

A Method to Account for Variation in Congenital Heart Surgery Charges

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Background. In response to societal pressure to reduce expenditures and increase quality, we sought to develop a methodology to predict hospital charges related to congenital heart surgery.

Methods. Patients undergoing congenital heart surgery at Boston Children's Hospital in fiscal years 2007 to 2009 comprised the derivation cohort. Clinical data, including Current Procedural Terminology coding of the primary surgical intervention, were collected prospectively and linked to total hospital charges for an episode of care. Surgical charge categories were developed to group surgical procedure types using empiric data and expert consensus. A multivariable model was built using surgical charge categories and additional patient and procedural characteristics to predict the outcome, total hospital charges. A contemporary cohort for fiscal years 2010 to 2012 was used to validate surgical charge categories and the multivariable model.

Results. In the derivation cohort, 2,105 cases met inclusion criteria. One hundred three surgical procedure

types were categorized into seven surgical charge categories, yielding a grouper variable with an R^2 explanatory value of 47.3%. Explanatory value increased with consideration of patient age, admission status, and pre-operative ventilator dependence (R^2 [59.4%]), as well as weight category, noncardiac abnormality, and genetic syndrome other than trisomy 21 (R^2 [61.5%]). Additional variability in charge was explained when extracorporeal membrane oxygenation utilization and greater than one operating room visit during the episode of care were added (R^2 [74.3%]). The contemporary cohort yielded an R^2 explanatory value of 67.7%.

Conclusions. The combination of clinical data with resource utilization information resulted in a statistically valid predictive model for total hospital charges in congenital heart surgery.

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As outcomes improve in congenital heart surgery (CHS), there is growing interest in the high resource utilization associated with congenital heart disease patients, but previous studies are limited. Congenital heart disease is estimated to account for \$6 billion annually in acute care alone [1]. Between 2005 and 2011 Smith and colleagues [2] found a 50% increase in costs and a 66% increase in mean charges among neonates undergoing CHS. In addition, there is significant variability among institutions in the costs and resource utilization for congenital heart disease, with prematurity, noncardiac abnormalities, age, length of stay, and in-hospital complications found to account for increased resource consumption [1, 3–7].

Methods to accurately predict resource utilization for CHS do not currently exist. In the diagnosis related groups system used for determining hospital reimbursement, coding occurs after discharge and depends on all cardiac and noncardiac diagnoses and procedures,

including diagnoses that have arisen during the hospitalization. Therefore, by definition it is not a predictive model. The Medicare resource-based relative value scale (RBRVS) for physician payment has limitations in predicting physician work and resource utilization in pediatrics and in accounting for the variability and complexity associated with cardiac catheterization [8, 9]. Risk stratification tools have been developed to evaluate in-hospital mortality and technical performance in CHS through consensus-based approaches and use of empiric data, but no similar risk stratification methods exist to predict resource utilization [10–12].

Given these limitations, our institution formed a multidisciplinary panel to develop a methodology to predict resource utilization for CHS. Using total hospital charges as the outcome, we developed a procedure-based financial grouper based on Current Procedural Terminology (CPT) codes to allow for generalizability in multicenter databases, and thus allow comparisons of charges at a single point in time and longitudinally. We hypothesized that the development of this procedure-based financial grouper including a priori characteristics could serve as a predictive model for patient resource utilization.

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Abbreviations and Acronyms

APR-DRG	= all patient refined diagnosis related groups
CHS	= congenital heart surgery
CPT	= Current Procedural Terminology
ECMO	= extracorporeal membrane oxygenation
EOC	= episode of care
OR	= operating room
RBRVS	= resource-based relative value scale
SCC	= surgical charge category
SOI	= severity of illness
STS-CHSD	= Society of Thoracic Surgeons Congenital Heart Surgery Database

Patients and Methods

This study was conducted as a quality improvement project according to the Institutional Review Board guidelines at Boston Children's Hospital.

Database Sources

The Boston Children's Hospital administrative and billing databases include charge data for patients receiving services at the institution. The Department of Cardiovascular Surgery clinical database supports professional billing by collection of primary and secondary CPT codes and includes clinical data used in the Society of Thoracic Surgeons Congenital Heart Surgery Database (STS-CHSD). Total hospital charges for an episode of care (EOC), defined as the time from admission to discharge, was chosen as the outcome variable for analysis. Total hospital charges from the administrative and billing databases were matched to CHS cases in the clinical database by medical record number and date of discharge to abstract patient characteristics. Cases were also linked to an All Patient Refined Diagnosis Related Groups (APR-DRG) version 20.0 value based on International Classification of Diseases, 9th revision, Clinical Modification procedure and diagnosis codes assigned in the hospital database.

