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ARTICLE

Is the obesity paradox present in left ventricular assist device recipients? A BMI-based analysis

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Abstract

While body mass index (BMI) is a known determinant of cardiovascular outcomes, its impact on patients undergoing left ventricular assist device (LVAD) implantation remains unclear. This study aimed to evaluate the association between BMI and in-hospital outcomes in LVAD recipients. We conducted a retrospective, cross-sectional analysis using the National Inpatient Sample (2016-2020), identifying adult hospitalizations for LVAD implantation. Patients were categorized into six BMI groups. Outcomes assessed included in-hospital mortality, acute stroke, pump thrombosis, LVAD infection, length of stay (LOS), and hospital costs. Multivariable logistic regression adjusted for demographic, clinical, and hospital-level confounders, to estimate adjusted odds ratios (ORs) and beta (β) coefficients. Among 25,250 weighted admissions, 29.3% were females, with a median age of 63 years (IQR: 52-71). Class III obesity (BMI ≥40 kg/m^2) accounted for the largest proportion (32.1%). The highest mortality rate was observed in the underweight group (6.7%), and class III obesity (5.8%) groups, while the lowest rate was noted in the class II obesity group (2.5%). Overall, a reverse J-shaped relationship between BMI and in-hospital mortality was observed. Compared to normal BMI, Class I (OR: 2.46; *p*=0.038), Class II (OR: 3.73; *p*=0.017), and Class III obesity (OR: 6.80; *p*<0.001) were significantly associated with increased odds of in-hospital mortality. Class III obesity was also associated with significantly prolonged LOS (β: 7.07 days; *p*=0.002) and higher hospital costs (β: $208,791.5; *p*=0.001). Overweight patients (BMI 25-29.9 kg/m^2) had significantly lower odds of acute stroke (OR: 0.40; *p*=0.030), while no BMI group showed a significant association with pump thrombosis and LVAD infection. Higher BMI, particularly Class III obesity, is independently associated with increased mortality, length of stay, and hospital costs in LVAD recipients. These findings challenge the obesity paradox and underscore the need for refined risk stratification in this population.

Key words: chronic HF treatment; ventricular assist devices; obesity.

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Introduction

Obesity has emerged as one of the most pressing and rapidly escalating global health crises of the 21st century. Since 1990, adult obesity has more than doubled, while adolescent obesity has quadrupled.[1] In the United States alone, approximately 40.3% of adults aged 20 and older are considered obese.[2]
Obesity is closely linked to a range of cardiovascular diseases, notably heart failure.[3] The underlying pathophysiology includes increased blood volume and cardiac workload, contributing to left ventricular hypertrophy and, ultimately, heart failure.[4,5] The left ventricular assist device (LVAD) has become a vital treatment for patients with end-stage heart failure. Functioning as a mechanical pump, the LVAD supports the failing left ventricle and is commonly used as a bridge to transplant, destination therapy, or bridge to recovery.[6] Although LVAD therapy significantly improves survival and quality of life, it also presents substantial risks, including bleeding, stroke, and infection.[7]
While obesity has been linked to worse outcomes in many cardiovascular conditions and interventions,[8,9] the data surrounding its impact on LVAD outcomes are mixed. Some studies suggest obesity may lead to higher adverse event rates, while others report no significant impact -or even a paradoxical survival benefit- particularly when compared to patients with low BMI.[10-12]
Given the rising prevalence of obesity and the expanding role of LVADs in advanced heart failure management, it is critical to better understand how BMI influences outcomes in this population. This study aims to assess the relationship between BMI and in-hospital outcomes -including mortality, acute

stroke, pump thrombosis, LVAD infection, length of stay, and hospital cost of care- among patients receiving LVAD support using a nationally representative database.

Methods

Study design and data source

This study is a retrospective, cross-sectional analysis of inpatient admissions for LVAD using data from the NIS database, spanning from January 1, 2016, to December 31, 2020. The NIS, part of the Healthcare Cost and Utilization Project (HCUP) and sponsored by the Agency for Healthcare Research and Quality (AHRQ), is the largest publicly available inpatient database in the United States.[13] It captures approximately 7 million unweighted hospitalizations annually, representing 20% of all U.S. admissions. When weighted, it estimates nearly 35 million hospitalizations per year. The dataset includes patient- and hospital-level data from over 4,500 hospitals across 48 states. Each record contains up to 40 discharge diagnoses and 25 procedures, coded using the International Classification of Diseases, 10th Revision (ICD-10), offering a comprehensive view of clinical events and interventions. As the data are de-identified and publicly accessible, this study was exempt from institutional review board approval and conducted in accordance with the NIS data-use agreement.

Study population

LVAD hospitalizations were identified in the database using ICD-10 diagnostic code Z95.811. Patients were categorized into six BMI groups based on ICD-10 BMI codes (Z68x): underweight (BMI ≤19.9 kg/m^2), normal weight (BMI 20.0-24.9 kg/m^2), overweight (BMI 25.0-29.9 kg/m^2), class I obesity (BMI 30.0-34.9 kg/m^2), class II obesity (BMI 35.0-39.9 kg/m^2), and class III obesity (BMI ≥40.0 kg/m^2).[14,15] Patients under the age of 20 years were also excluded from this study (Figure 1). Base-

