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ORIGINAL ARTICLE

Body Mass Index Affects Hospital-Associated Disability and Economic Burden in Elective Cardiovascular Surgery
— JROAD/JROAD-DPC Database —

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Background: Both underweight and overweight are recognized as important factors influencing outcomes in patients undergoing cardiovascular surgery. This study investigated the effects of body mass index (BMI) on hospital-associated disability (HAD) and hospitalization costs in patients undergoing elective cardiovascular surgery (coronary artery bypass grafting, valve surgery, aortic surgery) by analyzing data from the Japanese Registry of All Cardiac and Vascular Diseases – Diagnosis Procedure Combination (JROAD-DPC) database.

Methods and Results: All patients in the JROAD-DPC database were categorized into 5 groups according to the World Health Organization BMI criteria for Asians. HAD was defined as a decrease of ≥5 points in the Barthel Index from admission to discharge. The primary outcome was the prevalence of HAD, and the secondary outcome was hospitalization costs. Among the 228,891 patients included in the study, the median BMI was 23.2 kg/m^2. The prevalence of HAD was 8.7%, with a U-shaped relationship between BMI and HAD, indicating that both extremely low and high BMIs were associated with a higher incidence of HAD. Hospitalization costs also showed a U-shape relationship with BMI, with higher costs for patients with HAD.

Conclusions: Low BMI in any age group was associated with HAD, and older people with a BMI considered too high also had HAD. BMI could be an important risk stratification tool for functional outcomes and economic burden in patients undergoing elective cardiovascular surgery.

Key Words: Body mass index; Cardiovascular surgery; Healthcare costs; Hospital-associated disability; Japanese Registry of All Cardiac and Vascular Diseases

The increasing number of older patients undergoing cardiovascular surgery has led to higher perioperative risks and significant economic burden related to healthcare.[1] In particular, patients with frailty or sarcopenia show a marked decrease in postoperative activities of daily living (ADL), termed hospital-associated disability (HAD).[2] HAD is closely associated with a major reduction in quality of life and poor prognosis.[3,4] In addition, frail patients face healthcare costs that are twice as high as those of non-frail patients, both before and after surgery, posing a significant economic burden.[5] Recognizing these risks and developing appropriate preoperative risk assessments and interventions are crucial.

Body mass index (BMI) is recognized as a key indicator of a patient's nutritional status, and it is well-established that both low and excessively high BMI contribute to adverse outcomes.[6] In particular, obesity is associated with lifestyle diseases and an increased risk of cardiovascular

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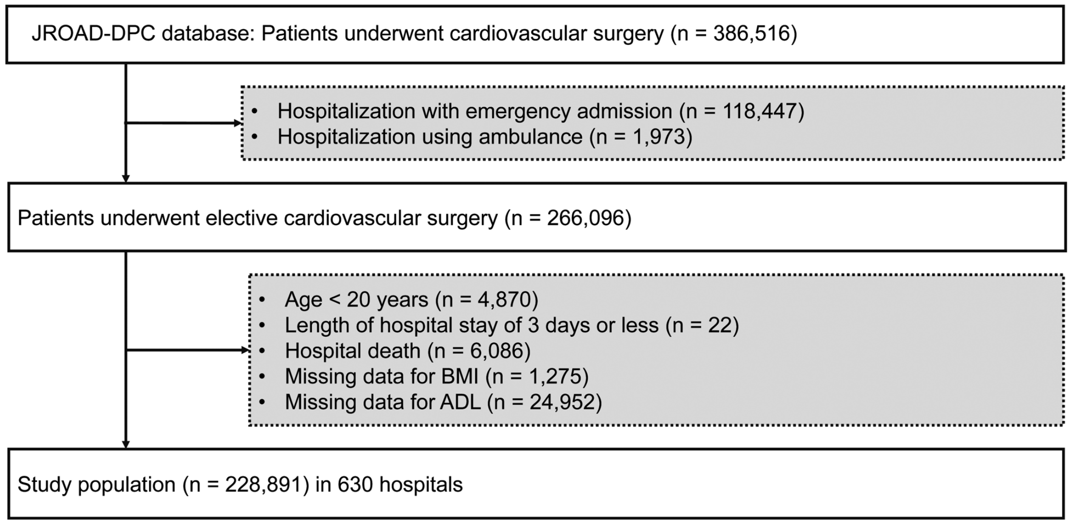

Figure 1. Study flowchart of patient enrollment in the study, showing exclusion criteria and number of patients excluded at each stage of data collection. ADL, activities of daily living; BMI, body mass index; JROAD-DPC, Japanese Registry of All Cardiac and Vascular Diseases – Diagnosis Procedure Combination.

disease.[7] A large international cohort study found that obesity was associated with higher 28-day mortality after cardiac surgery.[8] Being underweight, often related to malnutrition and cachexia,[9] has been shown to lead to a higher likelihood of mortality or complications than in patients with normal weight.[10] The correlation between BMI and perioperative cardiac risk, including the "obesity paradox," in which obese patients sometimes exhibit better outcomes than lean patients, remains a topic of debate, particularly within the predominantly lean Asian population.[11] Thus, exploring strategies to manage these risks, especially through preoperative interventions, is a key research focus.