Cohort

All cases with a CPT code linked to a congenital heart operation in the Department of Cardiovascular Surgery database were considered. Cases were excluded if they contained incomplete data, were patent ductus arteriosus ligations in premature infants, were minor same-day surgeries, or were for noncardiac surgeries during the EOC (eg, a patient whose only cardiac surgery was rescue extracorporeal membrane oxygenation [ECMO]). Fiscal years 2007 to 2009 comprised the derivation cohort. A validation cohort was examined for fiscal years 2010 to 2012.

Predictor Variables

We considered patient and procedural characteristics collected from the Department of Cardiovascular Surgery clinical database as potential predictor variables for total

hospital charges. A priori characteristics included age, weight, history of prematurity, previous cardiac surgery, noncardiac abnormality, genetic syndrome, admission status, ventilator before surgery, ventilation at admission, and weekend admission. As an exploratory analysis, ECMO utilization and the number of visits to the operating room (OR) for a cardiac surgery during the EOC, excluding cases of delayed or secondary closure of the sternotomy, were recorded.

Development of Surgical Procedure Types and Surgical Charge Categories

Because CHS includes a wide variety of case types, a surgical procedure type variable was developed based on the primary cardiac surgical procedure's CPT code during the EOC. The multidisciplinary panel stratified selected primary procedures by factors that seemed likely to influence resource intensity and complexity, such as patient age. Total hospital charges for mutually exclusive surgical procedure types were summarized and placed in rank order. The surgical procedure types were then grouped into surgical charge categories (SCCs) according to empiric similarity. After this, expert consensus was used to group surgical procedure types near the threshold of a category or with limited empiric data, such as a small sample size. Different numbers of categories were evaluated to minimize variation within a group and maximize the discrimination between groups until face validity no longer increased.

Statistical Methods and Development of Multivariable Model

Patient and procedural characteristics were summarized by geometric mean and interquartile range charges. Geometric mean charge was chosen to reduce skewed distribution effects. The distribution of cases in each of the four APR-DRG severity of illness (SOI) subclasses was summarized for each SCC. Mean SOI and geometric mean case mix index were calculated for each SCC. The coefficient of determination (R^2) was calculated by univariate and multivariable linear regression models, which were built using stepwise forward regression for the outcome. Starting with SCC, statistically significant ($p < 0.01$) a priori patient and procedural characteristics were considered for inclusion until no further explanatory value could be found. The panel then considered post-admission factors that might explain variability in resource utilization. The performance of the final SCC and multivariable model were assessed in the contemporary validation cohort.

Results

Derivation Cohort

In fiscal years 2007 to 2009, 2,105 CHS admissions qualified for analysis. Charges were summarized according to a priori patient and procedural characteristics and postadmission factors (Table 1). Geometric mean charge was higher for neonates, premature patients, and patients with noncardiac

Table 1. Summary of Charges by Predictor Variables^a

Variable	n (%)	Geometric Mean (\$)	75th Percentile (\$)	R ² (%)
Age at surgery				12.0
< 30 days	394 (19)	196,493	288,614	
30 days to < 1 year	670 (32)	108,013	139,414	
1–17 years	861 (41)	91,038	114,608	
≥ 18 years	180 (9)	100,059	125,756	
Weight at surgery (kg)				9.2
< 3	152 (7)	227,956	388,903	
3–9.9	1,002 (48)	122,393	174,031	
≥ 10	950 (45)	90,885	114,456	
Premature birth				1.1
Yes	170 (8)	149,517	225,200	
No	1,935 (92)	109,107	149,864	
Previous cardiac surgery				0.5
Yes	564 (27)	122,792	158,168	
No	1,541 (73)	108,185	151,583	
Noncardiac abnormality				9.0
Yes	262 (12)	212,950	380,953	
No	1,843 (88)	102,138	136,388	
Genetic syndrome other than trisomy 21				1.9
Yes	151 (7)	167,493	293,368	
No	1,954 (93)	108,486	148,250	
Admission status				30.1
Yes	793 (38)	197,788	319,645	
No	1,312 (62)	79,329	98,097	
Ventilator before surgery				23.8
Yes	300 (14)	293,659	532,559	
No	1,805 (86)	95,340	124,818	
Ventilation at admission				5.7
Yes	16 (1)	1,011,888	1,865,755	
No	2,089 (99)	110,048	151,179	
Weekend admission				5.1
No	1,958 (93)	106,481	143,552	
Yes	147 (7)	217,296	431,903	
Preoperative status consisting of age, ventilator status, and admission status				38.9
< 30 days and ventilator	190 (9)	236,514	380,018	
30 days to < 1 year and ventilator	83 (4)	353,314	678,789	
≥ 1 year and ventilator	31 (1)	711,465	1,401,209	
< 30 days and no ventilator	204 (10)	165,334	239,032	
≥ 30 days, no ventilator, and inpatient	296 (14)	146,353	204,666	
≥ 30 days, no ventilator, and not inpatient	1,301 (62)	78,955	97,733	
ECMO utilization				20.6
Yes	81 (4)	698,698	1,093,486	
No	2,024 (96)	104,010	142,295	
Number of visits to OR				35.3
1	1,901 (90)	95,650	130,266	
> 1	204 (10)	483,754	932,764	
Fiscal year				0.6
2007	689 (33)	105,126	146,054	
2008	656 (31)	109,269	148,908	
2009	760 (36)	120,932	174,288	