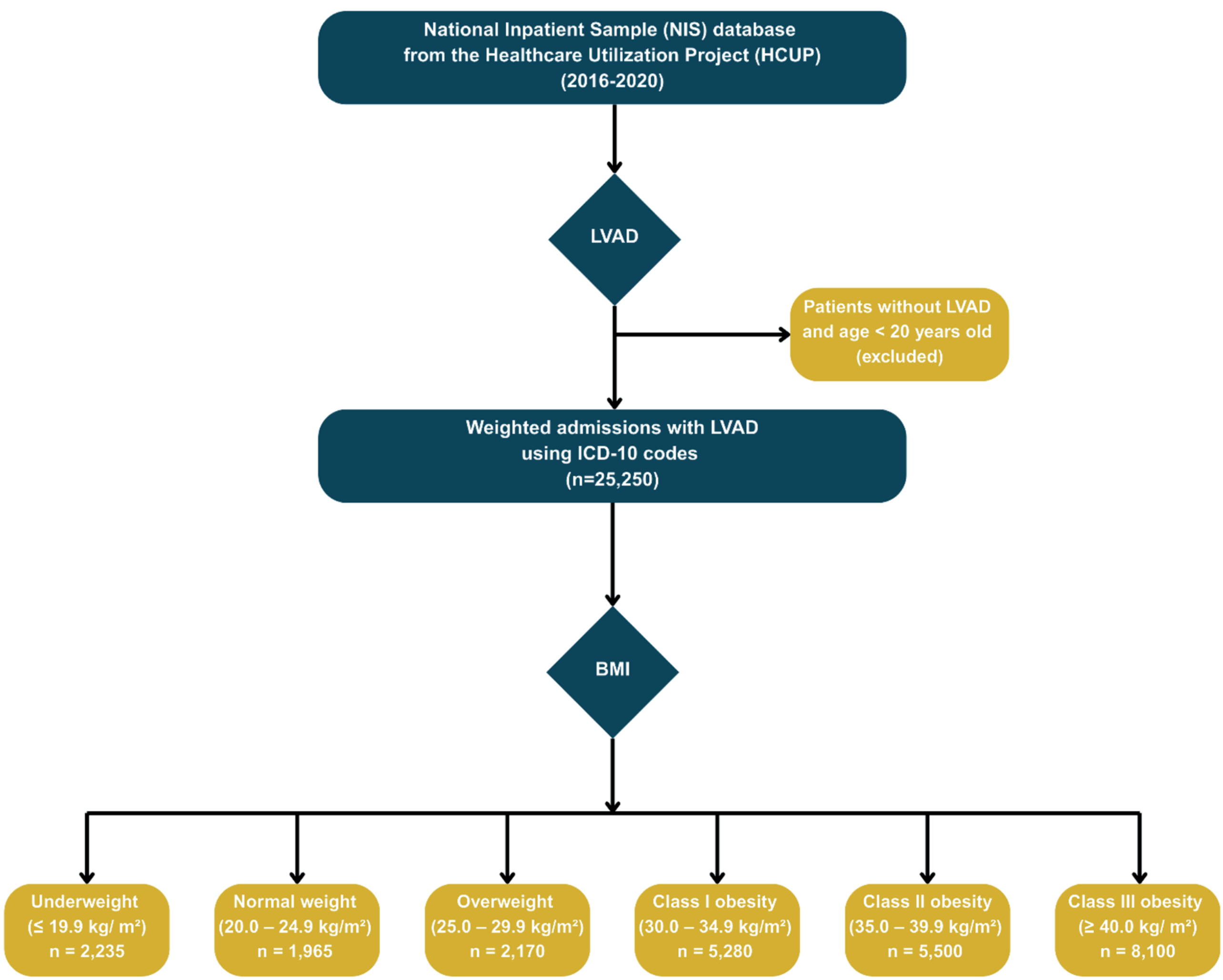

Figure 1. Reported numbers based on weighted analysis.

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line demographic characteristics, including age, sex and race, are available in the dataset. Comorbidities were identified from the database using ICD-10 diagnostic codes and Charlson comorbidities as reported in the HCUP dataset (*Supplementary Table S1*).

Study outcomes

The primary outcome was in-hospital mortality. Secondary outcomes included acute stroke, pump thrombosis, LVAD infection, total hospital cost, and length of stay. In-hospital mortality was defined as death occurring during the hospitalization and was recorded based on discharge status. The length of stay was measured as the number of days between hospital admission and discharge, with same-day discharges coded as zero days. Total hospital charges were obtained from the NIS database and adjusted for inflation to 2020 US dollars using the Consumer Price Index (CPI) provided by the US Bureau of Labor Statistics.

Statistical analysis

Continuous variables were reported as median with interquartile range (IQR) and compared using linear regression for weighted estimates. Categorical variables were expressed as proportions and analyzed using Pearson's chi-square test. A multivariable logistic regression model was constructed to compare all BMI categories against the normal BMI group (20.0-24.9 kg/m²), adjusting for: i) patient-level factors: age, sex, race, income quartile, primary payer, and comorbidities including hypertension, diabetes, ischemic heart disease, atrial fibrillation, chronic kidney disease, chronic obstructive pulmonary disease, hyperlipidemia, anemia, obstructive sleep apnea, cancer, previous CABG, previous PCI, and Elixhauser Comorbidity Index score;[16] and ii) hospital-level characteristics: bed size, location/teaching status, and geographic region. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were reported. For length of stay and total hospital charges, Beta (β) coefficients and 95% CIs were estimated using similarly adjusted models, with normal BMI as the reference.

Survey-weighted analysis was performed to generate nationally representative estimates using discharge weights from the NIS database. A *p*-value of <0.05 was considered statistically significant. All statistical analyses were conducted using Stata v17.0 (StataCorp, College Station, TX).