This study explored the relationship between BMI and outcomes after elective cardiovascular surgery, with an emphasis on HAD and healthcare-related costs. The study concentrated on individuals undergoing elective cardiovascular surgery, targeting a patient group that presented opportunities for preoperative intervention. Our goal was to develop intervention strategies for patients identified as having potential preoperative risks, including BMI, thereby enhancing patient recovery and the efficient use of healthcare resources. Given the rapidly aging population in Asia, data from Japan, a super-aged society,[12] could be clinically informative for other Asian countries. By providing detailed insights from a Japanese national database, this study sought to contribute to the optimization of preoperative care protocols and the reduction of healthcare costs, ultimately improving patient outcomes in cardiovascular surgery.

Methods

Data Source

This study was conducted using the Japanese Registry of All Cardiac and Vascular Diseases (JROAD) and the Diagnosis Procedure Combination (DPC) discharge databases, which are nationwide registries compiled by the Japanese Circulation Society (JCS).[13] The JROAD-DPC is a claims database derived from the Japanese DPC/per diem payment system that encompassed over 1,000 JCS-certified training hospitals during the study period, as described in the literature.[14,15] The database includes inpatient information such as age, sex, diagnosis, comorbidities, treatments, medications, discharge status, ADL, and hospitalization costs. The main diagnoses or comorbidities for each patient were coded using International Classification of Disease and Related Health Problems 10th revision (ICD-10) coding. Because no information specifying individuals was included, the requirement for informed consent was waived. Patient data were anonymized using the original DPC data. This study complied with the principles of the Declaration of Helsinki regarding investigations in human subjects and was approved by the Kobe University Institutional Review Board (Approval no. B210052).

Study Population

We included patients who were hospitalized between April 2012 and March 2022 for elective cardiovascular surgery as defined by the following ICD-10 codes: K539-2, K540, K544, K551, K552, K552-2, K553, K553-2, K554, K554-2, K555, K555-3, K556, K557, K557-2, K557-3, K557-4, K558, K559, K577, K592, K592-2, and K593.[12] This study focused on patients undergoing elective cardiovascular surgery, defined as planned procedures requiring thoracotomy, including coronary artery bypass grafting (CABG), valve surgery (including valve replacement and repair), and aortic surgery (ascending aortic replacement, aortic arch replacement, descending aortic replacement, thoracoabdominal aortic replacement, etc.). To maintain a more consistent level of invasiveness, we excluded patients undergoing endovascular aortic repair (K560-2, K561), transcatheter aortic valve implantation (K555-2), MitraClip procedures (K559-3), abdominal aortic aneurysm repair (K560), and peripheral vascular surgery (K612-K616). A flowchart of the selection of study participant is shown in

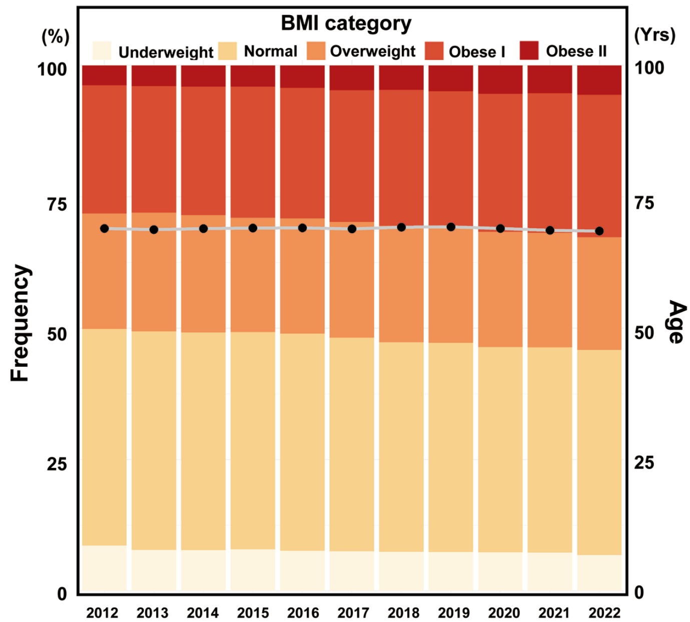

Figure 2. Annual trends in cardiovascular surgery stratified by body mass index (BMI). The bar chart shows the percentage of each BMI category and the line chart shows the trend in mean age.

