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Lesion Specific Factors Contributing to In-Hospital Costs in Adults with Congenital Heart Disease

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Abstract

The population of adults with congenital heart disease (ACHD) in the United States (US) is growing rapidly with concomitant increases in inpatient care costs. We sought to define the variables having the greatest influence on annual cost of inpatient care among ACHD patients in the US. To do so, we conducted a retrospective analysis of admissions in patients over age 18 with a 3-digit ICD-9 code of 745–747 from the State Inpatient Databases of Arkansas (2008–2010), California (2003–2012), Florida (2005–2012), Hawaii (2006–2010), Nebraska (2003–2011), and New York (2005–2012). We selected variables we believed would have the greatest effect on care costs and built a series of multivariable regression models grouping patients by congenital lesion, to examine the relative contribution of the specified variables to total annual inpatient cost. We analyzed a total of 68,314 patients aged 57±18.6, 51% of whom were women. The multivariable regression model had an overall R^2 of 0.35. Readmission was responsible for 10.3% of annual inpatient cost among all ACHD patients, and had the greatest effect on inpatient care cost for all congenital lesions except those with Eisenmenger syndrome and conotruncal abnormalities, for both of which it was the second most significant contributor. Other major contributors to annual inpatient care costs included length of stay and operative procedures. In conclusion, rehospitalization is the most significant contributor to annual inpatient cost for individual patients with ACHD in the US, regardless of underlying anatomy.

Keywords

Adult congenital heart disease; cost prediction; readmission

Introduction

A part of the recent increase in healthcare cost attributable to cardiovascular disease is due to the enlarging group of adult congenital heart disease (ACHD) patients^{1–3}. As the size of the

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Conflicts of Interest: None

ACHD population increases, so too do inpatient healthcare expenditures associated with provision of their care⁴⁻⁷. As this growing population ages, there is evidence that the importance of ACHD as a contributor to overall US healthcare expenditures will continue to rise^{8,9}. The first step in decreasing care costs and improving efficiency is the identification of high yield targets for intervention. In the present study, we examined the contribution of several variables to annual inpatient cost among patients with ACHD, with the goal of better understanding which have the greatest influence on inpatient spending in this population.

Methods

For this analysis, we used State Inpatient Databases (SID) which are part of the Healthcare Cost and Utilization Project (HCUP)¹⁰. We specifically used the SIDs for Arkansas (2008–2010), California (2003–2012), Florida (2005–2012), Hawaii (2006–2010), Nebraska (2003–2011), and New York (2005–2012). We selected these SIDs because they uniquely track hospitalizations in individual patients longitudinally, whereas data from other states track hospitalizations without tracking patients. The dates used were the most complete and up to date available at the time of analysis in April 2015. The primary outcome was financial burden accrued over a 12-month period for care of individual ACHD patients in the states investigated. The present study was approved by the institutional review board at Washington University School of Medicine.

As a first step, we identified patients in the databases with ACHD by selecting patients in the SIDs with an age of >18, and with a 3-digit ICD-9 diagnosis code of 745 (Bulbus cordis anomalies and anomalies of cardiac septal closure), 746 (Other congenital anomalies of heart), or 747 (Other congenital anomalies of circulatory system). To this group of patients we applied a validated hierarchical algorithm described by Broberg et al to categorize patients based on anatomy¹¹. Any patients who failed to be classified according to this algorithm were excluded to increase the probability that all patients included in fact had ACHD. We then excluded patients with an index hospitalization within the first or last 12 months of the investigated period, so that we were certain that: the index hospitalization was not a rehospitalization following one to which we were blind; and that a full 12 months of follow-up post index was available for every patient. We then excluded all patients for whom there was no cost data available and trimmed the top and bottom 1 percent of patients based on total annual cost as likely to be outliers. This treatment of the data resulted in a total of 68,314 patients whose data was analyzed.

We identified clinical and demographic characteristics that we thought were likely to have the greatest impact on inpatient care costs in ACHD. We then compared the prevalence of these variables in patients above versus below the overall median cost using Student's two-sample t-test and chi-squared tests for continuous and categorical data, respectively. Using this data, we further narrowed the list of variables to be included in our model. The final list of variables derived in this manner included: hospital readmission within 12 months, age, gender, length of stay, operative procedures, bacterial infection, diabetes without complications, anemia, coagulopathy, hypertension with complications, coronary artery disease (CAD), pulmonary vascular disease, arrhythmia, congestive heart failure (CHF),

peripheral vascular disease (PVD), reactive airway disease, acute renal failure, chronic kidney disease, complications of medical or surgical procedures, and aortic valve surgery.

