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Short-Term Costs and Hospitalization Rates in Adult Congenital Heart Disease Patients after Pulmonic Valve Replacement

Deana Mikhalkova, MD^a, Eric Novak, MS^b, and Ari Cedars, MD^c

^aWashington University, Barnes-Jewish Hospital, Cardiology

^bWashington University, Cardiology

^cWashington University, Baylor Heart, Vascular Hospital

Abstract

In the adult congenital heart disease (ACHD) population, pulmonary valve replacement (PVR) is a common intervention, its benefit, however, has been incompletely investigated. This study investigates short and intermediate-term outcomes following PVR in ACHD. Using State Inpatient Databases (SID) from the Healthcare Cost and Utilization Project we investigated both hospitalization rate and financial burden accrued over the 12-month period after PVR as compared to the 12-months before. Among 202 patients who underwent PVR, per patient-year hospitalization rates doubled in the year following PVR compared to the year prior (0.16 vs 0.36, $p=0.006$). With the exception of post-procedural complications, the most common reasons for hospitalization were unchanged after surgery: 22% of patients were admitted with equal or greater frequency after PVR. These patients experienced higher inpatient costs both at index admission and in the year following PVR ($p = 0.004$ and <0.001 , respectively). Univariate predictors of increased hospitalizations post PVR were age ≥ 50 ($p=0.016$), transposition of the great arteries (TGA) or conotruncal abnormalities ($p<0.001$), lipid disorders ($p=0.025$), hypertension, ($p=0.033$), and number of chronic conditions ≥ 4 ($p=0.004$). Multivariate analysis identified TGA or conotruncal abnormalities as an independent risk factor for increased hospitalization and cost post-PVR ($p<0.001$). In conclusion, short-term costs and hospitalization rates increase after PVR in a small group of ACHD patients.

Keywords

Pulmonary valve stenosis; Pulmonary valve regurgitation; re-hospitalization; health care costs; adult congenital heart disease

Address for Correspondence: Ari Cedars, MD, Baylor Heart and Vascular Hospital and Baylor University Medical Center, 621 N Hall St, Dallas, TX 75226, Cell: 314-922-4788 Phone: 469-800-7810 Fax: 469-800-7811, acedars97@gmail.com.

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Introduction

The number of adults with congenital heart disease (ACHD) is rapidly rising ¹. Many of the cardiac repairs performed during childhood deteriorate with the passage of time, making re-operation common among ACHD patients ²⁻⁴. These repeat operations are a source of significant morbidity and cost ^{2,4,5}. Among the repeat operations performed, pulmonary valve replacement (PVR) is particularly common for both pulmonary valve insufficiency (PI) and for pulmonary valve or right ventricular to pulmonary arterial conduit stenosis (PS) ³. Chronic right ventricular volume or pressure overload is not benign, and results in right ventricular dilation and dysfunction, impaired exercise tolerance⁶⁻⁸, and a propensity to ventricular arrhythmia and sudden cardiac death ⁹⁻¹¹. Despite this, identification of the patients most likely to benefit from and the optimal timing for PVR remain unclear. As the cost of caring for ACHD patients continues to rise, it is becoming more important to identify care strategies that improve quality and efficiency ¹²⁻¹⁴. In this study, we investigated outcomes in the first year following PVR with the goal of identifying clinical variables associated with increased rates of hospitalization and cost.

Methods

For this analysis, we used the State Inpatient Databases (SID) from the Healthcare Cost and Utilization Project (HCUP). 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 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 outcomes were hospitalization rate and cost of inpatient care in the 12-months prior to as compared to after PVR. The present study was approved by the institutional review board at Washington University School of Medicine.

We first identified patients in the databases with ACHD by selecting patients in the SIDs with an age of greater than 18, and with a 3-digit ICD-9 diagnosis code of 745, 746 or 747 (Figure 1). To this group of patients we applied a validated hierarchical algorithm described by Broberg et al. to categorize patients based on anatomy ¹⁵. Any patients who failed to be classified according to this algorithm were excluded to increase the probability that all the patients included for analysis in fact had ACHD.