Figure 1. Elective surgery per se was defined as a planned hospitalization, excluding emergency admissions and ambulance transports, based on the admission category recorded in the DPC dataset. We further excluded patients aged <20 years and those with missing BMI and ADL data at admission and/or discharge. Patients who died in hospital were also excluded because our primary outcome was ADL.

BMI and Categorization

BMI is defined as body weight divided by the body height squared and is expressed in units of kilograms per meters squared. We categorized patients according to the World Health Organization BMI classification for Asians[16] as follows: underweight, BMI <18.5 kg/m²; normal weight, BMI 18.5 to <23 kg/m²; overweight, BMI 23 to <25 kg/m²; obese I, BMI 25 to <30 kg/m²; and obese II, BMI ≥30 kg/m².

ADL, HAD, and Hospitalization Costs

We assessed ADL using the Barthel Index (BI).[17] The BI is a mandatory data element in JROAD and is assessed at 2 distinct time points: on admission and at discharge. This mandatory assessment ensures that BI scores are recorded for all patients in the JROAD database. The BI consists of 10 items (feeding, transfer, grooming, toilet use, bathing, ambulation, stair climbing, dressing, urination, and defecation management) to evaluate ADL on a scale of 0–100, with lower scores indicating greater dependency. The BI was used to evaluate ADL at 2 distinct time points, namely on admission and at discharge. We defined HAD as a ≥5-point decrease in the BI score at discharge compared with at admission, similar to that in a previous studies.[14,18–20] This definition is widely used in clinical research to identify meaningful functional decline, is associated with adverse patient outcomes,[3,4] and was chosen to capture any clinically relevant decline in functional status, regardless of the initial BI score. Hospitalization costs were calculated as the sum of bundled payments and fee-for-services excluding the fee for food. All charges were converted into US dollars (US$) according to the exchange rate on March 19, 2024 (US$1=¥150.0).

Other Outcomes

Postoperative complications assessed included stroke and pneumonia occurring during the hospital stay. Regarding rehabilitation, we analyzed both the frequency and scheduling of rehabilitation treatments. Patients receiving at least 1 rehabilitation treatment before surgery were considered to have undergone prehabilitation. After surgery, we examined both the prevalence and timing of initiation of postoperative rehabilitation interventions.

Statistical Analysis

Continuous data are presented as the median with interquartile range (IQR) and categorical data are presented as numbers and percentages. Continuous data were compared using one-way analysis of variance; Chi-squared analysis was used to compare categorical variables by BMI category (5 groups). To analyze factors predicting HAD, a multilevel mixed-effect logistic regression analysis with institution as a random intercept was performed to examine the association between the incidence of HAD and each variable. The independent variables were the BMI categories and factors theoretically related to HAD, such as age, sex, Charlson comorbidity index, number of hospital beds, type of surgery, use of postoperative mechanical circulatory support (MCS), implementation of prehabilitation, implementation of postoperative rehabilitation, and BI on admission. The odds ratios (ORs) and 95% confidence intervals (CIs) for HAD were calculated for each BMI category with respect to the reference value for normal BMI. We conducted a sensitivity analysis with categorization based on the implementation of postoperative rehabilitation and the presence or absence of prehabilitation. Restricted cubic spline models were used to assess the

Table 1. Patient Characteristics According to the World Health Organization BMI Classification for Asians

