BMI on short-term outcomes after cardiac surgery.

Design: A retrospective cohort study.

Setting: University teaching hospital, 2 centers.

Participants: The study comprised 4,740 patients who underwent cardiac surgery at 2 hospitals—from July 1, 2001, to June 30, 2013, in 1 hospital and from September 1, 2003, to August 31, 2014, in a second hospital.

Interventions: No changes to standard practice were required.

Measurements and Main Results: Patients were assigned into 6 BMI groups as follows: underweight (BMI < 18.5 kg/m²), normal weight (≥ 18.5 to < 25 kg/m²), overweight (≥ 25 to < 30 kg/m²), class I obese (≥ 30 to < 35 kg/m²), class II obese (≥ 35 to < 40 kg/m²), and class III obese (BMI ≥ 40 kg/m²). Short-term major postoperative complications (postoperative stroke, cardiac arrest, new atrial fibrillation/flutter, permanent rhythm device insertion, deep sternal infection, sepsis, prolonged ventilation, pneumonia, renal dialysis, renal failure, intensive care unit readmission, total intensive

care unit hours, and readmission in 30 days, and mortalities (in-hospital mortality, 30-day mortality, surgical mortality) were compared among various BMI groups after cardiac surgery. Age, sex, surgery type, family history of coronary artery disease, diabetes, hypertension, heart failure, and lipid-lowering medication were the risk factors for early outcomes. Multiple logistic regression analysis indicated that the underweight and class III obese BMI groups demonstrated significant, adverse differences in some short-term outcomes, including deep sternal infection, prolonged ventilation, new atrial fibrillation/flutter, and renal failure. However, being in the overweight or class I obese group demonstrated a positive effect on discharge and surgical mortality.

Conclusions: The results of this study demonstrated that extreme obesity and underweight were significantly associated with early major adverse clinical outcomes. However, there was an “obese paradox” in short-term mortality after cardiac surgery.

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KEY WORDS: body mass index, obese, outcome, cardiac surgery, mortality

BODY MASS INDEX (BMI) is a person's weight in kilograms divided by the square of height in meters and commonly is used in obesity classification as a surrogate measure. A BMI value of ≥ 30 kg/m² defines obesity, and a BMI value of 25 to 29.9 kg/m² defines being overweight.^{1,2} Obesity is associated with a cluster of risk factors for cardiovascular disease, known as the metabolic syndrome, which include hypertension, dyslipidemia, insulin resistance, and diabetes mellitus.^{2,3} The prevalence of obesity worldwide, especially in developed countries, has reached epidemic proportions. It is expected that an increasing number of obese

patients will require cardiac surgery.⁴ Even though not always accurate, BMI still is a useful measure of overall body habitus because it is highly correlated with body surface area⁵; it also commonly is used in anthropometric measurements in most previous and new risk models for the Society of Thoracic Surgeons (STS).⁵⁻⁷

Several studies have examined the effects of obesity on in-hospital mortality and long-term survival with variable conclusions. Some studies have suggested that obesity does not increase morbidity or mortality but actually is associated with favorable outcomes after cardiac surgery,⁸⁻¹¹ whereas other studies have demonstrated that obesity is a predictor of either morbidity or mortality.¹²⁻¹⁷ Because the relationship between BMI and surgical outcomes is complex, the aim of the study presented here was to evaluate the influence of BMI on early clinical outcomes in patients undergoing cardiac surgery.

METHODS

Study Design

This was a 2-center study involving 6,515 patients who underwent cardiac surgery at 2 hospitals, with the period in 1 hospital spanning from July 1, 2001, to June 30, 2013, and in the other hospital from September 1, 2003, to August 31, 2014. Institutional review board permissions of the 2 hospitals were granted for this retrospective study. Patients included in the study met the following criteria: coronary artery bypass grafting (CABG) and/or valve surgery and CABG and/or valve surgery combined with other procedures. Patients excluded from the study met 1 of the following criteria: emergency surgery, off-pump or robotic surgery, surgery requiring deep hypothermic circulatory arrest or involving the thoracic

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aorta, and patients with incomplete data. A total of 4,740 patients met the inclusion criteria and were assigned into the following 6 classes according to their BMI: underweight (BMI <18.5 kg/m²; n = 62), normal weight (≥18.5 to <25 kg/m²; n = 1,144), overweight (≥25 to <30 kg/m²; n = 1,774), class I obese (≥30 to <35 kg/m²; n = 1,044), class II obese (≥35 to <40 kg/m²; n = 441), and class III obese (BMI ≥40 kg/m²; n = 275).¹⁸ The study design is shown in Figure 1.