We next identified patients with a hospitalization specifically for PVR during the follow up period. We identified these hospitalizations by selecting those for which there was both a major operating room procedure flag, and who had an ICD-9 4-digit diagnosis code of 3525, 3526, 3592, or 3507 (Figure 1). We excluded patients with hospitalizations for PVR within the first or last 12 months of the investigated period, so that we were certain a full 12 months of data were present prior to PVR, and a full 12 months of follow-up post PVR were available for every patient. We excluded all patients who had an ICD9 code for any other cardiac operation at the time of PVR with the goal of identifying admissions specifically for PVR.

Rates of hospitalization and cost of inpatient care in the 12 months before and after PVR were then compared with a Poisson model using generalized estimating equation methods (GEE). GEE methods were used to handle repeated measures data given multiple time periods, e.g. pre and post PVR. Models were scaled using Pearson correlations to adjust for over-dispersion. Inpatient care costs for the 12 months prior to PVR were adjusted for inflation to reflect October 2015 dollars based on the consumer price index of medical care. The top 6 primary admitting diagnosis codes within 12 months pre and post index PVR were compared using McNemar's test. Patients who died during the hospitalization for PVR were excluded.

To identify variables associated with suboptimal outcomes in the first year after PVR, we defined 2 groups of patients. Patients who had fewer hospitalizations in the 12 months post PVR than pre or who had no hospitalizations during either time period were defined as group A. Those with a greater number of hospitalizations in the 12 months post PVR than pre or who had the same, non-zero number of hospitalizations during both time periods were defined as group B. Patients who died during index hospitalization were defined as group B. Patient data were summarized overall and by group A vs B. Comparisons between groups A and B were done using the Mann-Whitney U-test for continuous variables and Fisher's exact test or Pearson chi-square test for categorical variables. Continuous variables were summarized using the median (1st quartile, 3rd quartile) and categorical variables were summarized using counts (percents). Hospitalization cost in the 12 months after PVR was subtracted from that in the 12 months prior to PVR to compare the differences in cost between groups A and B based on the above definition. These cost differences were then compared using the Mann-Whitney U-test test. PVR reason was defined as "PI" if an admitting diagnosis code for index PVR hospitalization was ICD9 = 746.09 or "PS" if ICD9 = 746.02. Patients having both ICD9 codes were classified as "PI".

A multivariable logistic regression model was then built to examine independent predictors for being in group B. Based on subject knowledge and after examining univariate associations, the following variables were included: age, TGA/Conotruncal abnormalities, number of chronic conditions, and arrhythmia. Age and number of chronic conditions were dichotomized (age < 50 vs. ≥ 50; number of chronic conditions < 4 vs. ≥ 4) for this model. Odds ratios, 95% confidence intervals, and p-values were reported from the model results.

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

Results

Using the stated search criteria, 155,297 patients were identified who were admitted during the trial period. After excluding patients as indicated, 202 index PVR admissions were identified (Figure 2). Demographic characteristics of the patients identified are depicted in Table 1.

PVR was associated with 2-fold higher rates of admission in the 12 months following the procedure as compared to the 12 months before, and was associated with a non-significant trend towards increased inpatient cost (Table 2).

To investigate differences in reasons for admission in the year prior-to as compared to the year after PVR, we compared the frequency of admission for the most common primary admitting diagnoses (accounting for about 50% of all admissions) in the 12 months prior to PVR with the year after. Outside of complications of surgical procedures or medical care, the frequency of admission for the most common admission diagnoses were not significantly changed, although the absolute numbers of admissions for these diagnoses was higher post PVR (Figure 3). There was 1 admission for peri-, endo-, or myocarditis in the 12 months prior to PVR and there were 2 in the 12 months after PVR.

In an effort to identify the group of patients responsible for the increased numbers of admissions and increased cost associated with PVR, we divided patients into 2 cohorts, group A (n=158) and group B (n=44) as outlined in the methods section. One patient died during the index admission and was included in cohort B. Group A had lower costs at the time of index admission, and had significantly lower costs in the 12 months after as compared to prior to PVR when compared to group B (Table 3).

On univariate analysis, age ($p=0.016$), TGA or conotruncal abnormality ($p<0.001$), lipid disorders ($p=0.025$), hypertension ($p=0.033$), arrhythmia ($p=0.011$), sudden cardiac death (SCD) ($p<0.001$), chronic kidney disease (CKD) ($p=0.033$), and number of chronic conditions ($p=0.004$) were all associated with being in group B. On multivariable analysis, only having TGA or a conotruncal abnormality was found to independently predict being in group B (Table 4).

