## Title
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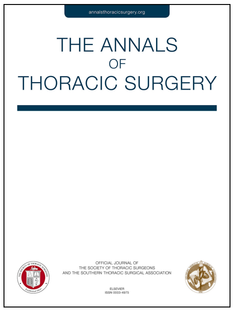


Factors Associated with High Resource Utilization in Elective Adult Cardiac Surgery from 2005 – 2016

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**Factors Associated with High Resource Utilization in Elective Adult Cardiac Surgery from 2005 – 2016**

Running head: Resource Use in Cardiac Surgery

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**Abstract**

***Background:*** Lack of consensus remains about factors that may be associated with high resource utilization (HRU) in adult cardiac surgical patients. We aimed to identify patient, hospital, and perioperative characteristics associated with HRU admissions involving elective cardiac operations.

***Methods:*** Data from the National Inpatient Sample was used to identify patients who underwent coronary artery bypass graft (CABG), valve replacement, and valve repair operations between 2005 and 2016. Admissions with HRU were defined as those in the highest decile for total hospital costs. Multivariable regressions were used to identify factors associated with HRU.

***Results:*** An estimated 1,750,253 hospitalizations coded for elective cardiac operations. The median hospitalization cost was $34.7K (IQR $26.8K - $47.1K), with HRU (N=175,025) cutoff at $66,029. Although HRU patients comprised 10% of admissions, they accounted for 25% of cumulative costs. On multivariable regression, patient characteristics predictive of HRU included female sex, older age, higher comorbidity burden, non-white race, and highest income quartile. Hospital factors associated with HRU were low volume hospitals for both CABG and valvular operations. Among postoperative outcomes, mortality, infectious complication, extracorporeal membrane oxygenation use, and hospitalization > 8 days were associated with greater odds of HRU.

***Conclusions:*** In this nationwide study of elective cardiac surgical patients, several important patient and hospital factors, including patient race, comorbidities, postoperative infectious complications, and low hospital operative volume were identified as predictors of HRU. These highly predictive factors may be used for benchmarking purposes and improvement in surgical planning.

Resource utilization has emerged as an important performance metric in healthcare with renewed efforts to contain costs and enhance the value of care. Patients at the extremes of resource use have been of particular interest, with several studies characterizing drivers of cost among surgical admissions.[1–3] The results of such work have advocated for increased focus on reducing complications as a strategy to mitigate overt resource use.

High resource use (HRU), generally defined as the top decile of hospitalization costs, has been well-studied in the setting of congenital cardiac surgery.[1–3] It has, however, not been examined in acquired adult cardiac operations thus far. With increased utilization of operations such as coronary artery bypass grafting (CABG) and valve replacement in patients with advanced age and increased comorbidities,[4,5] there may be a greater burden on available resources. Identification of patient and hospital factors associated with HRU may spur the impetus to develop the practice guidelines for hospitals and physicians to develop care practices that mitigate risk and reduce costs while improving outcomes.

The present study aimed to (1) characterize HRU admissions among adult cardiac operations, (2) identify factors linked with HRU, and (3) explore the association of HRU with in-hospital mortality, postoperative complications, and length of stay (LOS) following elective cardiac operations of a nationally representative cohort.

## Material and Methods

### *Study Cohort*

The 2005-2016 National Inpatient Sample (NIS) was used to identify all adult (≥18 years) patients who had undergone coronary artery bypass grafting (CABG), surgical valve replacement, and valve repairs (Supplemental Table 1). The NIS is an all-payer inpatient database maintained by the Agency for Healthcare Research and Quality's (AHRQ) Healthcare

Cost and Utilization Project (HCUP) and estimates more than 35 million hospitalizations in the United States.