Data Collection

Patient data from 2 hospitals’ medical records were both collected and organized following the template of the STS Adult Cardiac Surgery Database Data Specifications (version 2.81, 2014) and included demographics, patient history, medical record information, preoperative risk factors, preoperative medications, intraoperative variables, postoperative events, in-hospital mortality, 30-day mortality, and surgical mortality.

Outcome Definitions

Primary outcomes were in-hospital mortality, 30-day mortality, surgical mortality, and life-threatening cardiovascular events, including postoperative stroke, cardiac arrest, new atrial fibrillation/flutter, and permanent rhythm device insertion. Secondary outcomes included deep sternal infection, sepsis, prolonged ventilation, pneumonia, renal dialysis, renal failure, intensive care unit (ICU) readmission, total ICU hours, and readmission in 30 days.

The definitions of all these outcomes were based on the STS Adult Cardiac Surgery Database Data Specifications. Primary outcome definitions were as follows: in-hospital mortality—death during the hospitalization in which surgery occurred;

30-day mortality—death at 30 days after surgery (whether or not occurring in hospital); surgical mortality—(1) all deaths, regardless of cause, occurring during the hospitalization period in which the surgery was performed, even if after 30 days (including patients transferred to other acute care facilities), and (2) all deaths, regardless of cause, occurring after discharge from the hospital but before the end of the 30th postoperative day; stroke—the patient experiencing a postoperative stroke and the type of stroke (ie, any confirmed neurologic deficit of abrupt onset caused by a disturbance in blood supply to the brain) that did not resolve within 24 hours; cardiac arrest—the patient experiencing acute cardiac arrest documented by 1 of the 4 following diagnoses: ventricular fibrillation, rapid ventricular tachycardia with hemodynamic instability, asystole, and implantable cardioverter-defibrillator shocks; new atrial fibrillation/flutter (AF)—the patient experiencing AF requiring treatment (excluding AF at the start of surgery); and permanent device insertion—the patient developing new arrhythmia requiring insertion of a permanent device. Secondary outcomes definitions are as follows: deep sternal infection—a deep sternal wound infection or mediastinitis within 30 days of the procedure or any time during the hospitalization for surgery; sepsis—evidence of serious infection accompanied by a deleterious systemic response; prolonged ventilation—the patient experiencing prolonged postoperative pulmonary ventilation (>24 hours); pneumonia—the patient experiencing pneumonia according to the Centers for Disease Control definition; renal dialysis—the patient having a new requirement for dialysis postoperatively, which could include hemodialysis and peritoneal dialysis; renal failure—the patient experiencing acute renal failure or worsening renal function resulting in 1 or both of the following criteria: (1) increase in serum creatinine level 3 times greater than the baseline or serum creatinine level ≥4 mg/dL (acute rise must be at least 0.5 mg/d) and/or

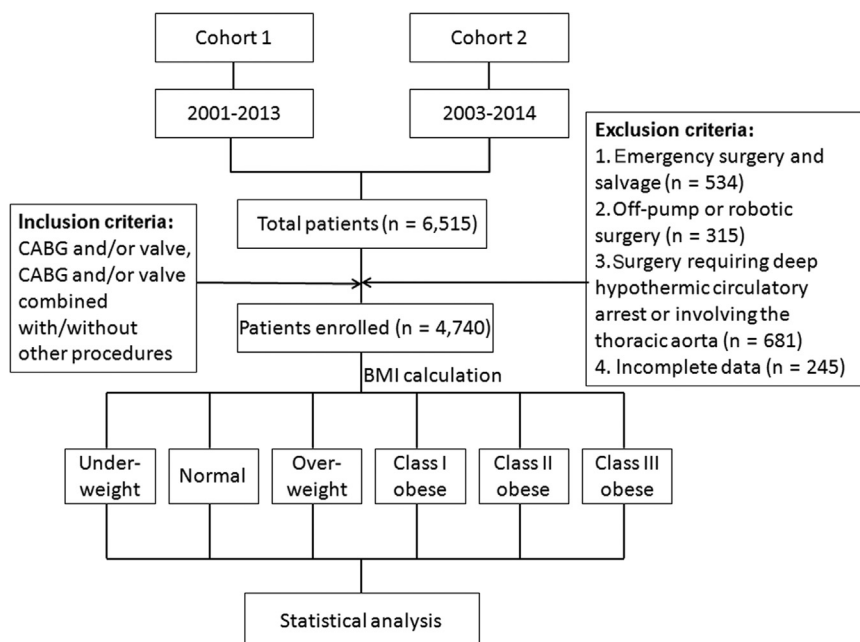


Fig 1. Study design. CABG, coronary artery bypass grafting.

