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ORIGINAL ARTICLE

Outcomes and Costs of Cardiac Surgery in Adults with Congenital Heart Disease

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Abstract Advances in pediatric cardiac surgical and medical care have led to increased survival of patients with congenital heart disease (CHD). Consequently, many CHD patients survive long enough to require cardiac surgery as adults. Using the 2013 Nationwide Inpatient Sample (NIS) database, we compared costs and outcomes for adult patients undergoing surgery for treatment of CHD to a reference population of adults undergoing CABG. Patients were identified using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9 CM) procedure codes. We recorded the demographic characteristics, gender, ethnicity, hospital bed size, hospital length of stay, in-hospital mortality, and comorbidities. Patients with ACHD have higher incidences of in-hospital mortality (2.6 vs. 1.8%), and complication rates including neurologic complications (2.6 vs. 0.9%), thromboembolic complications (3.9 vs. 1.4%), arrhythmias (51.6 vs. 29.8%), hepatic failure (4.44 vs. 2.03%), and sepsis (7.24 vs. 4.61%) (all $p < 0.001$). In addition, cost is higher in patients with CHD (Coefficient = 0.116, 95% CI, 0.105–0.128; $p < 0.001$), Elixhauser score ≥ 7 (Coefficient = 0.114, 95% CI, 0.108–0.121; $p < 0.001$), neurologic complications (Coefficient = 0.169, 95% CI, 0.143–0.196; $p < 0.001$), thrombotic complications (Coefficient = 0.243, 95% CI, 0.222–0.265; $p < 0.001$), sepsis (Coefficient = 0.198, 95% CI, 0.185–0.211; $p < 0.001$), acute kidney injury (Coefficient = 0.056, 95% CI, 0.041–0.063; $p < 0.001$), elective cases (Coefficient = 0.047, 95% CI, 0.041–0.053; $p < 0.001$), and length of stay > 6 days (Coefficient = 0.703, 95% CI, 0.697–0.710; $p < 0.001$). This study shows that ACHD patients undergoing cardiac surgery experience higher hospital costs and poorer outcomes than a reference population of adult CABG patients. Recognition and treatment of comorbidities in ACHD patients undergoing cardiac surgery may provide an opportunity to improve perioperative outcomes in this growing patient population.

Keywords Cost · Adult congenital heart disease · Outcomes · CABG

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Introduction

Advances in pediatric cardiac medical and interventional therapies have led to an increase in survival of patients with congenital heart disease (CHD) and an associated increase in prevalence of adults with CHD (ACHD) [1, 2]. In fact, between 1985 and 2000, the greatest increase in prevalence of patients with CHD was among adults [2]. This trend of increase continued from 2000 to 2010 with an increase in prevalence of 11% in children and of 57% in adults such that ACHD accounted for 66% of the entire CHD population in 2010 [3]. ACHD patients often require additional catheter-based and/or cardiac surgical procedures to manage the sequelae of CHD and to correct residual lesions. Many ACHD patients have subclinical multiorgan dysfunction (including renal and hepatic disease), with limited reserve, which places them at risk of postoperative complications. In addition, ACHD patients develop vascular conditions with the increasing age, including systemic hypertension, diabetes mellitus, cerebral vascular disease, and coronary artery disease similar to those seen in the non-ACHD population [4].

In recent years, the number of hospital admissions of ACHD patients has increased, particularly in those with complex CHD [5–7]. The number of ACHD hospital admissions increased from 28.9% of all CHD admissions from 1998 to 2004 to 36.5% of all CHD admissions from 2004 to 2010 [5]. Based on the Nationwide Inpatient Sample (NIS) database, the number of admissions has increased from 63,950 in 2003 to 116,085 in 2012, corresponding to an 81.5% increase in the admission rate over a 10-year period [6]. More importantly, the number of patients admitted with complex CHD has increased by 52.8% [6].

The total charges for ACHD hospitalizations rose from $691 million in 1998 to $3.16 billion in 2005 nationally in the United States [7]. Although, these patients constitute a fraction of cardiac patients presenting to adult hospitals, they consume a disproportionate quantity of resources [6, 8].

The goal of this study was to compare hospital costs, postoperative complications, and mortality in ACHD patients undergoing cardiac surgery to a reference population of adults undergoing coronary artery bypass graft (CABG) surgery. In addition, we sought to compare the ages and comorbidities of the two groups in an effort to identify potential sources of differences in cost and complications. We hypothesized that ACHD patients undergoing cardiac surgery would have higher hospital costs, higher complication rates and mortality, and a higher comorbidity index despite lower age than the reference CABG population.