*International Classification of Disease, Ninth Revision-Clinical Modification* (ICD-9-CM) codes (2005 to September 2015) and ICD-10-CM (October 2015- 2016) were used to tabulate patient diagnoses, complications and procedures. Patients with non-elective admissions, endocarditis, and those missing cost and mortality variables were excluded in order to reduce heterogeneity. We utilized aggregate hospitalization charges for the index visit as provided by the NIS. In accordance with HCUP's recommendations, costs were determined by applying hospital specific cost-to-charge ratios to the overall charges and then further adjusted for diagnosis related group-based severity. Costs were then standardized to the 2016 Personal Health Care – Hospital Care index to account for inflation.[6] Consistent with prior studies,[1–3] we defined HRU admissions as those in the top 10$^{th}$ percentile of index hospitalization costs.

*Study Variables*

Patient characteristics of interest included age, gender, and comorbidities among others. The Elixhauser Comorbidity Index, a composite score of 30 chronic conditions, was used to numerically assess the burden of preexisting conditions.[7] Hospital level characteristics included teaching status, geographic region, and annual volume of CABG and valvular operations. Using the unique hospital identification available in NIS, hospitals were stratified into low, medium, and high volume tertiles based on total annual CABG or valve operations. Volume cutoffs were then set at the 33$^{rd}$ and 67$^{th}$ percentiles for each year. Outcome variables of interest were in-hospital mortality, complication rates, and utilization of extracorporeal membrane oxygenation (ECMO). Length of stay (LOS) was grouped in to 0-4, 5-7, and ≥ 8 days. LOS groups were based on tertiles of hospitalization duration among patients, with cutoffs at the 33$^{rd}$ and 67$^{th}$ percentiles.

*Statistical Analysis*

Categorical values are reported as a percentage and continuous variables as a mean with standard deviation. Cost variables are reported as median and interquartile range (IQR). The chi-square test was used to compare categorical variables and the adjusted Wald test was used for continuous variables. A multivariable logistic model was constructed to determine the patient, hospital, and operative factors associated with HRU. The model was created with variables considered to be of clinical significance and the final model was selected following backwards stepwise elimination and optimization of the receiver-operator curve as well as the Akaike and Bayesian Information Criteria. All statistical analyses were performed using Stata 16.0 (Stata Corp, College Station, Tx). The study was deemed exempt from full review by the Institutional Review Board at the University of California at Los Angeles.



**Results**

*Baseline Characteristics*

Of an estimated 1,750,253 hospitalizations (95% CI: 1,645,111 – 1,855,396) for elective cardiac operations, 71% underwent CABG, 36% valve replacement and 8% valve repair. The median hospitalization cost was $34.7K (IQR: $26.8K - $47.1K), and the threshold for HRU cohort (N=175,025) was $66,029 (ranging to $1,428,476) (Figure 1). Although HRU admissions comprised 10% of total hospital admissions, they accounted for 25% of cumulative costs (Table 1). The contributions of the HRU cohort to overall costs by year are shown in Figure 2. The median costs for isolated valve replacement, valve repair, and CABG operations were $38.9K (IQR $30.5K – $52.1K), $34.4K (IQR $27.3K - $46.0K), $31.1K (IQR $24.4K - $40.9K), respectively. Hospitalizations for concomitant CABG and valve replacements had a median cost of $44.9K (IQR $35.0K – $61.5K) and $45.8K (IQR $34.7K – $64.5K) for concomitant CABG and valve repair.

*Univariate Analysis*

On univariate analysis, patient characteristics associated with HRU included older age (69 vs 66 years, p<0.001), non-white race, Medicare and Medicaid insurance status, and higher Elixhauser comorbidity index (Table 1). HRU was associated with the presence of heart failure (49 vs 23%, p<0.001), renal (23 vs 11%, p<0.001) and liver diseases (7 vs 1%, p<0.001). Hospital factors associated with HRU included lower CABG volume, higher valve volume, as well as Northeast and Western NIS regions (Table 1).