^a Probability value < 0.001 for all variables.

ECMO = extracorporeal membrane oxygenation; OR = operating room.

Category 1

Vascular ring repair
PDA closure (not premature)
Generator change
Sympathectomy
Coarctation repair, end to end, ≥ 1 month^a
ASD/PFO primary closure or patch
Aortopexy

Category 2

ASD primum repair
Subvalvar AS repair, no myectomy for IHSS
Tumor
Scimitar repair
Supravalvular mitral ring or cor triatriatum repair
Unroofing of coronary artery
Isolated VSD primary closure
Transitional AVC repair
Epicardial pacemaker
RV muscle resection for DCRV
Pulmonary valve replacement
Coarctation repair, end to end, < 1 month^a
AP window
PAB with SLL transposition^b
LVOT repair or enlargement
Isolated tricuspid valvuloplasty
Isolated BDG^d
Aortic or truncal valvuloplasty
Senning/Mustard for D-TGA
TOF repair - nontransannular patch

Category 3

Ascending aortic graft
Tricuspid valvuloplasty + RVOT procedure
Conduit reoperation
TOF repair - absent pulmonary valve^b
Aortic or truncal valve replacement
Isolated Fontan^d

Category 3

Coarctation repair, subclavian flap or patch
Subvalvar AS repair + myectomy for IHSS
Complete AVC repair, Trisomy 21^c
Unifocalization without bypass
Pulmonary valvotomy
Konno procedure
ALCAPA repair
Tricuspid valvuloplasty + non-RVOT procedure
Isolated arch repair on CPB
Supravalvular AS repair
Double switch for L-TGA/IVS
Mitral or AVV valvuloplasty, no aortic valve repair^d
BDG + additional procedure, non-AVV repair^d

Category 4

Fontan + additional procedure, non-AVV repair
TOF repair - transannular patch^b
VSD + pulmonary artery band removal
Aortic root replacement
Isolated atrial septectomy
DORV intraventricular tunnel repair
Ebstein's repair
TAPVC repair, ≥ 1 week^a
Reimplantation/isolated pulmonary artery
Complete AVC + TOF repair, Trisomy 21^c
Multiple VSD primary closures
Tricuspid Valvuloplasty + RV-PA conduit change
ASO for D-TGA/IVS
Mitral or AVV replacement, ≥ 5 year^a
DORV + RVOT repair
Double switch for L-TGA/VSD
Comprehensive Stage 2
BDG + AVV repair^d
TOF repair + RV-PA conduit + MAPCA^d
Mitral or AVV valvuloplasty + aortic valve repair^d
Fontan revision

Category 5

VSD repair + ASD repair + coarctation repair
Palliative repair for TOF/PA/MAPCA
Fontan + AVV repair^d
Modified Blalock-Taussig Shunt (MBTS)
Ross procedure
Complete AVC repair, no Trisomy 21^c
Tricuspid valve replacement
Repair TOF/PA with RV-PA conduit^d
ASO + VSD repair
Williams syndrome repair
Ross-Konno procedure
PAB, no SLL transposition^b
Damus-Kaye-Stansel procedure
Left ventricle rehab
ASO + VSD repair + coarctation repair
Rastelli/Senning for L-TGA/VSD
Nikaidoh procedure for TGA/VSD/PS
Truncus arteriosus repair
Biventricular repair
Unifocalization with BTS on CPB
TAPVC repair, < 1 week^a
Tricuspid valvuloplasty, with single ventricle
Pulmonary venous stenosis repair
DCRV repair + systemic shunt + PDA closure