Methods

We utilized the 2013 Nationwide Inpatient Sample (NIS) database, an administrative database that compiles patient level discharge data from specialty, public, and academic medical centers across 44 states in the United States. All patients above 18 years of age and discharged from hospitals in participating states were included. The NIS is one of the databases produced by the Healthcare Cost and Utilization Project (HCUP) that is coordinated by the federal Agency for Health care Research and Quality (AHRQ). The database includes use of clinical and resources, information typically available from discharge abstracts. The NIS database is composed of >100 clinical and nonclinical variables for each hospital stay, including a maximum of 25 diagnoses, and 15 procedures for each hospitalization. The AHA's (American Hospital Association, www.aha.org) Annual Survey of Hospitals determines hospital characteristics, location, teaching status, and size. Hospital bed-size categories assigned by the HCUP include small (1–99 beds), medium (100–399 beds), and large (≥400 beds). HCUP categorizes hospital location by region including Northeast, Mideast, South, and West.

Adult patients above 18 years of age with CHD who underwent cardiac surgery for treatment of a congenital heart lesion were identified using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9 CM) procedure codes. In addition, patients without CHD who underwent CABG surgery were identified. All ICD-9 codes are listed in Table S1. We recorded the demographic characteristics, gender, and ethnicity (White, Black, Hispanic, Asian, native American, and other), hospital bed size, hospital length of stay (LOS), and in-hospital mortality. Using the ICD-9 CM for diagnosis, we recorded the incidence of renal failure, hepatic failure, neurologic complications (intracerebral hemorrhage, seizures, stroke), thromboembolic complications (arterial and venous thrombosis), arrhythmias, and sepsis. In addition, we used the Elixhauser Score to adjust for preoperative comorbidities in the ACHD and CABG surgical groups [9, 10].

Statistical Analysis

The Shapiro–Wilk normality test was used to assess continuous variables for normality. Data are presented as median and interquartile range (IQR) due to the non-Gaussian distribution of the population data. Categorical variables are expressed as the number and percentage (%). Groups were compared using the Wilcoxon rank sum test for continuous variables and the Chi-square test for categorical variables.

After logarithmic transformation, multivariable linear regression was used to determine independent predictors for increased cost using predefined univariable cutoff values of $p < 0.10$ for inclusion and $p > 0.05$ for removal. Results of linear regression are reported as linear coefficient regression (B), standard error (SE), and p values. Area under the receiver-operating characteristic curve was calculated to assess the strength of the association between cost and the independent variables.

A p value <0.05 was considered statistically significant for all tests. All reported values in this study are absolute values measured from the dataset. Statistical analyses were performed using STATA version 13.1 for Mac OS (StataCorp, College Station, TX, http://www.stata.com).

Results

Of the 2261,265 patients included in the 2013 NIS database, we identified 6,920 adult patients with CHD who underwent cardiac surgery and 124, 365 patients who underwent CABG surgery.

Univariate analysis of demographic, hospital characteristics, patient characteristics (including Elixhauser score), mortality, and complication rates are shown in Table 1. We observed higher incidences of in-hospital mortality (2.63 vs. 1.84%), and complication rates including neurologic complications (2.57 vs. 0.93%), thromboembolic complications (3.86 vs. 1.38%), arrhythmias (51.6 vs. 29.79%), hepatic failure (4.44 vs. 2.03%), and sepsis (7.24 vs. 4.61%) (all $p < 0.001$) in ACHD patients compared to those who underwent CABG surgery. Figure 1 illustrates the differences in hospital costs between ACHD and CABG patients (32,405.86$ vs. 21,736.41$).