The HRU cohort had a greater proportion of patients who had undergone valve replacement (58 vs 34%, p<0.001) or repairs (13 vs 8%, p<0.001), as opposed to CABG (63 vs 72%, p<0.001). They were more likely to have received concomitant CABG and valve replacement (25 vs 11%, p<0.001), CABG and valve repair (5 vs 2%, p<0.001) operations, as well as multivalvular operations (12 vs 2.7%, p<0.001). Adverse outcomes associated with HRU included higher mortality (10 vs 1.1%, p<0.001), prolonged hospitalization (19 vs 7 days, p<0.001), higher rates of overall complications (83 vs 47%, p<0.001), and ECMO use (1.2 vs 0.1%, p<0.001). All complications ranging from infection to stroke were associated with HRU, as shown in Table 3.

*Multivariable Regression Models*

A multivariable model regression to identify independent predictors of HRU yielded an acceptable C-statistic (0.81). Factors independently associated with HRU included female sex (AOR 1.09, p<0.001), older age (AOR 1.01/year, p<0.001), increasing Elixhauser comorbidity index (AOR 1.48 per unit, p<0.001), CHF (AOR 1.44, p<0.001), as well as renal (AOR 1.31, p<0.001) and liver diseases (AOR 2.49, p<0.001). Conversely, obesity, diabetes, hypertension, hyperlipidemia, peripheral vascular disease, and chronic pulmonary disease were all associated with reduced odds of HRU (p<0.001) (Table 4). Concomitant CABG + valve replacement (AOR

1.80, p<0.001) and CABG + valve repairs (AOR 1.88, p<0.001) as well none-white race and low-income classification were all significantly associated with HRU (Table 4).

We assessed the impact of center operative volume on the risk of HRU status. Compared to low CABG volume hospitals, middle- (AOR 0.77, p<0.001) and high-volume (AOR 0.67, p<0.001) hospitals had reduced odds of HRU admissions. Among valve operations, only middle-volume hospitals (AOR 0.83, p=0.002) had significantly lower odds of HRU with low-volume as reference (Table 4). Lastly, hospitals in the Western NIS region (AOR 2.64, p<0.001) were predictive of HRU admissions while hospital teaching status had no effect on this outcome.

On multivariable analysis of postoperative outcomes (C = 0.90), we found all adverse events to be associated with higher odds for HRU as shown in Figure 3. These encompassed in-hospital mortality (OR 4.01, p<0.001), LOS greater than 8 days (AOR 16.0, p<0.001), cardiovascular (OR 1.90, p<0.001), respiratory (AOR 3.07, p<0.001), and infectious complications (AOR 4.09, p<0.001) as well as AKI (AOR 1.77, p<0.001), and ECMO utilization (AOR 10.0, p<0.001) (Figure 3, Supp. Table 2).



**Comment**

High resource utilizers have been reported in the surgical and medical literature, whereby a small portion of patients account for a significant proportion of costs.[1–3] Our results show that within adult cardiac surgery, HRU comprised only 10% of admissions, but accounted for 25% of the total hospital expenditures. This phenomenon may be due to a small portion of patients who experienced complications resulting in additional procedures, prolonged LOS, and thereby increasing costs. Additionally, there may be regional or institutional variations in implementation of cost-saving measures. Nonetheless, HRU admissions disproportionately expend a significant portion of, and could possibly strain, hospital and medical system resources. Therefore, preemptive identification of patients at risk for increased resource utilization can direct perioperative strategies that may mitigate hospital resource utilization.

Preoperative risk scores, such as the STS risk score, have been used to predict incremental costs in limited cohorts of cardiac surgical patients.[8–10] In patients undergoing aortic valve replacement, each 1% increase in STS risk score was associated with an additional $3000 in hospital charges.[9] Likewise, increasing burden of comorbidities, as measured by the Elixhauser Index, was associated with HRU. Interestingly, certain comorbidities, such as diabetes and hypertension, decreased risk for HRU. Similar paradoxical associations of chronic comorbidities and improved outcomes are noted in several administrative database studies.[11,12] One possible explanation is that patients with chronic conditions such as diabetes receive regular medical care and thus are better optimized. Additionally, those without listed comorbidities may have unknown underlying chronic conditions, worsening their outcomes. Lastly, the NIS only provides up to 30 fields to code ICD-9 or ICD-10 diagnostic codes. Therefore, patients with a more complicated course or history might not have all the comorbidities coded.