Results

Baseline characteristics

Between 2016 and 2020, a total of 25,250 weighted hospitalizations for LVAD implantation were identified. These hospitalizations were categorized into six BMI subgroups as follows: 2,235 (8.8%) admissions for underweight (BMI ≤19.9 kg/m^2), 1,965 (7.7%) for normal weight (BMI 20.0-24.9 kg/m^2), 2,170 (8.6%) for overweight (BMI 25.0-29.9 kg/m^2), 5,280 (21.0%) for class I obesity (BMI 30.0-34.9 kg/m^2), 5,500 (21.8%) for class II obesity (BMI 35.0-39.9 kg/m^2), and 8,100 (32.1%) for class III obesity (BMI ≥40.0 kg/m^2). Table 1 shows the baseline characteristics of the study cohort across the six BMI subgroups.

The median age of hospitalized individuals was 63 years (IQR: 52-71). Patients who were underweight (median: 64 years) or of normal weight (64 years) were generally older than those who were overweight (58 years), or had class I (54 years), class II (49 years), or class III obesity (56 years). Males accounted for 70.7% of LVAD hospitalizations, with the highest proportions in overweight (77.0%) and normal weight (78.4%) groups. Females made up 29.3% of the overall cohort, with the largest representation in class III obesity (37.2%). Race distributions varied across BMI categories. White individuals were predominant in overweight (62.4%) and class I obesity (61.0%) groups, while Black individuals were most represented in class III obesity (48.8%). Medicare was the most common primary payer (56.0%), followed by Medicaid (14.6%) and private/other insurance (29.4%). Across BMI categories, class I and class II obesity showed the highest reliance on Medicare (65.7% and 55.1%, respectively), whereas Medicaid and other insurance types were more common among patients with class III obesity (17.6% and 25.5%, respectively). The median Elixhauser comorbidity scores varied across BMI groups. Underweight patients had the highest median score (13; IQR: 7-20), followed by normal weight individuals (10; IQR: 6-15) and overweight individuals (8; IQR: 5–13). Scores were progressively lower in higher BMI groups, with class I obesity (7; IQR: 4-12), class II obesity (6; IQR: 3-10), and class III obesity (5; IQR: 3-8). The most common comorbidities across the cohort were peripheral vascular disease (88.1%), hypertension (81.3%), and chronic kidney disease (52.4%).

Outcomes

The overall in-hospital mortality rate for admissions with LVAD implantation was 4.7% (1,190 out of 25,250 admissions). The highest mortality rate was observed in the underweight group (6.7%), and class III obesity (5.8%) groups, while the lowest rate was noted in the class II obesity group (2.5%) (Table 2). Figure 2 illustrates a reverse J-shaped relationship between BMI and in-hospital mortality. In multivariable logistic analysis, overweight admissions had lower odds of in-hospital mortality (OR 0.84, 95% CI 0.40-1.91; *p*=0.681), while underweight patients had slightly higher odds (OR 1.06, 95% CI 0.53–2.14; *p*=0.851); however, neither finding was statistically significant. In contrast, class I obesity (OR, 2.46; 95% CI, 1.04-5.77; *p*=0.038), class II obesity (OR, 3.73; 95% CI, 1.26-11.02; *p*=0.017), and class III obesity (OR, 6.80; 95% CI, 2.88-16.00; *p*<0.001) were each associated with significantly higher odds of mortality (Figure 3; Table 3).

The overall rate of acute stroke among hospitalizations for LVAD implantation was 3.7%. The highest acute stroke rates were observed for normal weight (6.8%) and underweight (5.0%) (Table 2).

Table 1. Baseline characteristics of LVAD patients stratified by body mass index.