(2) a new requirement for dialysis postoperatively; ICU readmission—whether the patient spent time in an ICU after having been transferred to a step-down unit (total ICU hours was the summation of initial ICU hours and additional ICU hours); and readmission in 30 days—indicates whether the patient was readmitted for any reason to an acute-care facility as an in-patient within 30 days from the date of the initial surgery.

Statistical Analysis

SAS version 9.4 for Windows (SAS Institute, Cary, NC) was used for statistical analysis. BMI group categorical variables were compared using the chi-square test and are presented as numbers and percentages. Continuous variables were compared using *t*-test analysis and are presented as mean \pm standard deviation. Univariate and multivariate logistic regressions were performed to assess associations of demographic and preoperative risk factors and clinical outcome variables.

Parsimonious multivariate logistic regression and multivariable general linear analysis adjusted with patient demographic and clinical risk factors were performed to investigate the effect of BMI on short-term outcomes (categorical and continuous variables, respectively). To achieve model parsimony and stability, the backward selection procedure was applied with the drop-out criterion $p > 0.05$ from risk factors on the basis of variables collected in the database, forced inclusion of BMI, surgery type, age, sex, and status. The results are reported as numbers with percentages, mean \pm SD, and odds ratios (OR) with 95% confidence intervals (CI). All reported *p* values are 2-tailed, and *p* values < 0.05 were considered to be statistically significant.

RESULTS

Baseline and Intraoperative Characteristics

Table 1 demonstrates demographic data, the preoperative risk profile, and procedural characteristics of all groups. Patients in the normal weight group were the oldest (64.9 ± 13.5) among