	Underweight	Normal	Overweight	Obese I	Obese II
Sample size	17,407	92,596	50,376	58,045	10,467
Age (years)	72.0 [65.0–77.0]	72.0 [65.0–77.0]	71.0 [65.0–77.0]	70.0 [62.0–76.0]	65.0 [55.0–73.0]
Female sex (%)	53.8	34.2	24.1	24.5	32.4
BMI (kg/m^2)	17.5 [16.7–18.1]	21.2 [20.1–22.1]	23.9 [23.5–24.5]	26.6 [25.7–27.8]	31.8 [30.7–33.5]
Charlson comorbidity index score	1.0 [1.0–2.0]	1.0 [1.0–2.0]	1.0 [1.0–2.0]	2.0 [1.0–2.0]	2.0 [1.0–2.0]
Comorbidity (%)					
Diabetes	19.0	25.4	29.5	33.7	43.1
Chronic respiratory disease	5.6	4.8	4.6	4.8	4.9
Hypertension	48.8	56.4	61.5	64.2	66.3
Stroke	2.4	2.3	2.3	2.2	2.1
Dyslipidemia	22.4	33.1	40.1	44.0	47.1
Hyperuricemia	3.7	5.4	7.2	8.5	10.1
Chronic kidney disease	12.9	11.5	9.3	8.9	10.0
Hospital size (%)					
Large (>400 beds)	78.9	78.3	77.4	76.8	76.3
Medium (200–399 beds)	16.1	16.8	17.3	17.6	18.5
Small (<199 beds)	5.0	4.8	5.2	5.5	5.1
Medications (%)					
β-blockers	73.6	72.3	72.3	73.6	77.9
ACEi	17.4	15.0	13.8	12.9	13.3
ARBs	29.5	34.5	39.3	43.0	49.0
Statin	31.1	42.4	49.7	54.0	58.9
Diuretics	82.4	79.7	79.7	80.8	84.3
Type of surgery (%)					
CABG	12.0	20.5	25.2	27.6	31.7
Valve	52.2	39.8	32.4	29.4	30.1
Aortic	23.7	28.0	31.5	32.6	28.0
Others	2.1	1.9	1.8	1.6	2.0
Combination	10.0	9.7	9.2	8.7	8.1
Postoperative MCS	3.6	3.5	3.8	3.7	3.9
Postoperative stroke	1.8	1.7	1.7	1.7	1.5
Postoperative pneumonia	3.4	2.4	2.3	2.2	2.6
Nutrition counseling	41.9	45.2	47.0	48.5	50.0
Prehabilitation	23.9	22.4	22.2	22.6	24.6
No. days prehabilitation started prior to surgery	2.0 (1.0–4.0)	2.0 (1.0–4.0)	2.0 (1.0–4.0)	2.0 (1.0–4.0)	2.0 (1.0–4.0)
Postoperative rehabilitation	79.9	79.3	79.3	80.0	82.0
No. days rehabilitation started after surgery	1.0 (1.0–3.0)	1.0 (1.0–3.0)	1.0 (1.0–3.0)	1.0 (1.0–3.0)	1.0 (1.0–3.0)
Discharge location (%)					
Home	84.9	89.8	91.8	92.0	91.2
Transfer	14.2	9.6	7.7	7.5	8.2
Nursing facility	0.9	0.6	0.5	0.5	0.5
Hospital stay (days)	24.0 [18.0–34.0]	22.0 [17.0–30.0]	21.0 [17.0–28.0]	21.0 [17.0–29.0]	22.0 [17.0–31.0]
Hospital costs					
US dollars	32,469.4 [25,671.9–40,404.9]	29,672.6 [22,140.5–37,320.0]	28,190.1 [20,365.5–35,686.2]	27,884.3 [20,113.6–35,453.2]	28,663.7 [21,620.6–36,096.6]
Japanese yen	4,870,404.0 [3,850,784.0–6,060,741.0]	4,450,892.0 [3,321,067.0–5,597,995.0]	4,228,507.5 [3,054,820.0–5,352,934.0]	4,182,647.0 [3,020,043.0–5,317,977.0]	4,299,557.0 [3,243,096.0–5,414,490.5]
Barthel Index (points)					
On admission	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]
At discharge	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]	100.00 [100.0–100.0]
Hospital-associated disability (%)	12.9	9.0	7.3	7.6	8.4

Data are given as the median [interquartile range] or percentages. ACEi, angiotensin-converting enzyme inhibitor; ARBs, angiotensin II receptor blockers; BMI, body mass index; CABG, coronary artery bypass grafting; MCS, mechanical circulatory support.

Table 2. Logistic Regression Analysis for Hospital-Associated Disability

	OR	95% CI	P value
BMI category (reference: normal weight)			
Underweight	1.50	1.30–1.73	<0.0001
Overweight	0.84	0.75–0.94	0.04
Obese I	1.02	0.92–1.13	0.69
Obese II	1.22	1.01–1.49	0.04
Age (reference: <65 years)			
65–75 years	1.85	1.64–2.09	<0.0001
>75 years	3.51	3.12–3.96	<0.0001
Sex (reference: male)			
Female	1.32	1.21–1.44	<0.0001
Charlson comorbidity index	1.26	1.22–1.30	<0.0001
Hospital size (reference: small)			
Medium	1.74	1.13–2.69	0.01
Large	1.42	0.94–2.14	0.10
Type of surgery (reference: CABG)			
Valve	1.28	1.14–1.44	<0.0001
Aortic	1.41	1.24–1.604	<0.0001
Other type	1.42	1.08–1.87	0.01
Combination	2.16	1.89–2.47	<0.0001
Postoperative MCS	2.01	1.80–2.23	<0.0001
Prehabilitation	1.00	0.89–1.13	0.96
Postoperative rehabilitation	0.76	0.65–0.89	0.001
BI on admission (reference: <70)			
>70	0.95	0.79–1.13	0.53

BI, Barthel index; BMI, body mass index; CI, confidence interval; MCS, mechanical circulatory support; OR, odds ratio.