Comparisons of length of stay and cost at the time of index admission between patients who were and were not readmitted were compared using t-tests. All significance tests were two-sided with type I error set to 5%, i.e. $\alpha = 0.05$.

We next constructed a series of multivariable regression models to examine our primary outcome of interest: total cost. Total cost was defined as the index cost and, if readmission occurred, the summed cost of all readmissions within one year of the index visit. A different model for each congenital lesion group was constructed using the same set of pre-identified variables. We looked specifically at the eta squared statistic and p-value for each independent variable in each model to see the proportion of total cost for which each variable was responsible across all congenital lesion groups. The sample size of each model changed, due to the varying number of subjects in each group. The reference value is zero ("no") for each dichotomous variable included in the models. The eta-squared statistics, 95% confidence intervals, and p-values were reported from these models and all significance tests were two-sided with type I error set to 5%, i.e. $\alpha = 0.05$.

All analysis conducted in SAS v9.4 (SAS Institute Inc., Cary, NC).

Results

Our initial query of the SIDs resulted in 155,297 index admissions, and 619,720 readmissions among patients over 18 with a 3-digit ICD9 code of 745, 746, or 747. After applying exclusion criteria, a final sample size of $n=68,314$ was achieved as graphically depicted in Figure 1. Demographic information for the study population may be found in Table 1. A total of 27,580 patients experienced at least one readmission within 12 months of any index admission, while 40,733 did not. Patients who experienced a readmission had a 1.7 day longer average length of stay at the time of their index admission (6.7 days versus 8.4 days; 95% CI 1.75–2.03, $p<0.001$), but had lower costs at the time of their index admission (\$23,037 versus \$22,476, $p<0.001$). The average cost of a readmission was $\$15,863 \pm \$20,186$ and the average length of stay at readmission was 6.3 ± 12.6 days. The average number of readmissions among patients who were readmitted was 2.0 ± 1.7 and 90% of readmissions were unplanned, whereas 85% of index admissions were unplanned. The cost of an unplanned readmission was $\$15,573 \pm \$20,031$ whereas the cost of a planned readmission was $\$18,077 \pm \$20,759$.

Among patients who were not readmitted, 45% had an operation at the time of their index admission, while this was the case for only 33% of those who went on to be readmitted. Only 25% of patients who were readmitted underwent an operative procedure at the time of a readmission.

The multivariable regression model derived using the selected variables had an overall R-square of 0.35. All variables and the magnitude of their contribution to overall annual ACHD inpatient cost can be found in table 2.

When separated by anatomical lesion, there were inadequate data available to perform analysis on patients with atrioventricular canal defects or anomalous pulmonary venous return as their primary diagnosis. Among the remaining anatomical lesions, we found significant group-specific heterogeneity in the factors responsible for the majority of variability in annual inpatient care costs (table 3). Readmission had the greatest effect on annual inpatient cost in all but two anatomical groups. Exceptions included conotruncal abnormalities for which acute renal failure had the greatest effect on cost, and Eisenmenger syndrome for which aortic valve surgery had the greatest effect. Operative procedures and length of stay were also significant contributors to annual inpatient across diagnostic groups.

Discussion

In the present study, we developed models to investigate which clinical factors have the greatest effect on annual inpatient care costs among patients with ACHD. We found that regardless of anatomic lesion, readmission was responsible for a large proportion of cost variability. While this is not surprising, the present data demonstrate that the magnitude of this effect is double that of the next most significant contributor. We also demonstrate that, outside of readmission, there are significant lesion-specific differences in the influence of various clinical factors on inpatient costs, highlighting the potential pitfalls of treating the ACHD population as monolithic. Importantly, these data identify readmission as a high yield target for intervention to improve health care efficiency in ACHD.

Although the population analyzed in the present study was the largest to date in the US, the degree to which it represents the ACHD population as a whole in the US is difficult to assess. The lack of reliable data on ACHD prevalence in the US adult population continues to be a significant impediment to population-based research in the field. Assuming that the US population is similar to that in Quebec, however, the hospitalized ACHD population is significantly older than the total ACHD population⁵. This suggests that predictions that hospitalization rate might increase with aging of the ACHD population based on data from Canada and England are likely to be true in the US as well^{8,9}. The very large number of patients with simple shunt lesions in the present population is interesting. To be sure, simple shunt lesions are by far the most common congenital heart lesions. Nevertheless, the fact that the most commonly performed procedure in the total cohort was ASD closure suggests that newly diagnosed ACHD in adulthood is likely responsible for a significant portion of reported growth in ACHD prevalence. This fact has long been suspected, and is likely due to advances in imaging technology that permit detection of clinically silent lesions. The disproportionate prevalence of simple shunt lesions among hospitalized ACHD patients in the US also highlights the importance of categorizing patients based on lesion type when analyzing administrative data. Analyses that fail to do so are likely to result in conclusions only applicable to patients with simple shunt lesions.