The results of the multivariable regression analysis are shown in Table 2, and demonstrate that cost in adult cardiac patients is higher in patients with CHD (Coefficient = 0.116, 95% CI, 0.105–0.128; $p < 0.001$), Elixhauser score ≥7 (Coefficient = 0.114, 95% CI, 0.108–0.121; $p < 0.001$), neurologic complications (Coefficient = 0.169, 95% CI, 0.143–0.196;

Table 1 Demographic, hospital, and outcome characteristics in adult patients with CHD compared with CABG

Variables	CHD (n = 6920)	CABG (n = 124,365)	p
Age (years)	59 (47–69)	65 (56–73)	<0.001
Male (%)	4121 (59.5)	86,122 (69.25)	<0.001
Ethnicity			<0.001
White	4889 (77.55)	89,925 (77.31)	
Black	510 (8.09)	9931 (8.54)	
Hispanic	497 (7.88)	8715 (7.49)	
Asian	149 (2.36)	2909 (2.50)	
Other	27 (0.43)	592 (0.51)	
Unidentified	232 (3.68)	4240 (3.65)	
Elective (%)	3779 (54.82)	28,988 (23.4)	<0.001
Primary payer			<0.001
Medicaid/medicare	3312 (47.98)	73,363 (59.08)	
Private	3000 (43.46)	38,160 (30.73)	
Other	591 (8.56)	12,651 (10.19)	
Hospital bed size			<0.001
Small (<100beds)	471 (6.81)	10,277 (8.26)	
Medium (<400beds)	1250 (18.06)	28,643 (23.03)	
Large (≥400beds)	5199 (75.13)	85,445 (68.71)	
Hospital region			<0.001
Northeast	1414 (20.43)	21,408 (17.21)	
Midwest	1740 (25.14)	30,221 (24.3)	
South	2420 (34.97)	52,002 (41.81)	
West	1346 (19.45)	20,734 (16.67)	
Length of stay (days)	6 (4–9)	3 (2–6)	<0.001
Elixhauser score	8 (4–14)	5 (0–10)	<0.001
Complications			
Neurologic complications	178 (2.57)	1153 (0.93)	<0.001
Thromboembolic complications	267 (3.86)	1721 (1.38)	<0.001
Renal failure	1357 (19.61)	25,396 (20.42)	0.103
Arrhythmias	3571 (51.60)	37,048 (29.79)	<0.001
Hepatic failure	307 (4.44)	2521 (2.03)	<0.001
Sepsis	501 (7.24)	5728 (4.61)	<0.001
Mortality	182 (2.63)	2283 (1.84)	<0.001
Cost	32,405.86 (18,519.84–48,611.55)	21,736.41 (15,658.6–32,289.14)	<0.001

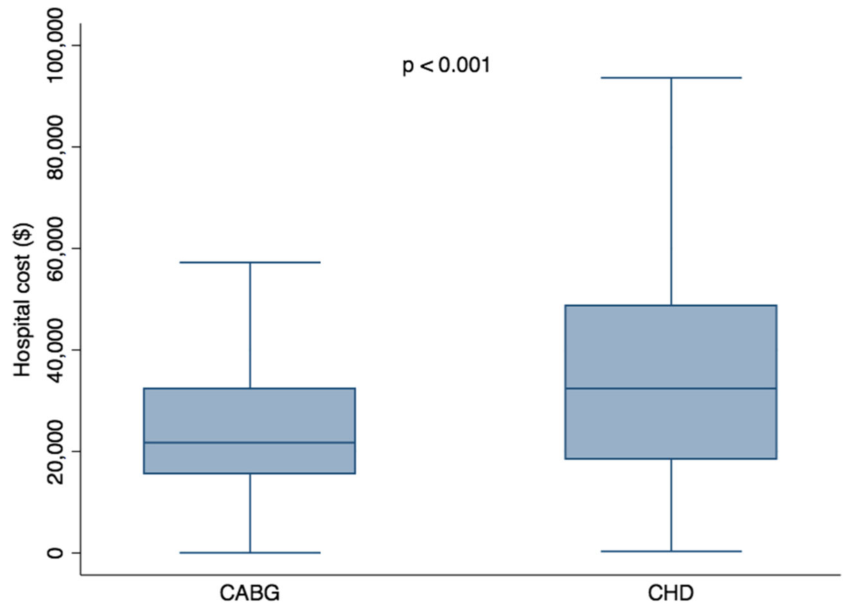

Fig. 1 Hospital costs for cardiac surgery in adults with CHD compared with CABG

Table 2 Factors independently associated with cost after multivariable logistic regression analysis