relationship between BMI and hospitalization costs or the risk of HAD. The relationships were stratified into 3 age subgroups (20 years≤age<65 years, 65 years≤age< 5 years, and ≥75 years). Splines were adjusted by age, sex, Charlson comorbidity index, number of hospital beds, type of surgery, use of postoperative MCS, implementation of prehabilitation, implementation of postoperative rehabilitation, and BI on admission. The splines were restricted to linear below the first and above the last knot point. We used 4 cut-off points for BMI (18.5, 22.0, 25.0, and 30.0 kg/m^2) as the knots for non-linear effects of continuous BMI assessment. Statistical analyses were performed with the "rms" package in R version 4.2.3 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline Characteristics

We reviewed 386,516 records of patients who had undergone cardiovascular surgery, excluding 120,420 patients with emergency or urgent procedures. Subsequently, 4,870 patients aged <20 years, 22 patients with hospital stays of ≤3 days, 6,086 patients who died in hospital, and 26,227 patients with missing data for BMI or ADL were excluded. Ultimately, 228,891 patients in 630 hospitals were analyzed in this study (**Figure 1**).

The median patient age was 71.0 years (IQR 64.0–77.0 years), 30.7% were female, and the median BMI was 23.2 kg/m^2 (IQR 20.9–25.6 kg/m^2; **Supplementary Figure 1**). According to the World Health Organization BMI classification for Asians, 7.6% of patients were classified as underweight, 40.5% were classified as normal weight, 22.0% were classified as overweight, 25.4% were classified as obese I, and 4.6% were classified as obese II. The trend for cardiovascular surgery stratified by BMI is shown in **Figure 2**. Age did not significantly change over the years, whereas the proportion of patients in the obese II category gradually increased. **Table 1** details the background characteristics of the study population stratified by each BMI category. The underweight group was generally older and predominantly female, whereas patients classified as obese II had higher rates of comorbidities, including diabetes, hypertension, and dyslipidemia. The types of surgery included CABG (23.2%), valve surgery (36.1%), aortic surgery (29.6%), and complex surgery (9.3%). In addition, 77.7% of patients received treatment in large hospital facilities with >400 beds.

Postoperative Course

The in-hospital mortality rate was 2.3%, and these cases were excluded from the study. Prehabilitation was implemented in 22.6% of the study cohort, whereas postoperative rehabilitation was implemented in 79.7%. During the postoperative course, MCS was used in 3.7% of patients, and stroke and pneumonia occurred in 1.7% and 2.4% of patients, respectively. Approximately 90% of patients were discharged directly to home. However, patients in the low BMI group were less likely to be discharged home and were more often transferred to another hospital or admitted to a nursing facility. Furthermore, the hospital stay was longer in the underweight group than in the other BMI groups (**Table 1**).