Discussion

In the present study, we investigated the short/intermediate-term outcomes after PVR in ACHD patients. We found an increase in rates of hospitalization and inpatient care costs in the year after PVR as compared to the year prior. This observation, however, was completely attributable to only ~22% of patients. The only risk factor independently associated with suboptimal outcome in the first year after PVR was an underlying diagnosis of either TGV or conotruncal abnormality. To our knowledge this is the first study to investigate clinical outcomes and changes in cost of care after PVR among ACHD patients.

The present data suggest that identifying strategies to improve short to intermediate term outcomes after PVR, the most common guideline-directed surgical procedure performed in ACHD patients, may have a significant impact on ACHD care quality^{3,16}. Given that the present data included a follow-up of only 12 months, and that the benefits of PVR in preventing progressive right ventricular enlargement and failure would be anticipated to be detectable only with longer follow-up, we do not believe that the present data should be used to identify patients likely to benefit from PVR long-term. In contrast, we believe the present data should be used to identify patients at particular risk for short-term adverse events, as targets for intervention.

We identified 3 independent risk factors for increased hospitalization rates and costs after PVR. The presence of TGA or conotruncal abnormality as a risk factor is not surprising as among the diagnostic groups in the present cohort who underwent PVR, those with TGA

and conotruncal abnormalities had the greatest anatomic complexity, and would therefore be anticipated to be at increased risk of adverse events^{17,18}. The present analysis also identified a trend toward increased risk among patients over 50 and those with multiple comorbidities. It is tempting to conclude that this supports recent data favoring earlier intervention for pulmonary valve disease, at a time when patients are younger and may have fewer comorbidities¹⁹. Nevertheless, as we are unable to determine if the present cohort had previously undergone PVR, their exact anatomy, or the duration and severity of the RVOT abnormality and physiologic sequelae, we cannot validly draw conclusions on PVR timing. We can conclude that, as is the case in various types of acquired heart disease, age and comorbidities are risk factors for readmission²⁰⁻²³.

We found that the rates of readmission after PVR increased, and that the only admitting diagnosis which increased significantly post PVR was that of complications of medical or surgical care. These observations indicate that defining optimal operative and perioperative management may be a target for intervention to improve care quality. Although available data remain inconclusive regarding the benefits of having surgery at ACHD specialized centers^{4,24,25}, the present data suggest that further investigation into the effects of surgical care on PVR outcomes may be high yield.

We found that the 5 most common preoperative causes of admission were unchanged by PVR. It is not surprising that the most common admitting diagnoses in this group were arrhythmias, chest pain, heart failure, device related, and congenital anomaly related. These are similar to those suggested by research from the Dutch CONCOR national registry which demonstrated that cardiovascular admissions accounted for 61% of all hospitalizations, with diagnoses of arrhythmia, chest pain, heart failure, perioperative care, and pacemaker related admissions dominating¹³. The present data suggest that in at-risk individuals, PVR is not decreasing short-term disease-related hospitalization. In view of this, we would propose using hospitalization for PVR as an opportunity to intervene with patient education, care coordination, and early follow-up along the lines of models which have demonstrated some success in congestive heart failure patients²⁶⁻²⁸. This intervention would be targeted at older individuals with multiple comorbidities and more complex lesions with the goal of improving outcomes in the short term so that the long term benefits of PVR might be realized.

There are many limitations to the present study related to the use of administrative data. The accuracy and completeness of the data are dependent on the accuracy of data entry, which is variable from institution to institution. As highlighted above, differentiation between differing congenital cardiac lesions is difficult and there is likely institutional variability in coding for similar lesions. We made every effort to include only ACHD patients who underwent PVR, however no algorithm is fool-proof, and there may be some patients in the present study who were mischaracterized. Although using SIDs permitted tracking of individual rates of readmission, tracking does not cross state lines. Within states, the same patient admitted at different hospitals may have failed to be recognized as the same and SIDs do not fully track deaths. Thus the hospitalization rates reported in the present study may be an underestimate.