It is not surprising that readmission might have the greatest impact on annual inpatient cost in ACHD. Between 2003 and 2004 it was estimated that approximately 17% of total medicare expenditures or \$17.4 billion were attributable to rehospitalization¹². Furthermore, readmissions for other chronic heart conditions such as atrial fibrillation or flutter, coronary artery disease, and congestive heart failure are known to increase cost of care^{13–16}. Among

patients with ACHD, recent studies demonstrate that admission rates and inpatient care costs have been increasing in the US and England over the past two decades^{7,17}. In these studies the increased rates of admission and costs, however, have generally been attributed to one of two factors. First, growth in size of the ACHD population thanks to both improved detection of simple lesions and improved overall survival^{4,5}. Second, aging of the ACHD population, with an associated increase in the burden of acquired or age-related disease^{8,9,18}. The data sources used in previous studies, however, have not permitted identification of readmission as a potential contributor to hospitalization rate and therefore overall cost of inpatient care. The present data suggest readmission as a third source for progressively increasing inpatient expenditures in ACHD. Importantly, the majority of readmissions were unplanned. This fact suggests that, unlike the demographic factors driving increases in ACHD spending, the portion of overall expenditure attributable to readmission may be preventable and a target for decreasing ACHD healthcare spending.

There are some indicators in the present analysis that patients readmitted within 12 months of an index hospitalization were either sicker than those who are not, or received suboptimal care. Length of stay at the time of index hospitalization was greater in patients who went on to be readmitted, and the majority of patients who were readmitted were readmitted more than just one time in the year following their index hospitalization. This group of patients needs further characterization, including analysis of patient-specific risk factors associated with both readmission and length of stay.

There are multiple limitations to the present study related to the use of administrative data. The completeness and accuracy of the data is dependent on the care with which data was entered, which is variable from institution to institution. Differentiation between differing congenital cardiac lesions is difficult given institutional variability in coding for similar lesions. Although we made every effort to include all ACHD patients, to exclude patients without ACHD from analysis, and to correctly characterize patients based on underlying anatomy, no algorithm is fool-proof, and it is almost certain that some patients in the present study were mischaracterized. One of the unique components of the present study was the exclusive use of SIDs which permitted tracking of individual patients to detect rates of readmission. Tracking of individual patients however does not cross state lines and we had no ability to reliably and exhaustively identify patients who died during follow-up. Even within states, the same patient admitted at different hospitals may have failed to be recognized as the same due to faulty data entry. Thus the rehospitalization rate and costs reported in the present study may be an underestimate. Finally, although geography including state of hospitalization may influence cost and outcomes, we did not include state of hospitalization as a variable due to incomplete state representation. As the states represented in the present analysis are limited, this may have biased our results.

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Figure 1. Inclusion and Exclusion Diagram

Graphical representation of the patients included in the present analysis. 155,297 index admissions were found with a total of 619,720 total readmissions. After excluding readmissions that took place longer than 1 year after the index admission, this left 112,113 readmissions which were then linked to their corresponding index admissions. The index admission data were then excluded if patients failed to be categorized by the algorithm to identify ACHD lesion, if a full 12-month follow-up period before and after index admission

was not available, if records were without cost information, and to remove outliers. This resulted in a final tally of 68,314 index admissions which were then used for analysis.

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Table 1**Subject Demographics**

Variable	N=68314
Age at index admission	57.2±18.6
Female	34,581 (51%)
Homeless	475 (1%)
White	47,146 (70%)
Black	6,188 (9%)
Hispanic	8,506 (12%)
Asian/Pacific islander	2,291 (3%)
Native American	174 (0%)
Other	2,618 (4%)
Primary Payer	
Medicare	28,875 (42%)
Medicaid	8,524 (12%)
Private Insurance	25,758 (38%)
Self-pay	2,395 (4%)
No charge	497 (1%)
Other	2,259 (3%)
Cardiac Lesion	
Eisenmenger syndrome	230 (<1%)
Single Ventricle	1,452 (2%)
Transposition of the great arteries	1,110 (2%)
Conotruncal abnormality	521 (1%)
Atrioventricular canal defect	534 (1%)
Ebstein anomaly	484 (1%)
Pulmonary stenosis	1,573 (2%)
Anomalous pulmonary venous return	45 (0%)
Coarctation	978 (1%)
Shunts	46,039 (67%)
Subaortic stenosis	455 (1%)
Congenital aortic stenosis	10,840 (16%)
Anomalous coronary artery	6,058 (9%)
Other congenital anomaly	4,517 (7%)
Surgical operation during follow-up	
Atrial septal defect repair	8,347 (12%)
Ventricular septal defect repair	446 (1%)
Mitral valve operation	2,668 (4%)
Aortic valve operation	7,158 (10%)
Tricuspid valve operation	533 (1%)
Pulmonary valve operation	358 (1%)
Electrophysiology study/ablation	1,898 (3%)