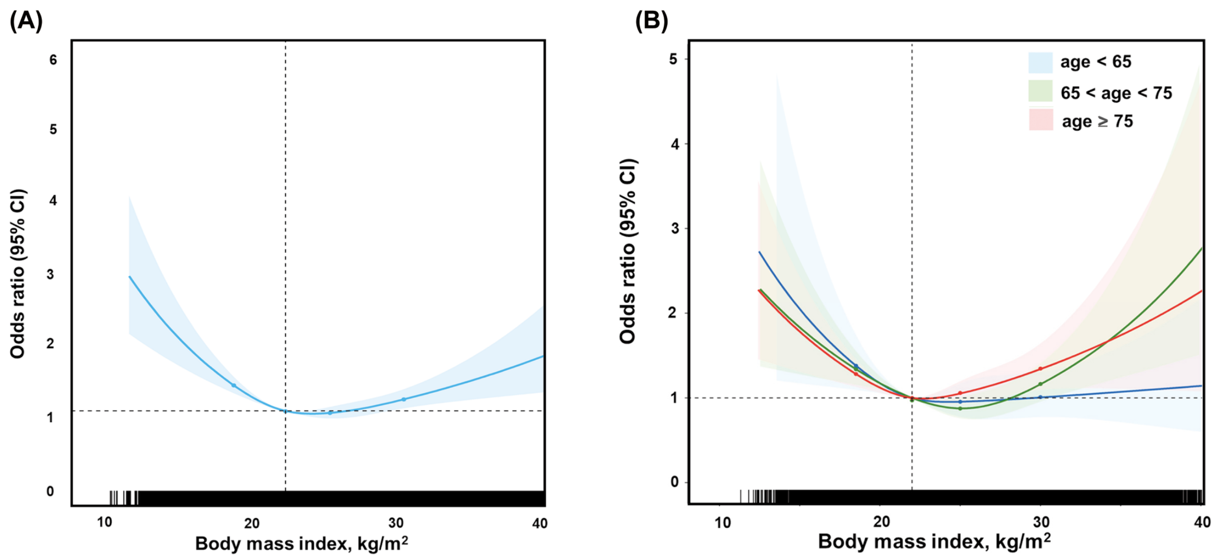

Figure 3. Association between body mass index (BMI) and the risk of hospital-associated disability. Restricted cubic spline models were adjusted for age, sex, Charlson comorbidity index, number of hospital beds, type of surgery, use of postoperative mechanical circulatory support, implementation of prehabilitation, implementation of postoperative rehabilitation, and Barthel Index on admission. The dotted vertical line at 22.0 kg/m² denotes the reference BMI. (**A**) Total cohort. (**B**) Shows spline curves stratified into 3 age subgroups (20 years≤age<65 years, 65 years≤age<75 years, and ≥75 years). CI, confidence interval.

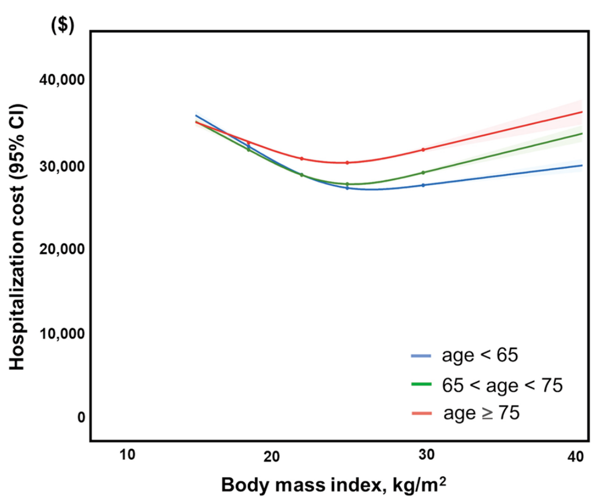

Figure 4. Association between body mass index (BMI) and hospitalization costs among the 3 age subgroups (20 years≤age<65 years, 65 years≤age<75 years, and ≥75 years). Restricted cubic spline models were adjusted for age, sex, Charlson comorbidity index, number of hospital beds, type of surgery, use of postoperative mechanical circulatory support, implementation of prehabilitation, implementation of postoperative rehabilitation, and Barthel Index on admission. Confidence intervals are shown by the shaded areas.

HAD

The overall proportion of patients with HAD was 8.7%, distributed as follows: underweight, 12.9%; normal, 9.0%; overweight, 7.7%; obese I, 7.6%; and obese II, 8.4% (**Supplementary Figure 2A**). There was no significant annual trend in the incidence of HAD over the years (**Supplementary Figure 2B**), but the leaner group was more susceptible to developing HAD. In every BMI category, the prevalence of HAD led to a longer hospital stay and higher hospital costs (**Supplementary Table**).

Table 2 presents the results of the multilevel mixed-effects multiple logistic regression analysis. Being underweight was significantly associated with a higher incidence of HAD (OR 1.50; 95% CI 1.30–1.73). Conversely, the overweight group was significantly associated with a lower incidence of HAD (OR 0.84; 95% CI 0.75–0.94). Older age was also significantly associated with the development of HAD (65 years≤age<75 years, OR 1.85 [95% CI 1.64–2.09]; age ≥75 years, OR 3.51 [95% CI 3.12–3.96]). In addition, the Charlson comorbidity index (OR 1.26; 95% CI 1.22–1.30) and postoperative MCS (OR 2.01; 95% CI 1.80–2.23) were associated with HAD. Patients who underwent aortic and complex surgery were at high risk of HAD. Conversely, hospital volume was not linked to the prevalence of HAD. Postoperative rehabilitation significantly reduced the incidence of HAD (OR 0.76; 95% CI 0.65–0.89), whereas prehabilitation had no effect.

The restricted cubic spline analysis also indicated that HAD increased with decreasing BMI (**Figure 3A**). When stratified by age, the risk of HAD tended to increase with lower BMI across all age groups, whereas in patients aged >65 years the risk increased with higher BMI (**Figure 3B**). In a subanalysis, the relationship between BMI and HAD remained consistent when considering only those who underwent prehabilitation and those who received postoperative rehabilitation (**Supplementary Figure 3**).

Hospitalization Costs

The median hospitalization cost was US$29,068 (¥4,360,329). Within each BMI category, the prevalence of HAD led to increased hospitalization costs (**Supplementary Table**). The overweight group had the lowest hospitalization costs, whereas costs increased for both underweight and obese patients (**Figure 4**). A U-shaped relationship was identified, which indicated that costs were lowest in the overweight group and increased for both underweight and obese patients. This pattern held true across all age groups, although older patients faced higher costs overall.