Table 1. Observed Patient Risk Profile by BMI Category

Variable n (%) or mean \pm SD	BMI Groups						Overall 4,740	p Value
	Normal Weight 1,144 (24.1)	Overweight 1,774 (37.4)	Class I Obese 1,044 (22.0)	Class II Obese 441 (9.3)	Class III Obese 275 (5.8)	Underweight 62 (1.3)		
Age	64.9 \pm 13.5	64.3 \pm 12.2	63.3 \pm 11.5	61.8 \pm 11.2	59.1 \pm 11.4	62.0 \pm 15.6	63.6 \pm 12.4	<0.0001*
Sex: F (v M)	399 (34.9)	436 (24.6)	322 (30.8)	163 (37.0)	135 (49.1)	30 (48.4)	1,485 (31.3)	<0.0001*
Status: urgent (v elective)	581 (50.8)	859 (48.4)	491 (47.0)	209 (47.4)	142 (51.6)	30 (48.4)	2,312 (48.8)	0.482
Surgery type								
CABG	529 (46.2)	985 (55.5)	614 (58.8)	249 (56.5)	156 (56.7)	22 (35.5)	2,555 (53.9)	<0.0001*
CABG + valve	213 (18.6)	303 (17.1)	156 (14.9)	62 (14.1)	33 (12.0)	7 (11.3)	774 (16.3)	
CABG + other	38 (3.3)	57 (3.2)	25 (2.4)	14 (3.2)	8 (2.9)	3 (4.8)	145 (3.0)	
Valve	277 (24.2)	326 (18.4)	196 (18.8)	91 (20.6)	68 (24.7)	20 (32.3)	978 (20.7)	
Valve + other	87 (7.6)	103 (5.8)	54 (5.2)	25 (5.7)	10 (3.6)	10 (16.1)	289 (6.1)	
Family CAD	415 (36.3)	772 (43.5)	483 (46.3)	210 (47.6)	119 (43.3)	24 (38.7)	2,023 (42.7)	<0.0001*
Diabetes	264 (23.1)	573 (32.3)	440 (42.1)	234 (53.1)	149 (54.2)	13 (21.0)	1,673 (35.3)	<0.0001*
Smoking	491 (42.9)	768 (43.3)	432 (41.4)	183 (41.5)	103 (37.5)	31 (50.0)	2,008 (42.4)	0.356
Hypertension	834 (72.9)	1,391 (78.4)	884 (84.7)	381 (86.4)	233 (84.7)	42 (67.7)	3,765 (79.4)	<0.0001*
Heart failure	372 (32.5)	467 (26.3)	287 (27.5)	118 (26.8)	89 (32.4)	23 (37.1)	1,356 (28.6)	0.002*
Renal failure	64 (5.6)	96 (5.4)	61 (5.8)	24 (5.4)	18 (6.6)	5 (8.1)	268 (5.6)	0.930
Creatinine	1.3 \pm 1.1	1.3 \pm 1.1	1.3 \pm 1.1	1.3 \pm 1.2	1.2 \pm 1.0	1.3 \pm 1.2	1.3 \pm 1.1	0.892
Chronic lung disease								
None	896 (78.3)	1440 (81.2)	827 (79.2)	346 (78.5)	199 (72.4)	46 (74.2)	3,754 (79.2)	0.014*
Mild	172 (15.0)	257 (14.5)	152 (14.6)	68 (15.4)	52 (18.9)	9 (14.5)	711 (15.0)	
Moderate	57 (5.0)	62 (3.5)	57 (5.5)	24 (5.4)	21 (7.6)	5 (8.1)	2,275 (4.8)	
Severe	19 (1.7)	14 (0.8)	8 (0.8)	3 (0.7)	3 (1.1)	2 (3.2)	49 (1.0)	
CVD	200 (17.5)	261 (14.7)	150 (14.4)	61 (13.8)	37 (13.5)	7 (11.3)	716 (15.1)	0.179
PAD	160 (14.0)	193 (10.9)	122 (11.7)	50 (11.3)	23 (8.4)	10 (16.1)	558 (11.8)	0.054
Previous valve	505 (44.1)	703 (39.6)	381 (36.5)	174 (39.5)	97 (35.3)	30 (48.4)	1,890 (39.9)	0.003*
Previous PCI	93 (8.1)	188 (10.6)	137 (13.1)	50 (11.3)	32 (11.6)	5 (8.1)	505 (10.7)	0.009*
Lipid-lowering drugs	575 (50.3)	947 (53.4)	595 (57.0)	255 (57.8)	169 (61.5)	24 (38.7)	2,565 (54.1)	0.0001*
IABP	116 (10.1)	169 (9.5)	93 (8.9)	36 (8.2)	21 (7.6)	4 (6.5)	439 (9.3)	0.634
Cross-clamp time	111.0 \pm 58.6	107.0 \pm 53.5	109.2 \pm 56.8	109.2 \pm 58.6	110.5 \pm 58.6	101.2 \pm 59.9	108.8 \pm 56.4	0.426
CPB time	155.9 \pm 77.7	150.1 \pm 69.3	153.9 \pm 79.4	152.7 \pm 76.8	157.3 \pm 78.4	146.7 \pm 74.2	152.9 \pm 75.0	0.321

NOTE. The *t* test was used to analyze continuous variables, and the chi-square test was used for categorical variables.

Abbreviations: BMI, body mass index; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CVD, cerebrovascular disease; CPB, cardiopulmonary bypass; F, female; IABP, intra-aortic balloon pump; M, male; PAD, peripheral arterial disease; PCI, percutaneous coronary intervention; SD, standard deviation.

**p* < 0.05 was considered as statistically significant.

all BMI groups. The proportion of females in the underweight (48.4%) and class III (49.1%) obese groups was significantly higher ($p < 0.0001$) than the normal weight (34.9%), overweight (24.6%), class I obese (30.8%), and class II obese groups (37.0%), respectively. Surprisingly, a greater percentage of patients in the underweight group (32.3%) had undergone valve surgery than did those from all the other groups (24.2%, 18.4%, 18.8%, 20.6%, 24.7%, respectively; $p < 0.0001$), and more patients in the overweight (55.5%) and all 3 obese groups (58.8%, 56.5%, 56.7%, respectively) had undergone CABG ($p < 0.0001$) than those in the normal weight group (35.5%). Family history of coronary artery disease ($p < 0.0001$), diabetes history ($p < 0.0001$), hypertension history ($p < 0.0001$), and lipid-lowering medication ($p < 0.0001$) were more prevalent in the overweight and all the obese groups. There were significantly more chronic lung diseases (total in moderate and severe) in the class III obese (8.7%) and underweight groups (11.3%) than in the normal weight group (6.7%, $p = 0.014$). Heart failure prevailed in the leanest cohort ($p = 0.002$). Underweight patients tended to have experienced previous valve procedures ($p = 0.003$), and obese patients tended to have experienced previous percutaneous coronary interventions ($p = 0.009$). Renal function before surgery was similar across the groups. There were no differences in surgery status, smoking history, peripheral artery disease, cerebrovascular disease, cross-clamp time, cardiopulmonary bypass time, or intra-aortic balloon pump.