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ICD-9 Diagnosis Code and Definition

- 745** Bulbus cordis anomalies and anomalies of cardiac septal closure
- 746** Other congenital anomalies of the heart
 - 746.02** Stenosis of the pulmonary valve, congenital
 - 746.09** Other congenital anomalies of the pulmonary valve
- 747** Other congenital anomalies of the circulatory system
- 3525** Open and other replacement of pulmonary valve with tissue graft
- 3526** Open and other replacement of pulmonary valve
- 3507** Endovascular repair of pulmonary valve

Figure 1.
ICD-9 Diagnosis Code and Definition - List of diagnosis codes used for defining patients' diagnosis and type of surgery.

Figure 2.

Study patients and exclusion criteria - Flow chart of initial admissions and applied exclusion criteria. Total of 202 patients were included in the final dataset for analysis.

Figure 3.

Reasons for re-admission - Top reasons for admission within a 12-month period pre and post PVR. NA = not applicable; PVR = pulmonary valve replacement.

Table 1
Patient Demographics

	Overall (N=202)	
Age in years at admission	26.0	(20.0, 37.0)
Age >50 years	12	(6%)
Female	90	(45%)
4 chronic medical conditions	93	(46%)
White	129	(69%)
Black	13	(7%)
Hispanic	29	(16%)
Asian/Pacific Islander	10	(5%)
Other	6	(3%)
Congenital heart disease not categorized	75	(37%)
Single Ventricle	4	(2%)
Transposition of the great arteries	16	(8%)
Conotruncal abnormality	14	(7%)
Ebstein anomaly	1	(0%)
Pulmonic stenosis	44	(22%)
Shunts	42	(21%)
Aortic stenosis	3	(1%)
Anomalous coronary artery	3	(1%)
Main PVR reason		
Pulmonic valve insufficiency	49	(53%)
Pulmonic valve stenosis	44	(47%)
Primary expected payer		
Medicare	14	(7%)
Medicaid	35	(17%)
Private Insurance	140	(69%)
Self-pay	5	(2%)
Other	8	(4%)
Patient Location: Urban-Rural 4 Categories		
Metro >= 1 million pop	144	(71%)
Metro < 1 million pop	48	(24%)
Micro	7	(3%)
Not metro nor micro	3	(1%)
Median household income national quartile		
0-25th percentile (lowest)	27	(20%)
26th to 50th percentile (median)	29	(22%)
51st to 75th percentile	36	(27%)
76th to 100th percentile (highest)	41	(31%)

Values are %(n) or median (1st quartile, 3rd quartile).

PVR = pulmonary valve replacement, TGA = transposition of great arteries.

Table 2
Cost and rate of admission one-year pre and one-year post PVR

	Pre-PVR	Post-PVR	p-value
Admission rate per patient year within 1-year of PVR (n=201)	0.16 (0.10, 0.27)	0.36 (0.25, 0.51)	0.006
Inpatient cost average (n=189)	\$1975 (\$1084, \$3597)	\$7001 (\$2762, \$17,746)	0.14

Values are mean (95% confidence interval). Of note, there were total of n=12 missing cost data from either pre or post PVR groups.
PVR = pulmonary valve replacement

Table 3
Cost at PVR and in the year after as compared to the year before PVR

	Group A	Group B	P value
Total Cost at PVR	\$44,694 (\$29,814, \$56,742)	\$51,327 (\$43,788, \$70,936)	0.004
Total difference in cost between post PVR and pre PVR	0.0	\$9304.3 (\$4024.6, \$22,862)	<0.001
Total Cost difference = post PVR total cost– pre PVR total cost			

Group A: Patients who had fewer hospitalizations in the 12 months post PVR than pre or who had no hospitalizations during either time period;
 Group B: Patients with a greater number of hospitalizations in the 12 months post PVR than pre, who had the same nonzero number of hospitalizations during both time periods, or who died during index hospitalization; Values are median; PVR = pulmonary valve replacement (1st quartile, 3rd quartile).

Table 4
Multivariable logistic model

Variable	Odds Ratio (OR)	95% Confidence Interval	p-value
Age 50 (vs. < 50)	3.108	(0.901, 10.718)	0.07
TGA or Conotruncal Abnormality (yes vs. no)	5.052	(2.135, 11.957)	<.001
Number of chronic conditions 4 (vs. < 4)	2.042	(0.939, 4.441)	0.07
Arrhythmia (yes vs. no)	1.708	(0.791, 3.689)	0.17

Multivariable logistic model to identify independent risk factors for not benefiting from PVR.

TGA = transposition of great arteries.