Discussion

This study using the JROAD-DPC database provides critical insights into how BMI affects HAD and hospitalization costs in patients undergoing elective cardiovascular surgery. The study has several novel findings. First, the prevalence of HAD among these patients was 8.7%, with the risk of HAD increasing proportionally with lower BMI. A U-shaped relationship between BMI and HAD was evident across all age groups, with the lowest risk at a BMI of around 25 kg/m^2. Second, the occurrence of HAD was consistently linked to higher hospitalization costs across all BMI categories. These findings underscore the need for targeted intervention strategies based on BMI, highlighting the potential for BMI-based risk stratification and tailored rehabilitation programs to prevent HAD. Furthermore, given Japan's position as a leader among super-aged societies, these results offer valuable guidance for global clinical practices, providing a roadmap for managing similar demographic shifts in other countries.

To the best of our knowledge, this is the first study to show the prevalence of HAD stratified by BMI category using a large national dataset. In the Japan Cardiovascular Surgery Database, 63,054 cardiovascular surgeries were performed in 2021.[21] Considering that the present study included only elective cardiovascular surgery and excluded endovascular treatment to match the level of invasiveness, our dataset provides a representative sample of real-world data in Japan. The BMI distribution in our study was similar to that in other Asian countries.[22] However, the BMI and prevalence of obese patients were substantially lower than in Western countries.[23] Importantly, our results indicate that the proportion of obese patients is increasing year by year, with a notable rise in patients in the obese II category. This trend highlights a shifting landscape in the patient population, which may have significant implications for future perioperative management. Although the obesity paradox suggests that obese patients tend to have better outcomes once they have developed a disease, our findings revealed that severe obesity was associated with a higher risk of HAD following cardiovascular surgeries. Our results demonstrated a U-shaped relationship, indicating that both underweight and extremely obese patients were at increased risk of HAD but that a moderate BMI offered some protective benefits. Although recent attention has focused on underweight, malnutrition, and sarcopenia in cardiac surgery patients,[24] the growing number of obese patients in Asia underscores the need for comprehensive strategies that address both ends of the BMI spectrum. The U-shaped association between BMI and HAD may be interpreted differently depending on age. In this study, higher BMI was associated with an increased risk of HAD only in older adults. This discrepancy may be attributable to a combination of factors, including age-related declines in muscle strength and cardiorespiratory function and an increased prevalence of comorbidities. This dual focus is essential to optimize perioperative care and improve outcomes in an aging population that is experiencing changes in nutritional status.

The U-shaped relationship between BMI and HAD suggests that both underweight and obesity contribute to postoperative functional decline but likely through different pathways. Underweight individuals may experience malnutrition, leading to impaired immune function and decreased muscle mass, which can compromise recovery and increase the risk of complications. Obesity, however, is associated with chronic inflammation, which can impair tissue repair and contribute to postoperative complications.[25] Furthermore, obesity can lead to reduced cardiorespiratory function due to decreased lung compliance and impaired gas exchange, increasing the risk of postoperative pneumonia.[26,27] This observation could explain the increased risk of postoperative pneumonia observed in obese patients in our study, which could contribute to their higher incidence of HAD. Although some studies suggest that obesity may offer some protection through macrophage activation switching during critical illnesses,[28,29] this protective effect may not outweigh the negative effects of obesity in the context of postoperative recovery after cardiovascular surgery. Further research is needed to fully elucidate the complex interplay of these mechanisms and their impact on HAD in cardiovascular surgery patients.

As a critical finding of our study, the prevalence of HAD was 8.7%, and it increased as BMI decreased, regardless of patient age. Although few reports are available regarding HAD in patients undergoing elective cardiovascular surgery, previous studies have shown that the prevalence of HAD ranges from 5.2% to 27.5%,[4,30,31] with some studies reporting a higher prevalence of HAD than we found in the present study. A possible explanation for this discrepancy is that the definition of HAD varies slightly between studies.

According to a large Japanese survey,[32] the rate of rehabilitation after surgery is already high, with interventions being implemented in many cases as early as the second postoperative day, which aligns with our study. However, even with postoperative rehabilitation treatment, the decline in ADL and worsening outcomes after surgery remain significant issues. Other studies have shown that postoperative functional decline is an independent predictor of adverse outcomes.[4] This suggests that early postoperative rehabilitation alone may not be sufficient to prevent HAD, particularly in underweight patients, and different measures may be necessary. Moreover, underweight patients in the present study were more likely to develop postoperative complications such as pneumonia or stroke. The intervention rate for nutritional guidance during hospitalization for both underweight and obese patients was below 50%, indicating a potential opportunity for interventions to prevent HAD and improve prognosis.