Postoperative Outcomes

Table 2 shows unadjusted short-term postoperative outcomes of all BMI groups. The incidence of sternal infection in the class III obese group was much higher than that of the normal weight group ($p = 0.002$). Class III obese and underweight patients tended to have prolonged ventilation hours after surgery ($p = 0.001$). Furthermore, more patients in the class III obese group required dialysis postoperatively ($p = 0.01$). Class III obese and underweight groups experienced significantly greater in-hospital mortality ($p = 0.004$), 30-day mortality ($p = 0.042$), surgical mortality ($p = 0.033$), and patient readmission within 30 days ($p = 0.005$) than the other groups.

Table 3 shows risk-adjusted ORs of BMI for short-term postoperative outcomes. The observed increase of sternal infection (OR: 4.682; 95% CI: 1.787-12.269; $p = 0.002$), renal dialysis (OR: 2.864; 95% CI: 1.412-5.807; $p = 0.004$), and readmission within 30 days (OR: 1.726; 95% CI: 1.225-2.433; $p = 0.002$) in the class III obese group persisted after being adjusted for demographic, preoperative risk factors, and intraoperative characteristics. Likewise, the prolonged postoperative ventilation in the class III obese (OR: 1.814; 95% CI: 1.228-2.679; $p = 0.003$) and underweight groups (OR: 2.457; 95% CI: 1.272-4.745; $p = 0.007$) also persisted after risk adjustment. In addition, the adjusted rate of renal failure significantly increased in the class III obese group (OR: 2.62; 95% CI: 1.512-4.54; $p = 0.001$) compared with the normal weight group. The rate of new-onset atrial fibrillation/flutter in the class II obese (OR: 1.331; 95% CI: 1.027-1.724; $p = 0.031$) and underweight groups (OR: 1.84; 95% CI: 1.042-3.25; $p = 0.036$) increased compared with that of the normal weight group. Similarly, the class III obese group experienced

markedly more frequent readmissions within 30 days regardless of risk adjustments. Interestingly, total ICU hours in the overweight (mean: 108.7; 95% CI: 105.7-111.7; $p < 0.05$) and class I obese groups (mean: 106.2; 95% CI: 102.3-110.0; $p < 0.05$) were significantly shorter than those of the normal weight group after risk adjustment. There were no statistical differences in 30-day mortality between the normal weight and other groups. However, there were significant reductions of in-hospital mortality (OR: 0.457; 95% CI: 0.248-0.843; $p = 0.012$) and surgical mortality (OR: 0.531; 95% CI: 0.304-0.927; $p = 0.026$) for class I obese patients.

DISCUSSION

Obesity is a risk factor for diabetes mellitus, hypertension, and cardiovascular diseases. Obesity accounts for a large proportion (37.1% in this study) of the population undergoing cardiac surgery. Previous studies have shown that extremely obese or underweight patients have increased risks for some early major complications, such as deep sternal infection,^{11,13} prolonged ventilation,^{14,19} and renal failure¹³; however, patients who are either overweight or mildly obese may have a lower in-hospital and surgical mortality.⁸⁻¹¹ Findings of this study demonstrated that there were higher rates of deep sternal infection, renal dialysis, and renal failure in class III obese patients, increased prolonged ventilation in class III obese and underweight patients, and increased new atrial fibrillation/flutter in class II obese and underweight patients. On the other hand, although extreme obesity increased the rate of readmission within 30 days, patients who were either overweight or mildly obese experienced significantly decreased in-hospital mortality, surgical mortality, and total time spent in the ICU.

BMI and Preoperative Profiles

Similar to other published results,¹⁹⁻²¹ the preoperative characteristics of patients in this cohort showed that obese patients were more likely to be younger, male, and have diabetes and hypertension compared with normal weight BMI patients. They also were more likely to have a significantly increased family history of coronary artery disease, experience moderate or severe chronic lung disease, and use lipid-lowering medication. More overweight and obese patients had experienced previous percutaneous coronary interventions than had the other groups. These findings implied that obese patients tend to develop coronary artery disease earlier and undergo surgical revascularization at a younger age, likely because of the higher risks of diabetes, hypertension, hyperlipidemia, and family history of coronary disease.