Demographic	Overall n=25,250 (100)	Underweight (≤19.9 kg/m²) n=2,235 (8.8)	Normal weight* (20.0-24.9 kg/m²) n=1,965 (7.7)	Overweight (25.0-29.9 kg/m²) n=2,170 (8.6)	Class I obesity (30.0-34.9 kg/m²) n=5,280 (21.0)	Class II obesity (35.0-39.9 kg/m²) n=5,500 (21.8)	Class III obesity (≥0.0 kg/ m²) n=8,100 (32.1)	*p*-value
Age, y, median (IQR)	63 (52-71)	64 (54-70)	64 (55-70)	58 (49-65)	54 (45-63)	49 (39-59)	56 (45-65)	
Age groups								<0.001
20-39	3,945 (15.6)	275 (12.3)	155 (7.9)	145 (6.6)	485 (9.2)	815 (14.8)	2,070 (25.6)	
40-59	10,965 (43.4)	610 (27.3)	520 (26.5)	650 (30.0)	2,305 (43.7)	2,730 (49.6)	4,150 (51.2)	
60-79	9,995 (39.6)	1,250 (56.0)	1,230 (62.6)	1,325 (61.1)	2,430 (46.0)	1,910 (34.7)	1,850 (22.8)	
80+	345 (1.3)	100 (4.8)	60 (3.0)	50 (2.3)	60 (1.1)	45 (0.8)	30 (0.3)	
Sex								<0.001
Male	17,850 (70.7)	1,630 (73.0)	1,540 (78.4)	1,670 (77.0)	3,935 (74.5)	3,990 (72.5)	5,085 (62.8)	
Female	7,400 (29.3)	605 (27.1)	425 (21.6)	500 (23.0)	1,345 (25.5)	1,510 (27.5)	3,015 (37.2)	
Race								<0.001
White	12,840 (52.7)	1,155 (53.2)	1,125 (59.5)	1,325 (62.4)	3,095 (61.0)	2,765 (52.2)	3,375 (43.2)	
Black	8,985 (37.0)	660 (30.4)	535 (28.3)	505 (23.8)	1,540 (30.3)	1,935 (36.5)	3,810 (48.8)	
Hispanic	1,550 (6.3)	170 (7.8)	105 (5.5)	150 (7.0)	295 (5.8)	435 (8.2)	395 (5.0)	
Others	990 (4.0)	185 (8.5)	125 (6.6)	145 (6.8)	145 (2.8)	160 (3.0)	230 (3.0)	
Household income								<0.001
Quartile1 ($1-$51,999)	8,550 (34.3)	635 (28.7)	535 (26.0)	615 (59.0)	1,835 (35.3)	1,890 (34.8)	3,040 (38.0)	
Quartile2 ($52,000 - $65,999)	6,825 (27.4)	575 (26.0)	480 (24.7)	585 (27.5)	1,475 (28.3)	1,560 (28.7)	2,150 (26.8)	
Quartile3 ($66,000 - $87,999)	5,725 (23.0)	575 (26.0)	415 (21.3)	550 (26.0)	1,125 (21.6)	1,175 (21.6)	1,885 (23.5)	
Quartile4 ($88,000 or more)	3,830 (15.4)	430 (19.4)	515 (26.5)	375 (17.6)	770 (14.8)	805 (14.8)	935 (11.7)	
Expected primary payer								<0.001
Medicare	14,090 (56.0)	1,225 (54.8)	1,185 (60.3)	1,425 (65.7)	2,850 (54.0)	3,030 (55.1)	4,375 (54.2)	
Medicaid	3,685 (14.6)	340 (15.2)	220 (11.2)	200 (9.2)	700 (13.3)	800 (14.5)	1,425 (17.6)	
No charge	6,590 (26.1)	535 (24.0)	515 (26.2)	470 (21.7)	1,515 (28.7)	1,495 (27.2)	2,060 (25.5)	
Other	860 (3.4)	135 (6.0)	45 (2.3)	75 (3.4)	215 (4.0)	175 (3.1)	215 (2.6)	
Elixhauser groups#								0.435
0-1	280 (1.1)	30 (1.3)	25 (1.2)	15 (0.7)	50 (0.9)	60 (1.1)	100 (1.2)	
2-3	7,090 (28.1)	620 (27.7)	515 (26.2)	570 (26.3)	1,405 (26.6)	1,485 (27.0)	2,495 (30.8)	
4+	17,880 (70.8)	1,585 (71.0)	1,425 (72.5)	1,585 (73.0)	3,825 (72.4)	3,955 (72.0)	5,505 (68.0)	
Comorbidities								
Atrial fibrillation	11,095 (44.0)	915 (41.0)	1,015 (51.7)	1,015 (46.8)	2,410 (45.6)	2,450 (44.5)	3,290 (40.6)	0.001
Cerebrovascular disease	1,425 (5.6)	175 (7.8)	200 (10.2)	145 (6.6)	285 (5.4)	255 (4.6)	365 (4.5)	<0.001
Peripheral vascular disease	22,255 (88.1)	1,830 (82.0)	1,695 (86.3)	1,910 (88.0)	4,790 (90.7)	5,040 (91.6)	6,990 (86.3)	<0.001
Dementia	800 (3.1)	140 (6.2)	125 (6.3)	70 (3.2)	145 (2.7)	150 (2.7)	170 (2.1)	<0.001
COPD	4,630 (18.3)	495 (22.1)	300 (15.3)	525 (24.2)	1,035 (19.6)	880 (16.0)	1,395 (17.2)	0.001
Valvular heart disease	5,670 (22.5)	675 (30.2)	665 (33.8)	630 (29.0)	1,205 (22.8)	1,225 (22.3)	1,270 (15.7)	<0.001
Liver disease	1,660 (6.5)	215 (9.6)	215 (11.0)	145 (6.6)	395 (7.4)	205 (3.7)	485 (6.0)	<0.001
Diabetes mellitus	12,055 (47.7)	555 (24.8)	670 (34.1)	930 (43.0)	2,735 (51.8)	3,000 (54.5)	4,165 (51.4)	<0.001
Hypertension	20,525 (81.3)	1,580 (70.7)	1,455 (74.0)	1,680 (77.4)	4,380 (83.0)	4,695 (85.4)	6,735 (83.1)	<0.001
Chronic kidney disease	13,230 (52.4)	995 (44.5)	1,005 (51.1)	1,175 (54.1)	2,915 (55.2)	2,920 (53.1)	4,220 (52.1)	0.018
Dialysis dependence	480 (2.0)	60 (2.6)	40 (2.0)	65 (3.0)	115 (2.1)	70 (1.2)	130 (1.6)	0.200
Anemia	3,150 (12.5)	275 (12.3)	295 (15.0)	300 (13.8)	660 (12.5)	630 (11.5)	990 (12.2)	0.543
Hyperlipidemia	11,030 (43.7)	790 (35.3)	755 (38.4)	1,165 (53.7)	2,635 (50.0)	2,640 (48.0)	3,045 (37.6)	<0.001
Cancer	540 (2.1)	80 (3.5)	85 (4.3)	105 (4.8)	90 (1.7)	60 (1.1)	120 (1.4)	<0.001
Previous myocardial infarction	4,600 (18.2)	360 (16.1)	470 (24.0)	545 (25.1)	1,160 (22.0)	1,045 (19.0)	1,020 (12.6)	<0.001
Previous PCI	3,020 (12.0)	195 (8.7)	330 (16.8)	435 (20.0)	735 (14.0)	660 (12.0)	665 (8.2)	<0.001
Previous CABG	2,645 (10.5)	245 (11.0)	295 (15.0)	440 (20.3)	620 (11.7)	640 (11.6)	405 (5.0)	<0.001

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Table 1. Continued from previous page.