	Coefficient	Standard error	95% CI	*p*
CHD	0.116	0.006	0.105–0.128	<0.001
Elixhauser Score ≥7	0.114	0.003	0.108–0.121	<0.001
Neurologic complications	0.169	0.013	0.143–0.196	<0.001
Thrombotic complications	0.243	0.011	0.222–0.265	<0.001
Sepsis	0.198	0.006	0.185–0.211	<0.001
Acute kidney injury	0.056	0.004	0.041–0.063	<0.001
Elective case	0.047	0.003	0.041–0.053	<0.001
Length of stay ≥6 days	0.703	0.003	0.697–0.710	<0.001

ROC 0.814 (0.811–0.816)

$p < 0.001$), thrombotic complications (Coefficient = 0.243, 95% CI, 0.222–0.265; $p < 0.001$), sepsis (Coefficient = 0.198, 95% CI, 0.185–0.211; $p < 0.001$), acute kidney injury (Coefficient = 0.056, 95% CI, 0.041–0.063; $p < 0.001$), elective cases (Coefficient = 0.047, 95% CI, 0.041–0.053; $p < 0.001$), and length of stay ≥ 6 days (Coefficient = 0.703, 95% CI, 0.697–0.710; $p < 0.001$).

Discussion

This is the first study, to our knowledge, to make comparison of costs and outcomes of cardiac surgery in ACHD patents with the adult CABG population, a group where hospital costs are well characterized and benchmarking has been undertaken [11, 12]. ACHD patients undergoing cardiac surgery had higher costs, complication rates, and mortality than their non-ACHD counterparts undergoing CABG surgery. In addition, despite being younger, ACHD patients had significantly higher comorbidity scores than CABG patients. Consistent with our findings, Seckeler et al. have shown adults with single ventricle CHD admitted for noncardiac diagnoses have longer length of stay (LOS) and higher intensive care unit admission rates compared with similarly aged patients without CHD [13].

Currently, care of ACHD occurs in both pediatric and adult hospitals with a trend toward regionalization and referral of patients to specialized centers [14]. ACHD cardiac surgical admissions to adult hospitals utilize significant hospital resources. ACHD patients in the high resources use category (>90th percentile for total hospital charges) consume 32% of resources while constituting only 10% of the high resources use admissions [8]. In exploratory analysis, these same investigators found similar costs associated with high resource use admissions when adult congenital heart surgery was undertaken in pediatric hospitals [15]. This suggests that the site of care, adult versus pediatric hospital, is less important than patient characteristics, the procedures performed, and subsequent complications. While the cost of cardiac surgery in ACHD patients is high compared with CABG patients, it is interesting to note that ACHD patients undergoing cardiac surgery in pediatric hospitals did not consume a disproportionate amount of resources compared with children undergoing cardiac surgery. This is likely due to the fact that many children undergoing cardiac surgery undergo extremely complex repairs that consume an enormous quantity of resources [15].

In our cohort of adult cardiac surgical patients, higher costs were associated with CHD; sepsis; LOS ≥6 days; Elixhauser score ≥7; elective cases; and neurologic, thrombotic, and renal complications. Brown et al. demonstrated that any major complication following CABG surgery added substantial cost (+15,468$) to the procedure and increased LOS by +5.3 days [16]. CABG patients with renal dysfunction incur higher cost and increased postoperative length of stay compared to those without renal dysfunction [17]. The incidence of arrhythmias in our ACHD cohort was 51.6% compared to 29.79% of adults with non-CHD. Hospital admissions for arrhythmias in adults with single ventricle physiology have been shown to be substantially more expensive and resource consumptive than non-arrhythmia admissions [18].

This study has several limitations similar to other studies using large database. It is a retrospective study, and the findings may certainly differ from those of a prospectively enrolled cohort. These analyses were performed using a large administrative dataset which provides limited clinical information and may not have captured other important risk factors for adverse outcomes. In addition, miscoding of diagnosis and procedures may have occurred. Overlapping codes or missing data may limit the validity of the analyses in large datasets.

As advances in pediatric care and treatment strategies keep improving, the number of adult patients will continue to increase as will the number surviving to reach the geriatric age group [19]. The association of ACHD with significant comorbidities, despite a relatively young age, will lead to an increase in hospital-resource utilization as this cohort of patients continues to grow. A coordinated transition of care as patients mature to adulthood with an emphasis on multiorgan disease prevention may help decrease the costs associated with the treatment of ACHD. Future studies assessing the impact of comprehensive, preventative care for ACHD patients on cost and resource utilization are needed.

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Compliance with Ethical Standards

Conflict of interest The authors have no conflict of interest.

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