BMI and Early Outcomes

In this study, with and without risk adjustment, earlier postoperative outcomes demonstrated the incidence of deep sternal infection in class III obese patients as being significantly higher than in the other groups, which corresponded to a previous study.²² This indicated an association between obesity and deep sternal infection; therefore, extreme obesity (BMI ≥ 40 kg/m²) could be identified as an independent risk factor for deep sternal infection after cardiac surgery.

Table 2. Observed Short-Term Outcomes by BMI Category

Outcomes n (%), mean ± SD	BMI groups						Overall 4,740	p Value
	Normal Weight 1,144 (24.1)	Overweight 1,774 (37.4)	Class I Obese 1,044 (22.0)	Class II Obese 441 (9.3)	Class III Obese 275 (5.8)	Underweight 62 (1.3)		
Stroke	23 (2.0)	35 (2.0)	14 (1.3)	7 (1.6)	2 (0.7)	2 (3.2)	83 (1.8)	0.450
Cardiac arrest	23 (2.0)	21 (1.2)	16 (1.5)	8 (1.8)	8 (2.9)	2 (3.2)	78 (1.7)	0.263
Deep sternal infection	8 (0.7)	18 (1.0)	11 (1.1)	5 (1.1)	10 (3.6)	0 (0.0)	52 (1.1)	0.002*
Sepsis	18 (1.6)	21 (1.2)	14 (1.3)	6 (1.4)	6 (2.2)	1 (1.6)	66 (1.4)	0.807
Prolonged ventilation	156 (13.7)	192 (10.8)	124 (11.9)	54 (12.2)	49 (17.8)	15 (24.2)	590 (12.5)	0.001*
Pneumonia	43 (3.8)	48 (2.7)	38 (3.6)	14 (3.2)	8 (2.9)	4 (6.5)	155 (3.3)	0.391
New atrial fibrillation/flutter	275 (24.0)	435 (24.5)	269 (25.8)	119 (27.0)	65 (23.6)	20 (32.3)	1,183 (24.9)	0.528
Permanent rhythm device insertion	22 (1.9)	27 (1.5)	15 (1.4)	5 (1.1)	5 (1.8)	1 (1.6)	75 (1.6)	0.888
Renal dialysis requirement	27 (2.4)	39 (2.2)	22 (2.1)	8 (1.8)	16 (5.8)	2 (3.2)	114 (2.4)	0.010†
Renal failure	50 (4.4)	82 (4.6)	47 (4.5)	23 (5.2)	24 (8.7)	3 (4.8)	229 (4.8)	0.067
ICU readmission	53 (4.6)	82 (4.6)	40 (3.8)	15 (3.4)	11 (4.0)	4 (6.5)	205 (4.3)	0.713
In-hospital mortality	45 (3.9)	43 (2.4)	19 (1.8)	17 (3.9)	13 (4.7)	4 (6.5)	141 (3.0)	0.004*
30-day mortality	45 (3.9)	51 (2.9)	22 (2.1)	16 (3.6)	14 (5.1)	4 (6.5)	152 (3.2)	0.042*
Surgical mortality	49 (4.3)	55 (3.1)	23 (2.2)	17 (3.9)	14 (5.1)	4 (6.5)	162 (3.4)	0.033*
Readmission within 30 days	150 (13.1)	243 (13.7)	158 (15.1)	65 (14.7)	61 (22.2)	11 (17.7)	688 (14.5)	0.005†
Total ICU Hours	116.1 ± 175.9	108.5 ± 258.4	105.9 ± 160.9	118.7 ± 193.9	118.0 ± 145.4	128.8 ± 158.0	111.5 ± 207.9	0.712

NOTE. All outcomes were explained in outcomes abbreviation and definitions; the *t* test was used to analyze continuous variables, and the chi-square test was used for categorical variables.

Abbreviations: BMI, body mass index; ICU, intensive care unit; SD, standard deviation.

*p < 0.05 was accepted as statistically significant.