Although the preoperative risk scores enable physicians to predict morbidity and mortality risk based on patient medical characteristics, they do not account for socioeconomic and hospital level factors. Additionally, derivation of scoring algorithms using data collected from participating academic hospitals may introduce selection bias.[13] The present study identifies predictors of HRU using a nationally representative database and may provide more widely applicable risk assessment.

Race and socioeconomic status were also associated with HRU. All non-white races including Black, Hispanic, and Asian were predictive of HRU. Higher rates of adverse outcomes in non-white race are well reported in the literature.[14–17] Specifically, Black and Hispanic patients incurred greater costs during end-of-life hospitalizations as they were less likely to be placed in hospice, spent longer times in the ICU, and were more likely to receive invasive procedures.[18] Additionally, lower socioeconomic status has been associated with higher mortality and costs in surgical patients.[15] For example, patients of the lowest socioeconomic status incurred 1-18% higher hospital charges.[19] However, in our analysis, the top income quartile had higher odds of HRU when compared to the bottom quartile. This distinction is likely attributable to the fact that previous studies focused incremental increases in cost whilst we compared the highest resource utilizers. For example, patients belonging to the highest income quartile may be receiving care at tertiary facilities that provide more expensive and complex procedures. Nonetheless, this study adds to the growing body of literature on the impact of social determinants of health on clinical outcomes following medical and surgical hospitalizations. With factors including barriers to routine care, underdiagnosis, and more advanced disease presentation, much remains to be done in promoting equity in access and delivery of care.

Beyond patient characteristics, hospital factors also appear to play an important role in operative costs. First, hospitals in the Western NIS region had increased odds for HRU, consistent with prior studies of general and orthopedic operations.[20–22] Center volume is established as a major predictor of lower mortality and complications in many high-risk procedures.[23,24–26] Studies comparing congenital cardiac operative volume and cost have noted reduced overall costs at high-volume centers,[27,28] which were attributed to lower mortality and complication rates at these hospitals.[28] In agreement with these reports, our study demonstrates increasing volume to reduce the likelihood of HRU in CABG, although a similar relationship was not found for valve operations. This may be due to higher rates of concomitant or multiple valvular operations, which have higher complexity and inherently greater costs. In addition, high volume centers are likely tertiary referral centers that manage patients with more severity of illnesses, requiring increased resource use. Further studies on valve replacement volume outcomes are warranted to further evaluate this phenomenon.

Postoperative outcomes including mortality, LOS, and complications, were associated with HRU in our multivariable analysis. Prior studies have demonstrated a strong association between postoperative infection and costs in open-heart and abdominal surgery.[29–33] Infectious complications had the highest adjusted odds for HRU (AOR 4.06) in our study. After adjustment, LOS >8 days was the strongest predictor (AOR 16.2), in agreement with findings of Riordan and colleagues.[8] Not surprisingly, ECMO utilization (AOR 10.1) was strongly associated with HRU. Although incremental costs of ECMO following cardiac surgery are difficult to ascertain, they have been estimated to be around $73K with an average 9.5 days on ECMO.[34]

There are several limitations to this study including those inherent to its retrospective nature. First, the NIS does not report illness severity or functional status, increasing the potential for bias. For instance, preoperative left ventricular ejection fraction, albumin, or creatinine levels would likely affect postoperative outcomes and cost but could not be accounted for in the present work. Lastly, we only sampled elective CABG and valve operations to render a more homogenous patient population. As such, our results may not be generalizable beyond such elective operations. Nonetheless, we chose the NIS, because it is the largest available patient and costs database that represents nearly all US hospitalizations.