Recently, preoperative rehabilitation, known as prehabilitation, has attracted attention as an effective strategy for improving postoperative outcomes,[33] with 22.6% of our cohort undergoing prehabilitation. Systematic reviews on prehabilitation have concluded that physical prehabilitation programs conducted 2–12 weeks before surgery can enhance selected postoperative functional performance measures and slightly reduce the hospital length of stay after cardiac surgery.[34] However, the median preoperative intervention period in the present study was only 2 days, which is unlikely to have been sufficient. This short prehabilitation period likely reflects preoperative assessments and postoperative orientation rather than a structured program, which ideally should last 2–8 weeks and include exercise therapy, nutritional support, and psychological interventions.[33,35] Furthermore, patients with higher preoperative risk or urgent conditions may have been less likely to receive prehabilitation, thus introducing potential selection bias. It is also possible that patients with significant frailty may experience limited benefits from prehabilitation.[36] Therefore, the low prevalence of prehabilitation in our real-world cohort, coupled with the existing evidence supporting its potential benefits, underscores the need for increased efforts to implement structured prehabilitation programs in routine clinical practice.

Although little evidence exists regarding hospitalization costs for elective cardiovascular surgery, we believe that this is the first report of a U-shaped association between BMI and hospitalization costs. The relationship between increased costs for both thin and obese individuals, regardless of age, underscores the importance of BMI from a health economics perspective. According to the Nationwide Readmissions Database in the US, the median cost of CABG was US$36,400 (IQR US$29,500–46,700),[37] which is slightly higher than our result. Comparing the cost-effectiveness of cardiac surgery across different countries is particularly challenging because these procedures are typically performed in high-income countries where costs vary widely based on national healthcare systems and insurance schemes.[38] Nevertheless, the variation in costs according to BMI and age trends is a novel finding. Given the increased healthcare costs associated with HAD, implementing nutritional guidance and rehabilitation could contribute to reducing overall healthcare costs.

Study Limitations

Our study has several limitations. First, we analyzed only a limited number of facilities included in the JROAD centers, focusing on hospitals certified by the JCS. This may have led to selection bias and prevent the application of our findings to other non-certified hospitals. Although DPC data must be confirmed by a physician and are generally highly reliable, some of the data are based on medical claims. Therefore, it is possible that these data may contain potential errors. In addition, although we aimed to identify elective surgeries by including only patients admitted for planned hospitalization and excluding emergency admissions and ambulance transports, this approach may not perfectly capture all nuances of "elective" within the limitations of the DPC data. Although this database provides a large-scale real-world dataset, it may lack the granularity and clinical detail available in dedicated surgical registries such as the National Clinical Database in the Japan Cardiovascular Surgery Database. This may limit our ability to fully capture the nuances of surgical procedures and their impacts on patient outcomes. This should be considered when interpreting the results.

Second, the database only included information related to the period of hospitalization; thus, we could not analyze long-term outcomes. In addition, the patient's prehospitalization status, including place of residence and severity of heart failure, remain unknown.

Third, although we focused on open thoracotomy procedures to minimize variations in invasiveness, the DPC dataset does not provide granular detail on surgical complexity or specific techniques, which may still contribute to heterogeneity in patient outcomes. Furthermore, although BMI is a convenient and widely used metric, it does not account for variations in body composition, such as muscle mass and fat mass, and therefore may not fully capture the complexities of nutritional status.

Fourth, this study reflects the BMI distribution patterns observed in patients only in Japan. It is well documented that Asian populations, including Japanese, tend to have lower BMI values but higher body fat percentages and abdominal obesity than non-Asian populations.[39] In addition, Asian populations may have a higher risk of metabolic complications even at lower BMIs,[40] thus suggesting that the interpretation of BMI categories may differ between Asian and non-Asian populations.

Lastly, we excluded patients who died in hospital because we used ADL as an outcome of this study. This exclusion may have led to the omission of more severely ill patients, resulting in potential information bias due to missing data. Therefore, our findings as they relate to clinical practice should be interpreted with caution. Despite these limitations, considering that there are over 6,000 cardiovascular operations performed annually in Japan alone, the present data provide a more comprehensive understanding of the true burden of HAD.

Conclusions

We found a U-shaped association between BMI and the incidence of HAD or hospitalization costs, indicating that both lower and higher BMI were linked to increased HAD and hospitalization costs, regardless of patient age. These findings underscore the critical need for targeted interventions, particularly for underweight patients, to prevent HAD and manage hospitalization costs effectively. This study highlights the importance of considering BMI in perioperative care and offers a foundation for future research and policymaking aimed at improving outcomes for cardiovascular surgery patients.

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Disclosures

K.H. is a member of *Circulation Journal*'s Editorial Team. The remaining authors have no conflicts of interest to declare.

IRB Information

This study was approved by the Kobe University Institutional Review Board (Approval no. B210052).

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Supplementary Files

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