Table 3. Adjusted Odds Ratios of BMI for Postoperative Outcomes

Outcomes OR/mean (95% CI)	BMI groups					
	Normal Weight n = 1,144	Overweight n = 1,774	Class I Obese n = 1,044	Class II Obese n = 441	Class III Obese n = 275	Underweight n = 62
Stroke	1	1.102 (0.643-1.887)	0.715 (0.362-1.411)	0.854 (0.359-2.032)	0.418 (0.096-1.809)	1.533 (0.342-6.869)
Cardiac arrest	1	0.753 (0.412-1.377)	0.85 (0.436-1.659)	1.039 (0.451-2.395)	1.64 (0.696-3.861)	1.896 (0.426-8.436)
Deep sternal infection	1	1.482 (0.632-3.476)	1.552 (0.616-3.907)	1.633 (0.525-5.081)	4.682* (1.787-12.269)	NA
Sepsis	1	0.936 (0.483-1.816)	0.944 (0.447-1.995)	1.092 (0.409-2.918)	1.715 (0.642-4.584)	1.02 (0.12-8.691)
Prolonged ventilation	1	0.912 (0.713-1.166)	0.987 (0.748-1.3)	1.034 (0.719-1.487)	1.814* (1.228-2.679)	2.457* (1.272-4.745)
Pneumonia	1	0.853 (0.554-1.313)	1.109 (0.699-1.759)	1.06 (0.564-1.995)	0.877 (0.397-1.935)	2.003 (0.672-5.969)
New atrial fibrillation/flutter	1	1.073 (0.897-1.283)	1.199 (0.982-1.465)	1.331* (1.027-1.724)	1.236 (0.897-1.703)	1.84* (1.042-3.25)
Permanent rhythm device insertion	1	1.011 (0.562-1.82)	0.809 (0.407-1.609)	0.7 (0.256-1.91)	1.163 (0.419-3.231)	0.796 (0.102-6.232)
Renal dialysis requirement	1	1.074 (0.634-1.82)	0.914 (0.497-1.68)	0.766 (0.324-1.813)	2.864* (1.412-5.807)	1.403 (0.3-6.563)
Renal failure	1	1.207 (0.826-1.763)	1.127 (0.732-1.733)	1.371 (0.798-2.354)	2.62* (1.512-4.54)	1.302 (0.379-4.464)
ICU readmission	1	1.199 (0.833-1.726)	0.995 (0.647-1.53)	0.888 (0.489-1.611)	1.18 (0.597-2.333)	1.36 (0.467-3.959)
In-hospital mortality	1	0.829 (0.519-1.322)	0.457† (0.248-0.843)	1.276 (0.672-2.423)	1.46 (0.719-2.962)	2.048 (0.648-6.476)
30-day mortality	1	1.029 (0.66-1.604)	0.574 (0.323-1.02)	1.214 (0.639-2.307)	1.633 (0.823-3.241)	1.951 (0.626-6.079)
Surgical mortality	1	0.959 (0.626-1.469)	0.531† (0.304-0.927)	1.15 (0.618-2.138)	1.438 (0.732-2.823)	1.747 (0.56-5.451)
Readmission within 30 days	1	1.069 (0.857-1.335)	1.139 (0.89-1.457)	1.067 (0.773-1.473)	1.726* (1.225-2.433)	1.334 (0.677-2.629)
Total ICU hours	115.8 (112.1-119.5)	108.7† (105.7-111.7)	106.2† (102.3-110.0)	115.3 (109.3-121.2)	117.5 (110.0-125.0)	128.8 (113.0-144.7)

NOTE. All outcomes were explained in outcomes definition; normal weight group was the reference group in all analyses. Parsimonious multivariate logistic regression was used for categorical variables and multivariable general linear analysis was used for continuous variables.

Abbreviations: BMI, body mass index; CI, confidence interval; ICU, intensive care unit; OR, odds ratio.

*Not beneficial, with p < 0.05

†Beneficial, with p < 0.05.

Likewise, patients in both the class III obese and underweight groups experienced prolonged ventilation after cardiac surgery compared with the normal weight group with or without risk adjustment. After general anesthesia and during the immediate postoperative period, morbidly obese patients were more likely to have significant impairments of pulmonary gas exchange and respiratory mechanics due to the patients already having experienced severe alterations of their respiratory mechanics, such as decreased chest wall and lung compliance and decreased functional residual capacity. Eichenberger et al found that general anesthesia in morbidly obese (BMI >35 kg/m²) patients generated much more atelectasis than in nonobese patients.²³ This explained why in the cohort study presented here that patients with a BMI >40 kg/m² experienced a higher incidence of prolonged ventilation. The finding presented here for underweight patients was consistent with the finding of Potapov et al in that cachectic patients (BMI <18.5 kg/m²) demonstrated significantly more complications compared with the overall study population.²⁴ The authors suggested that poor nutrition status led to less reserves, which may make it difficult for cachectic patients to handle surgical stress and postoperative complications efficiently.²¹ These facts suggested that low BMI may be a surrogate marker for comorbidities and stratification of perioperative risks; patients with low body weight, especially cachectic patients, also should be given the same considerations as those for obese patients when surgical and postoperative risk factors are assessed.