The present analysis provides important new information on perioperative factors strongly associated with high resource use. Older patients with a high burden of comorbidities, specifically heart failure, renal, and liver disease, as well as non-white patients are at higher risk of HRU. HRU was associated with low-CABG and valve operation volume hospitals. Lastly, all adverse postoperative events, including in-hospital mortality, infectious complication, placement on ECMO, and prolonged LOS, all lead to an increased risk of HRU. Risk stratification for high resource utilization may provide opportunities for hospitals and physicians to develop care practices that reduce risk of excess cost while improving the care of these patients.

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**Table 1: Baseline Patient and Hospital Characteristics**

| | Total (N=1,750,253) | Non-HRU (N=1,575,228) | HRU (N=175,025) | P-value |
|---|---|---|---|---|
| **Age (years) *** | 66 ± 12 | 66 ± 12 | 69 ± 12 | <0.001 |
| **Sex, female (%)** | 31 | 30 | 38 | <0.001 |
| **Elixhauser comorbidity index *** | 3.9 ± 2.0 | 3.7 ± 1.9 | 5.1 ± 2.2 | <0.001 |
| **Comorbidities (%)** | | | | |
| Diabetes | 33 | 34 | 29 | <0.001 |
| Hypertension | 75 | 76 | 61 | <0.001 |
| Hypercholesterolemia | 57 | 59 | 38 | <0.001 |
| Peripheral vascular disease | 8.1 | 8.1 | 7.8 | <0.001 |
| Obesity | 17 | 17 | 14 | <0.001 |
| Chronic lung disease | 25 | 24 | 34 | <0.001 |
| Renal disease | 12 | 11 | 23 | <0.001 |
| Liver disease | 2.0 | 1.4 | 7.4 | <0.001 |
| Heart Failure | 25 | 23 | 49 | <0.001 |
| **Race (%)** | | | | <0.001 |
| White | 83 | 83 | 78 | |
| Black | 5.5 | 5.4 | 6.5 | |
| Hispanic | 6.0 | 5.8 | 7.7 | |
| Asian | 2.2 | 2.0 | 3.7 | |
| Native American | 0.5 | 0.5 | 0.5 | |
| Other | 2.9 | 2.8 | 3.3 | |
| **Income quartile (%)** | | | | <0.001 |
| <25$^{th}$ | 24 | 24 | 21 | |
| 25 – 50$^{th}$ | 27 | 27 | 25 | |
| 50 – 75$^{th}$ | 26 | 26 | 26 | |
| >75$^{th}$ | 23 | 23 | 28 | |
| **Insurance status (%)** | | | | <0.001 |
| Medicare | 57 | 56 | 67 | |
| Medicaid | 4.4 | 4.3 | 5.1 | |
| Private | 35 | 36 | 24 | |
| Self-pay | 1.7 | 1.8 | 1.4 | |
| **Hospital CABG volume (%)** | | | | <0.001 |
| Low | 34 | 34 | 43 | |
| Medium | 34 | 34 | 30 | |
| High | 32 | 32 | 27 | |
| **Hospital valve surgery volume (%)** | | | | <0.001 |
| Low | 35 | 36 | 34 | |
| Medium | 33 | 33 | 29 | |
| High | 32 | 32 | 37 | |
| **Hospital location teaching status (%)** | | | | 0.201 |
| Rural | 3.2 | 3.3 | 2.6 | |
| Urban, nonteaching | 33 | 33 | 32 | |
| Urban, teaching | 64 | 64 | 65 | |
| **Hospital region (%)** | | | | <0.001 |
| Northeast | 15 | 15 | 15 | |
| Midwest | 27 | 28 | 22 | |

| | | | |
|---|---|---|---|
| South | 39 | 40 | 28 |
| West | 19 | 17% | 35% |
| **Cumulative Cost ($ billions)** | 14.3 | 10.5 | 3.84 |

* Continuous variables are listed as mean ± standard deviation.