Demographic	Overall n=25,250 (100)	Underweight (≤19.9 kg/m²) n=2,235 (8.8)	Normal weight* (20.0-24.9 kg/m²) n=1,965 (7.7)	Overweight (25.0-29.9 kg/m²) n=2,170 (8.6)	Class I obesity (30.0-34.9 kg/m²) n=5,280 (21.0)	Class II obesity (35.0-39.9 kg/m²) n=5,500 (21.8)	Class III obesity (≥0.0 kg/ m²) n=8,100 (32.1)	*p*-value
Hospital bed size								0.300
Small	740 (3.0)	75 (3.3)	35 (1.7)	70 (3.2)	180 (3.4)	170 (3.1)	210 (2.6)	
Medium	2,375 (9.4)	220 (9.8)	140 (7.1)	215 (10.0)	545 (10.3)	595 (10.8)	660 (8.1)	
Large	22,135 (87.7)	1,940 (86.8)	1,790 (91.1)	1,885 (87.0)	4,555 (86.3)	4,735 (86.1)	7,230 (89.3)	
Hospital location/teaching status								<0.260
Rural	120 (0.4)	0 (0)	NA	15 (0.7)	50 (0.9)		30 (0.5)	20 (0.2)
Urban nonteaching	490 (1.9)	45 (2.0)	35 (1.7)	55 (2.5)	100 (1.9)	85 (1.5)	170 (2.1)	
Urban teaching	24,640 (97.6)	2,190 (98.0)	1,925 (98.0)	2,100 (96.8)	5,130 (97.2)	5,385 (98.0)	7,910 (97.7)	
Hospital region								0.005
Northeast	4,255 (17.0)	485 (21.7)	360 (18.3)	305 (14.1)	875 (16.6)	870 (15.8)	1,360 (16.8)	
Midwest	8,135 (32.2)	605 (27.1)	725 (37.0)	705 (32.5)	1,765 (33.4)	1,825 (33.2)	2,510 (31.0)	
South	10,155 (40.2)	800 (35.8)	675 (34.4)	880 (40.6)	2,075 (39.3)	2,195 (40.0)	3,530 (43.6)	
West	2,705 (10.7)	345 (15.4)	205 (10.4)	280 (13.0)	565 (10.7)	610 (11.1)	700 (8.6)	

Values are n (%) unless otherwise indicated; *normal weight was used as the reference category; #Elixhauser Comorbidity Index is a method of categorizing comorbidities of patients based on ICD diagnosis codes found in administrative data; Group <4 represents patients with fewer than 4 comorbidities; Groups 4-6 includes patients with four to six comorbidities and >6 comprises patients with more than six comorbidities; COPD, chronic obstructive pulmonary disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft.

Table 2. In-hospital outcomes of LVAD patients by body mass index.

Outcomes	Overall n=25,250 (100)	Underweight (≤19.9 kg/ m²) n=2,235 (8.8)	Normal weight* (20.0-24.9 kg/m²) n=1,965 (7.7)	Overweight (25.0-29.9 kg/m²) n=2,170 (8.6)	Class I obesity (30.0-34.9 kg/m²) n=5,280 (21.0)	Class II obesity (35.0-39.9 kg/m²) n=5,500 (21.8)	Class III obesity (≥40.0 kg/ m²) n=8,100 (32.1)	p-value
In-hospital mortality	1,190 (4.7)	150 (6.7)	110 (5.6)	100 (4.6)	215 (4.0)	140 (2.5)	475 (5.8)	<0.001
Acute stroke	955 (3.7)	110 (5.0)	135 (6.8)	70 (3.2)	190 (3.6)	165 (3.0)	285 (3.5)	0.015
Pump thrombosis	935 (3.7)	60 (2.6)	65 (3.3)	65 (3.0)	195 (3.7)	180 (3.2)	370 (4.5)	0.312
LVAD infection	2,950 (11.7)	235 (10.5)	165 (8.4)	215 (9.9)	625 (11.8)	675 (12.3)	1,035 (12.8)	0.135
Total hospital charges, US $	$78,582 (34,592–367772)	$139,189 (50,700–658,752)	$117,279 (47,293-646,960)	$102,780 (43,200-554,521)	$73,892 (34,036-331,880)	$62,502 (28,302-219,405)	$72,659 (32,239-287,902)	<0.001
Length of stay, days	8 (4-19)	14 (7-29)	12 (6-28)	10 (5-22)	8 (4-16)	7 (3-14)	8 (4-18)	<0.001

Values are n (%) unless otherwise indicated; *normal weight was used as the reference category.

Upon multivariable logistic regression, overweight individuals demonstrated significantly lower odds of acute stroke (OR, 0.40; 95% CI, 0.18-0.90; *p*=0.030), while underweight individuals also showed reduced odds, although this finding was not statistically significant (OR, 0.76; 95% CI, 0.33-1.71; *p*=0.506). Conversely, admissions for class I, class II, and class III obesity demonstrated higher odds of acute stroke, but none of these findings reached statistical significance (Figure 3; Table 3).