In the study presented here, there was a significant increase in the incidence of postoperative atrial fibrillation/flutter in both the class II obese and underweight groups after risk factor adjustment using parsimonious multivariable logistic regression. This finding was similar to the finding from the study by Kuduvali et al involving 4,713 patients that demonstrated obesity as a risk factor for atrial arrhythmia.²⁵

There was a significant increase in postoperative renal dialysis requirement in both the class III obese and underweight groups compared with the normal weight group in the original observed outcomes. After risk factor adjustment, only class III obese patients experienced significantly higher rates of postoperative renal dialysis and renal failure. The links between obesity and the development of chronic kidney disease have been known for several years, but the association with acute kidney injury is less clear.^{26,27} A study suggested that visceral adipose tissue, through secreted hormones and cytokines coupled with insulin resistance and hyperinsulinemia in obese patients, could lead to inappropriate activation of the renin-angiotensin-aldosterone axis and increased oxidative stress in the kidneys.²⁸

Even though it is widely accepted that obesity increases the risk of heart disease, a growing number of recent reports have documented a significant survival benefit in obese patients once they have been diagnosed. This has been called “obesity paradox,” which was demonstrated in the study presented here in that both the class III obese and underweight groups experienced significantly higher short-term postoperative mortality (in-hospital mortality, 30-day mortality, and surgical mortality) and 30-day readmission rates, but, after risk factor adjustment, there was a statistically significant benefit to in-hospital mortality and surgical mortality in just the mildly obese (class I) group (see Table 3). Furthermore, there was

significantly shorter total ICU stay in the overweight and class I obese groups. The data indicated that mild obesity could decrease short-term postoperative mortality, which was consistent with previous studies that postulated the existence of an obesity paradox in a mixed cardiac surgical population in terms of in-hospital outcomes and mortality.²⁹⁻³³ This beneficial effect may be related to the lower systemic vascular resistance and plasma renin activity of obese patients compared with leaner patients.³⁴ In addition, overweight and obese patients have lower levels of circulating atrial natriuretic peptides, attenuated sympathetic nervous systems, and renin-angiotensin responses.^{35,36} It is plausible that patients who are overweight may have the necessary metabolic reserves to overcome the further increased catabolic stress resulting from a stressful surgery.³⁷

With and without risk adjustment, even severe obesity (class III obese group) was not found to be associated with increased rates of pneumonia, ICU readmission, in-hospital mortality, 30-day mortality, and surgical mortality or increased total ICU hours. Although some may postulate that this could be due to the lack of BMI's definition to differentiate between body fat and lean mass,³⁸ there is no reasonable and definite explanation for these surprising and contradictory results in both this study and the most recent research.³⁹

Study Limitations

Limitations of this study included all those inherent in any retrospective analysis. To minimize this, the authors performed the data analysis with appropriate risk-adjusted statistical models to adjust for differences in preoperative risk factors. BMI was used as a measure of obesity in this study because it continued to be the most widely used anthropometric measure to quantify adiposity. However, BMI has certain inherent limitations, including not being able to identify differences in body composition and distribution of body fat.⁴⁰ BMI also does not quantify visceral adipose tissue, which may be the cornerstone in the obesity-associated pathophysiologic processes. It is possible to skew the results if BMI is used as the sole measure of obesity without adjusting for the other indices of adiposity (eg, waist-to-hip ratios, quantification of visceral fat mass). Unfortunately, this study contained data from only 2 hospitals, and therefore the data may not be generalizable, which could change some of the observed outcomes that resulted in variability among different studies.

CONCLUSIONS

In conclusion, the results of this study demonstrated that patients undergoing cardiac surgery who were either extremely obese or underweight experienced significantly higher risks associated with early major adverse clinic outcomes. However, patients who were either mildly obese or overweight experienced improved in-hospital mortality, surgical mortality, and total ICU hours, which support the presence of an obesity paradox for cardiac surgery. Despite this finding, the presence of the obesity paradox needs to be confirmed by larger, multiple-center surgical experiences before definitive recommendations are made regarding the utility of BMI measurements in preoperative risk assessments.

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