Variable	N=68314
Permanent pacemaker/Implantable cardiac defibrillator	2,828 (4%)
Ventricular assist device (percutaneous)	23 (0%)
Heart transplant	41 (0%)
Heart/Lung transplant	4 (0%)
Totally anomalous pulmonary venous connection repair	38 (0%)
Atrioventricular canal defect repair	94 (0%)
Tetralogy of Fallot repair	22 (0%)
Transposition of the great arteries repair	22 (0%)
Atriopulmonary Fontan	29 (0%)
Total cavo-pulmonary anastomosis Fontan	23 (0%)
Systemic-pulmonary arterial shunt	6 (0%)
Truncus repair	3 (0%)
Infundibulectomy	21 (0%)

Table 2

Contribution of various factors to overall annual inpatient care cost

Variable	Eta-Square	Variable Rank
Readmission	0.1033	1
Age	0.0008	13
Sex (Female)	0.0013	11
Length of Stay	0.0094	4
Operative Procedure	0.0513	2
Bacterial Infection	0.0113	3
Diabetes without complications	0.0004	16
Anemia	0.0023	10
Coagulopathy	0.0033	9
Hypertension with complications or secondary	0.0001	18
CAD	0	19
Pulmonary heart disease	0.0013	11
Arrhythmia	0.0007	14
Congestive heart failure	0.0064	8
Peripheral vascular disease	0.0006	15
Reactive airway disease	0	19
Acute renal disease	0.0069	7
Chronic renal disease	0.0003	17
Complications of surgery or medical care	0.0094	4
Aortic valve operation	0.0082	6

CAD: coronary artery disease

Table 3

Variables with the greatest impact on annual inpatient care costs for each anatomic lesion

ACHD Group	Variable 1	Variable 2	Variable 3	Variable 4
Eisenmenger/ Cyanotic	Aortic valve operation (7.1%)	Readmission (6.0%)	Length of stay (3.6%)	OR procedure (2.7%)
Single ventricle/ Fontan	Readmission (7.4%)	Length of stay (3.1%)	OR Procedure (1.7%)	CHF (1.0%)
Transposition of the great arteries	Readmission (9.5%)	Length of stay (3.7%)	OR Procedure (3.3%)	Acute renal failure (3.0%)
Conotruncal abnormality	Acute renal failure (3.8%)	Readmission (3.0%)	Length of stay (2.9%)	OR procedure (2.9%)
Atrioventricular canal defect	N/A	N/A	N/A	N/A
Ebstein anomaly	Readmission (8.6%)	Length of stay (5.6%)	OR procedure (3.1%)	Aortic valve surgery (1.1%)
Pulmonary stenosis	Readmission (11.2%)	Length of stay (7.2%)	OR procedure (3.4%)	Pulmonary heart disease (0.7%)
Anomalous pulmonary venous return	N/A	N/A	N/A	N/A
Coarctation of the aorta	Readmission (7.1%)	Length of stay (5.0%)	CHF (2.2%)	OR procedure (1.6%)
Shunts	Readmission (10.3%)	OR procedure (5.4%)	Length of stay (1.9%)	Bacterial infection (1.0%)
Subaortic stenosis	Readmission (13.9%)	Length of stay (5.1%)	OR procedure (3.4%)	Pulmonary heart disease (2.2%)
Congenital aortic stenosis/Bicuspid aortic valve	Readmission (9.3%)	Length of stay (4.1%)	Operative procedure (3.1%)	Aortic valve surgery (0.8%)
Anomalous coronary artery	Readmission (10.4%)	OR procedure (6.0%)	Length of stay (2.6%)	Medical complications (1.1%)
Other congenital heart abnormality	Readmission (11.4%)	OR procedure (4.4%)	CHF (1.2%)	Bacterial infection (1.0%)

CHF: congestive heart failure; OR: operative. The numbers in parentheses indicate the percent of variability in cost attributable to the indicated variables