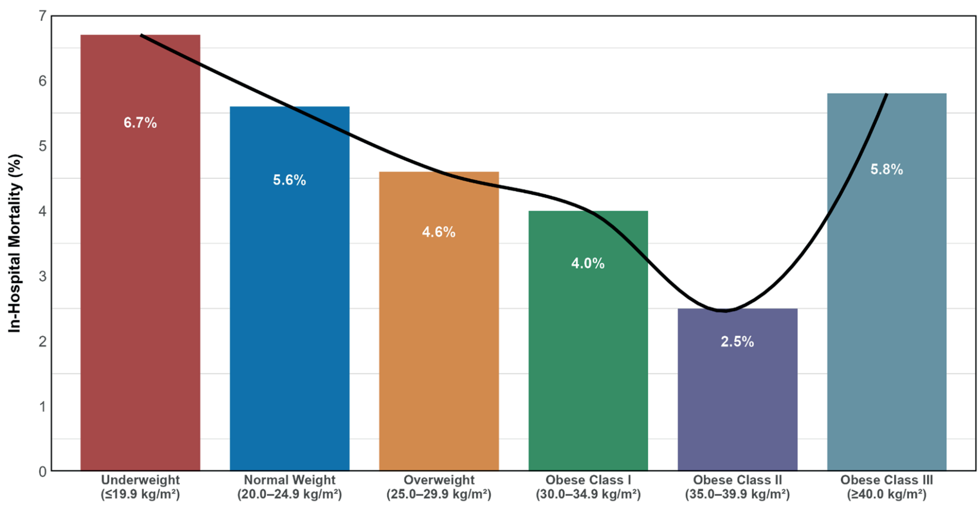

Figure 2. In-hospital mortality rates for different BMI categories. The bar heights represent the percentage of in-hospital deaths, with corresponding values labeled inside each bar. Mortality is highest in the underweight group (6.7%) and declines through the normal weight (5.6%), overweight (4.6%), and obese class I (4.0%) categories, reaching the lowest rates in obese class II (2.5%). An increase is observed in obese class III (5.8%). A trendline highlights the J-shaped pattern of in-hospital mortality across BMI categories.

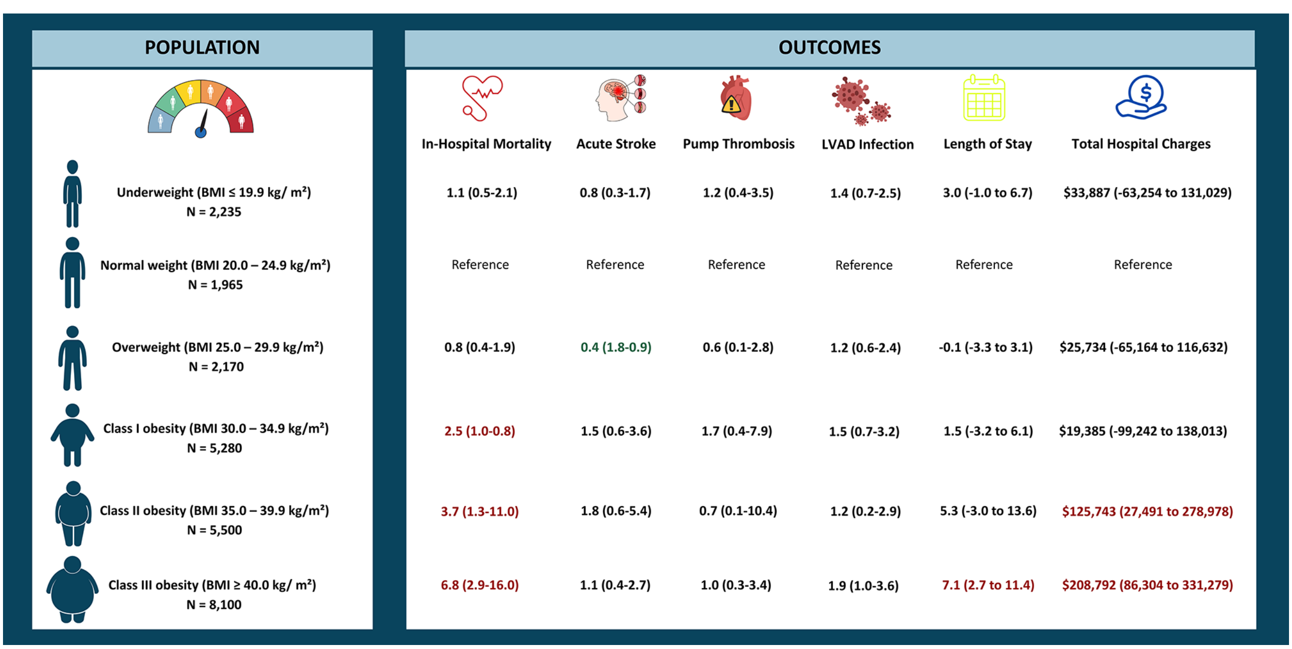

Figure 3. Impact of BMI among LVAD patients. Adjusted odds ratios (for in-hospital mortality, acute stroke, and pump thrombosis) and beta coefficients (for length of stay and total hospital charges) were based on multivariable logistic regression model adjusted for age, sex, race, income quartile, primary payer, and comorbidities including hypertension, diabetes, valvular heart disease, peripheral vascular disease, atrial fibrillation, chronic kidney disease, dialysis dependence, chronic obstructive pulmonary disease, liver disease, hyperlipidemia, anemia, cancer, dementia, previous myocardial infarction, previous CABG, previous PCI, Elixhauser Comorbidity Index score, hospital bed size, hospital location/teaching status, and hospital geographic region.

Table 3. Association of body mass index with in-hospital outcomes in LVAD patients.