**Table 2: Operative Characteristics of HRU and non-HRU Admissions**

| | Total (N=1,750,253) | Non-HRU (N=1,575,228) | HRU (N=175,025) | P-value |
|---|---|---|---|---|
| **CABG** | 71 | 72 | 63 | <0.001 |
| **Valve replacement (%)** | 36 | 34 | 58 | <0.001 |
| **Valve repair (%)** | 8.3 | 7.8 | 13 | <0.001 |
| **Isolated operations (%)** | | | | |
| CABG | 57 | 60 | 34 | <0.001 |
| Valve replacement | 22 | 21 | 25 | <0.001 |
| Aortic | 17 | 17 | 17 | 0.510 |
| Mitral | 3.9 | 3.6 | 6.8 | <0.001 |
| Tricuspid | 0.2 | 0.2 | 0.7 | <0.001 |
| Pulmonary | 0.3 | 0.3 | 0.4 | 0.184 |
| Valve repair | 5.1 | 5.2 | 4.8 | 0.055 |
| Aortic | 0.5 | 0.4 | 0.8 | <0.001 |
| Mitral | 4.1 | 4.3 | 2.9 | <0.001 |
| Tricuspid | 0.2 | 0.2 | 0.5 | <0.001 |
| Pulmonary | 0.2 | 0.2 | 0.5 | <0.001 |
| **Combined operations (%)** | | | | |
| CABG + valve replacement | 12 | 11 | 25 | <0.001 |
| CABG + valve repair | 2.0 | 1.7 | 4.8 | <0.001 |
| Multiple valves | 3.6 | 2.7 | 12 | <0.001 |

**Table 3: Outcomes of HRU and Non-HRU Admissions**

| | Total (N=1,750,253) | Non-HRU (N=1,575,228) | HRU (N=175,025) | P-value |
|---|---|---|---|---|
| **Mortality (%)** | 2.0 | 1.1 | 10 | <0.001 |
| **Length of Stay (days)** | 8.1 ± 6.5 | 6.9 ± 3.2 | 18.8 ± 14.1 | <0.001 |
| **Overall complication (%)** | 50 | 47 | 83 | <0.001 |
| **Cardiovascular complication (%)** | 13 | 11 | 28 | <0.001 |
| Stroke | 1.0 | 0.7 | 3.7 | <0.001 |
| Myocardial infarction | 6.7 | 6.2 | 11 | <0.001 |
| DVT | 0.6 | 0.4 | 2.6 | <0.001 |
| Pulmonary embolism | 0.3 | 0.2 | 1.1 | <0.001 |
| Ventricular arrhythmia | 4.7 | 3.9 | 12 | <0.001 |
| Cardiac tamponade | 0.5 | 0.3 | 2.6 | <0.001 |
| **Respiratory complication (%)** | 16 | 12 | 52 | <0.001 |
| Pneumonia | 3.5 | 2.0 | 18 | <0.001 |
| ARDS | 14 | 11 | 47 | <0.001 |
| Prolonged Ventilation* | 2.6 | 0.6 | 21 | |
| **Infection (%)** | 2.2 | 0.9 | 14 | <0.001 |
| Sepsis | 1.7 | 0.6 | 12 | <0.001 |
| Wound infection | 0.8 | 0.4 | 4.1 | <0.001 |
| **Acute Kidney Injury (%)** | 11 | 8.5 | 36 | <0.001 |
| **ECMO (%)** | 0.2 | 0.1 | 1.2 | <0.001 |

*Prolonged ventilation = mechanical ventilation > 96 hours.