Outcomes	Underweight (≤19.9 kg/m²)	Overweight (25.0-29.9 kg/m²)	Class I obesity (30.0-34.9 kg/m²)	Class II obesity (35.0-39.9 kg/m²)	Class III obesity (≥40.0 kg/m²)
In-hospital mortality (OR [95% CI], *p*-value)	1.06 (0.53-2.14), 0.851	0.84 (0.40-1.91), 0.681	2.46 (1.04-.77), 0.038	3.73 (1.26-11.02), 0.017	6.80 (2.88-16.00), <0.001
Acute stroke (OR [95% CI], p-value)	1.20 (0.41-3.46), 0.730	0.61 (0.13-2.76), 0.522	1.68 (0.35-7.94), 0.512	0.71 (0.05-10.42), 0.807	0.99 (0.30-3.35), 0.997
Pump thrombosis (OR [95% CI], *p*-value)	0.76 (0.33-1.71), 0.506	0.40 (1.80-0.90), 0.030	1.50 (0.63-3.57), 0.348	1.77 (0.57-5.44), 0.314	1.058 (0.43-2.70), 0.857
LVAD infection	1.35 (0.71-2.54), 0.348	1.23 (0.63-2.43), 0.536	1.50 (0.71-3.18), 0.280	1.24 (0.54-2.88), 0.603	1.87 (0.98-3.55), 0.055
Total hospital charges, US $ (Beta [95% CI], *p*-value)	$33,887 (-$63,253 to $131,029), 0.500	$25,733 (-$65,164 to $116,632), 0.578	$19,385 (-$99,242 to $138,013), 0.748	$125,743 (-$27,491 to $278,978), 0.017	$208,792 ($86,304 to $331,279), 0.001
Length of stay, days (Beta [95% CI], *p*-value)	2.83 (-1.03 to 6.70), 0.150	-0.12 (-3.31 to 3.06), 0.938	1.50 (-3.15 to 6.14), 0.527	5.30 (-3.00 to 13.60), 0.210	7.07 (2.71 to 11.43), 0.002

Effect sizes are based on multivariable logistic regression model adjusted for age, sex, race, income quartile, primary payer, and comorbidities including hypertension, diabetes, valvular heart disease, peripheral vascular disease, atrial fibrillation, chronic kidney disease, dialysis dependence, chronic obstructive pulmonary disease, liver disease, hyperlipidemia, anemia, cancer, dementia, previous myocardial infarction, previous CABG, previous PCI, Elixhauser Comorbidity Index score, hospital bed size, hospital location/teaching status, and hospital geographic region.

The overall rate of pump thrombosis among hospitalizations for LVAD implantation was 3.7%. The lowest rates of pump thrombosis were observed in the underweight (2.6%) and overweight (3.0%) groups. In contrast, the highest rate was noted in class III obesity group (4.5%) (Table 2). Multivariable logistic analysis did not identify significant differences in the odds of pump thrombosis across BMI groups when compared to the reference normal weight group (ORs ranging from 0.61 to 1.68, all $p>0.50$) (Figure 3; Table 3).

The overall rate of LVAD infection among hospitalizations for LVAD implantation was 3.7%. Infection rates were lowest in the normal weight group (8.4%) and highest in patients with class III obesity (12.8%) (Table 2). However, in multivariable logistic regression, the odds of LVAD infection did not differ significantly across BMI categories when compared with the normal weight reference group (ORs 1.23-1.87, all $p>0.05$) (Figure 3; Table 3).

The median total charges for hospitalizations involving LVAD implantation were $78,582 (IQR: $34,592-$367,772). The highest median charges were observed in the underweight group ($139,189; IQR: $50,700-$658,752), while the lowest median charges were noted in class II obesity ($62,502; IQR: $28,302-$219,405) (Table 2). Upon multivariable logistic regression, class II and class III obesity groups incurred significantly greater costs (β, $125,743.4; 95% CI: $27,491.35 to $278,978.1; $p=0.017$) and (β, $208,791.5; 95% CI: $86,304.43 to $331,278.6; $p=0.001$) respectively (Figure 3; Table 3). The median length of stay for hospitalizations involving LVAD implantation was 8 days (IQR 4-19). Underweight patients had the longest stays (14 days; IQR 7-29), while class II obesity patients had the shortest stays (7 days; IQR: 3-14) (Table 2). Multivariable logistic regression identified class III obesity to have a significantly longer length of stay (β, 7.07; 95% CI: 2.71 to 11.43; $p=0.002$) (Figure 3; Table 3).

Discussion

This large-scale, nationally representative study examines the relationship between BMI and in-hospital outcomes among patients undergoing LVAD implantation. Utilizing weighted data from 25,250 hospitalizations in the National Inpatient Sample (2016-2020), we assessed how BMI influences mortality, acute stroke, pump thrombosis, length of stay, and hospital costs. After multivariable adjustment, a linear relationship emerged between increasing obesity class and in-hospital mortality, with higher obesity classes exhibiting progressively elevated odds relative to the normal BMI group. Overweight patients had significantly lower odds of acute stroke, while individuals with class II obesity incurred higher hospital charges. Class III obesity was associated with both increased costs and prolonged hospitalizations compared to normal BMI counterparts.

While existing literature presents varying perspectives on the impact of BMI on LVAD recipients, our study provides a more definitive characterization. Some studies have linked obesity to increased mortality and worse outcomes, often attributed to technical challenges during implantation and higher infection rates.[17-19] In contrast, other investigations have found no significant correlation between obesity and early postoperative outcomes[20-22] and some have even described a potential obesity paradox, wherein elevated BMI may be associated with improved survival in patients with advanced heart failure.[11,23] A meta-analysis of 26,852 patients supports this notion, showing reduced short-term mortality among obese individuals.[24] Although our unadjusted analysis initially appeared to support this paradox, the association did not persist after multivariable adjustment. Instead, class I, II, and III obesity were each linked to increased odds of in-hospital mortality compared to normal BMI, suggesting that elevated BMI may not be protective in the postoperative setting of LVAD implantation. This finding is consistent with the 2023 International Society for Heart and Lung Transplantation (ISHLT) guidelines for Mechanical Circulatory Support, which note that while obesity is not a contraindication to LVAD therapy, higher BMI is more clearly associated with perioperative morbidity -including infection, pump thrombosis, right heart failure, and readmissions- and that careful patient selection and optimization of comorbidities are essential.[25]

Beyond mortality, prior studies have also demonstrated higher complication rates after LVAD implantation in obese patients.[21,26] Increased prevalence of diabetes and prediabetes in this population may contribute to greater surgical site infection risk, while obesity-related impairments in immune surveillance, chemotaxis, and macrophage function further heighten susceptibility to infection.[27,28] Postoperative hyperglycemia, even in non-diabetic obese patients undergoing cardiac surgery, has also been shown to predispose to infection and sepsis.[29] These mechanisms may partly explain the higher morbidity burden described in earlier reports and highlighted by the ISHLT guidelines, and they reinforce the need for careful perioperative management in obese LVAD recipients. While the obesity paradox has been debated, its applicability to LVAD recipients is limited. More importantly, obesity has distinct LVAD-related implications, including higher risks of infection, pump thrombosis, and right heart failure.

The obesity paradox -where overweight and mildly obese patients seem to have better outcomes than those with normal weight- has been described in cardiovascular disease and advanced heart failure.[30,31] Proposed mechanisms include greater metabolic reserve, lower natriuretic peptide levels, and potentially protective adipokine activity.[32,33] However, much of this paradox may reflect methodological issues, including selection bias, unrecognized cachexia, and unintentional weight loss from underlying illness.[34-37] In addition, confounding and collider bias can distort associations, as lower BMI often coexists with frailty or advanced disease.[38]

Our study also explored secondary outcomes, including acute stroke and pump thrombosis, in relation to BMI among LVAD recipients. Overweight individuals exhibited significantly lower odds of experiencing acute stroke following LVAD implantation compared to those with a normal BMI. Potential mechanisms for this protective effect could include favorable hemodynamic responses and modulation of inflammatory pathways.[39] Elevated leptin levels may offer neuroprotection through anti-apoptotic and anti-inflammatory effects, while higher levels of lipids and lipoproteins in overweight individuals may help neutralize inflammatory cytokines and reduce systemic inflammation, further enhancing cerebrovascular stability.[40-42] Additionally, obesity is linked to prothrombotic state due to elevated coagulation factors, chronic inflammation, and altered anticoagulant pharmacokinetics, which could influence pump function.[43-45] However, our analysis did not identify a definitive relationship between BMI and the odds of stroke or pump thrombosis.

While BMI is commonly used in risk assessment, it is an incomplete metric that overlooks critical factors such as body composition, fat distribution, and functional capacity.[46,47] Alternative measures such as central adiposity and muscle mass may provide a more accurate reflection of cardiometabolic risk. Emerging evidence also suggests that higher levels of cardiorespiratory fitness can mitigate the adverse effects of obesity on clinical outcomes, highlighting the importance of evaluating fitness in conjunction with BMI.[48] These limitations underscore the need for a more nuanced, individualized approach to risk stratification -particularly in patients with severe obesity undergoing LVAD implantation.

Our findings have important clinical implications for the management of patients with severe obesity in the context of LVAD therapy. Comprehensive preoperative optimization -including aggressive control of comorbidities, weight reduction when feasible, and meticulous perioperative planning- may help mitigate the increased risk of complications. However, adherence to lifestyle interventions remains a major challenge in this population, particularly given the complex interplay of comorbidities in advanced heart failure.[49] Importantly, BMI should not be viewed in isolation but rather incorporated into a broader assessment framework. Future research should focus on developing and validating multifactorial risk models that integrate body composition, fitness, and metabolic health to guide clinical decision-making and improve outcomes in LVAD recipients.

Limitations

This study should be considered within the context of several important limitations. As it is based on the NIS, an administrative claims database, there is an inherent risk of misclassification and coding errors, particularly due to reliance on ICD-10 codes for identifying diagnoses and procedures. The dataset also lacks access to detailed clinical variables, such as laboratory results, imaging data, and perioperative details, including LVAD type, implantation indication, and preoperative optimization strategies -which may influence patient outcomes. Additionally, key confounding factors such as nutritional interventions, medication use, and functional status are not captured, limiting the ability to fully account for clinical complexity. Although BMI is a widely used metric, it does not reflect body composition or fat distribution, which may be more closely associated with postoperative risk. Furthermore, because the NIS records hospitalizations rather than unique patients, individuals with multiple admissions may be represented more than once, potentially introducing sampling bias. Finally, as with all observational studies, causality cannot be inferred, and the possibility of residual confounding from unmeasured variables remains.

Conclusions

In conclusion, our study found no evidence supporting the obesity paradox among LVAD recipients. After adjusting for relevant confounders, a linear association emerged, where higher classes of obesity were associated with increased odds of mortality compared to normal BMI. Notably, for acute stroke, overweight individuals demonstrated significantly lower odds compared to those with normal BMI. Class II obesity was associated with higher hospital charges, while Class III obesity conferred both increased costs and prolonged hospitalizations. These findings underscore the need for refined risk stratification approaches that incorporate body composition and comorbid burden to guide clinical management and improve outcomes, particularly in class I-III obese populations.

Contributions

All authors made a substantive intellectual contribution, read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest

The authors declare no competing interests, and all authors confirm accuracy.

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Online supplementary material:
Table S1. ICD-10 CM of medical comorbidities