DVT = deep venous thromboembolism, ARDS = acute respiratory distress syndrome, ECMO = extracorporeal membrane oxygenation

**Tables 4: Multivariable Analysis of Preoperative Predictors of HRU**

| | AOR | 95% Confidence Interval | P-value |
|---|---|---|---|
| **Female sex** | 1.09 | 1.06 – 1.13 | <0.001 |
| **Age** | 1.01 | 1.00 – 1.01 | <0.001 |
| **Elixhauser Comorbidity Index** | 1.48 | 1.44 – 1.51 | <0.001 |
| **Comorbidities** | | | |
| Obesity | 0.69 | 0.66 – 0.73 | <0.001 |
| Diabetes | 0.66 | 0.63 – 0.69 | <0.001 |
| Hypertension | 0.38 | 0.36 – 0.40 | <0.001 |
| Hyperlipidemia | 0.61 | 0.58 – 0.65 | <0.001 |
| Peripheral vascular disease | 0.78 | 0.73 – 0.83 | <0.001 |
| Chronic pulmonary disease | 0.73 | 0.69 – 0.77 | <0.001 |
| Congestive heart failure | 1.44 | 1.38 – 1.51 | <0.001 |
| Renal disease | 1.31 | 1.24 – 1.37 | <0.001 |
| Liver disease | 2.49 | 2.32 – 2.68 | <0.001 |
| **Race** | | | |
| White | Ref | | |
| Black | 1.51 | 1.38 – 1.65 | <0.001 |
| Hispanic | 1.31 | 1.18 – 1.46 | <0.001 |
| Asian | 1.39 | 1.23 – 1.56 | <0.001 |
| Native American | 0.95 | 0.71 – 1.28 | 0.742 |
| Other | 1.22 | 1.08 – 1.38 | 0.002 |
| **Income Quartile** | | | |
| <25$^{th}$ | Ref | | |
| 25-50$^{th}$ | 1.02 | 0.97 – 1.07 | 0.465 |
| 50-75$^{th}$ | 1.09 | 1.02 – 1.16 | 0.009 |
| >75$^{th}$ | 1.22 | 1.14 – 1.31 | <0.001 |
| **Hospital CABG volume** | | | |
| Low | Ref | | |
| Medium | 0.77 | 0.69 – 0.86 | <0.001 |
| High | 0.67 | 0.55 – 0.82 | <0.001 |
| **Hospital valve surgery volume** | | | |
| Low | Ref | | |
| Medium | 0.83 | 0.74 – 0.93 | 0.002 |
| High | 1.19 | 0.98 – 1.43 | 0.072 |
| **Hospital Region** | | | |
| Northeast | Ref | | |
| Midwest | 0.93 | 0.72 – 1.20 | 0.587 |
| South | 0.86 | 0.65 – 1.14 | 0.301 |
| West | 2.64 | 1.99 – 3.49 | <0.001 |
| **Hospital location, teaching status** | | | |
| Rural | Ref | | |
| Urban, nonteaching | 0.89 | 0.66 – 1.22 | 0.476 |
| Urban, teaching | 0.91 | 0.68 – 1.22 | 0.550 |
| **Operation** | | | |
| Isolated CABG | Ref | | |
| Isolated Valve Replacement | | | |
| Aortic | 0.75 | 0.70 – 0.80 | <0.001 |
| Mitral | 0.96 | 0.87 – 1.06 | 0.416 |
| Tricuspid | 1.58 | 1.67 – 1.90 | <0.001 |
| Pulmonary | 1.05 | 0.81 – 1.35 | 0.717 |

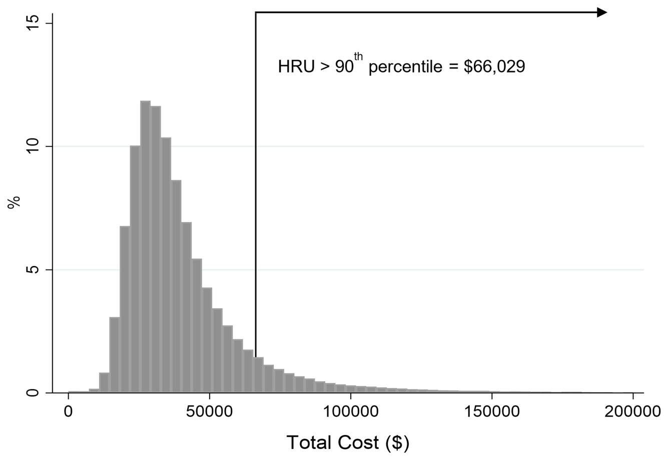
| | | | |
|---|---|---|---|
| Isolated Valve Repair | | | |
| Aortic | 1.57 | 1.28 – 1.92 | <0.001 |
| Mitral | 0.47 | 0.41 – 0.53 | <0.001 |
| Tricuspid | 1.68 | 1.31 – 2.15 | <0.001 |
| Pulmonary | 1.40 | 0.48 – 4.08 | 0.541 |
| CABG + Valve Replacement | 1.80 | 1.69 – 1.92 | <0.001 |
| CABG + Valve Repair | 1.89 | 1.71 – 2.08 | <0.001 |
| Multiple valves | 1.93 | 1.74 – 2.13 | <0.001 |

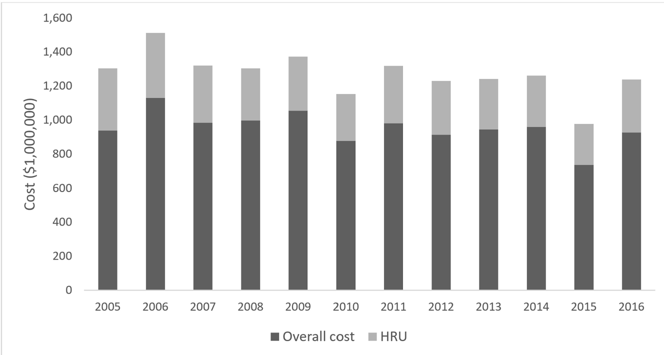
**Figure Legends**

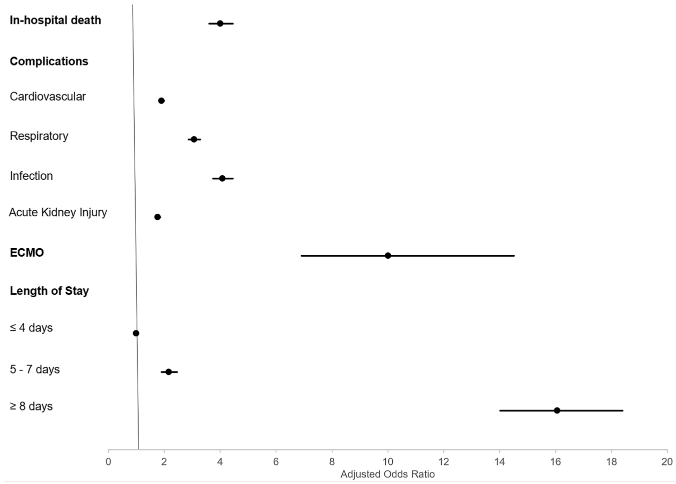
**Figure 1:** Distribution of hospital costs for elective cardiac surgery. HRU indicates high resource use.

**Figure 2:** Distribution of HRU cost compared to overall cost of elective cardiac surgery admissions.

**Figure 3:** Postoperative outcomes associated with HRU based on multivariable logistic regression


HRU > 90th percentile = $66,029
15
10
5
0
%
0
50000
100000
150000
200000
Total Cost ($)


1,600
1,400
1,200
1,000
800
600
400
200
0
Cost ($1,000,000)
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Overall cost
HRU


In-hospital death
Complications
Cardiovascular
Respiratory
Infection
Acute Kidney Injury
ECMO
Length of Stay
≤ 4 days
5 - 7 days
≥ 8 days
0
2
4
6
8
10
12
14
16
18
20
Adjusted Odds Ratio