Category 6

Complete AVC repair + TOF repair, no Trisomy 21^c
Mitral or AVV replacement, < 5 year^a
Norwood procedure
Truncus arteriosus repair + IAA repair
Hybrid PAB^b
Norwood procedure, MS/AA^b
ASO for D-TGA/VSD and PAB takedown
Heart transplant, ≥ 1 year^a

Category 7

Double lung transplant
Heart transplant, < 1 year^a
HLHS biventricular repair
VAD

Fig 1. One hundred three procedure types surgically grouped into associated surgical charge categories. ^aStratified by age. ^bStratified by diagnosis. ^cStratified by genetic syndrome. ^dStratified by secondary procedure. (AA $\frac{1}{2}$ aortic atresia; ALCAPA $\frac{1}{2}$ anomalous left coronary artery from the pulmonary artery; AP $\frac{1}{2}$ aortopulmonary; AS aortic stenosis; ASD $\frac{1}{2}$ atrial septal defect; ASO $\frac{1}{2}$ arterial switch operation; AVC $\frac{1}{2}$ atrioventricular canal; AVV $\frac{1}{2}$ atrioventricular valve; BDG $\frac{1}{2}$ bidirectional Glenn; BTS $\frac{1}{2}$ Blalock-Taussig shunt; CPB $\frac{1}{2}$ cardiopulmonary bypass; DCRV $\frac{1}{2}$ double-chambered right ventricle; DORV $\frac{1}{2}$ double-outlet right ventricle; D-TGA $\frac{1}{2}$ dextro transposition of the great arteries; HLHS $\frac{1}{2}$ hypoplastic left heart syndrome; IAA $\frac{1}{2}$ interrupted aortic arch; IHSS $\frac{1}{2}$ idiopathic hypertrophic subaortic stenosis; IVS $\frac{1}{2}$ intact ventricular septum; L-TGA $\frac{1}{2}$ levo transposition of the great arteries; LVOT $\frac{1}{2}$ left ventricular outflow tract; MAPCA $\frac{1}{2}$ major aortopulmonary collateral artery; MS $\frac{1}{2}$ mitral stenosis; PA $\frac{1}{2}$ pulmonary atresia; PAB $\frac{1}{2}$ pulmonary artery band; PDA $\frac{1}{2}$ patent ductus arteriosus; PFO $\frac{1}{2}$ patent foramen ovale; PS $\frac{1}{2}$ pulmonary stenosis; RV $\frac{1}{2}$ right ventricle; RVOT $\frac{1}{2}$ right ventricular outflow tract; RV-PA $\frac{1}{2}$ right ventricle to pulmonary artery; TAPVC $\frac{1}{2}$ total anomalous pulmonary venous connection; TOF $\frac{1}{2}$ tetralogy of Fallot; VAD $\frac{1}{2}$ ventricular assist device; VSD $\frac{1}{2}$ ventricular septal defect.)

abnormalities or nontrisomy 21 genetic syndromes. Although the majority of a priori characteristics were statistically significant ($p < 0.01$), none individually explained the variability in charges. As important interactions existed among ventilator status before surgery, admission status, and age category, a preoperative status variable accounting for these variables was created maximizing the coefficient of determination ($R^2 \frac{1}{2}$ 38.9%).

Certain postadmission factors had a highly significant effect on charges. For patients who required an additional OR visit for cardiac surgery ($n \frac{1}{2}$ 204), geometric mean charge was more than five times higher. If ECMO was used during the EOC ($n \frac{1}{2}$ 81), the 75th percentile for total hospital charges in this group exceeded \$1 million. The post-admission factors, ECMO utilization during the EOC ($R^2 \frac{1}{2}$ 20.6%) and number of visits to the OR ($R^2 \frac{1}{2}$ 35.3%), also did not individually explain the variability in outcome charge.

Surgical Procedure Types

Several surgical procedure types demonstrated increased discrimination when stratified by modifying factors such as secondary procedures, diagnosis, genetic syndrome, or patient age. Procedure types that led to increased discrimination, such as total anomalous pulmonary venous connection repair at less than 1 week versus greater than 1 week of age, were stratified, leading to the final 103 surgical procedure types summarized in Figure 1.

Surgical Charge Categories

The multidisciplinary panel looked for an optimal number of surgical procedure categories with face validity, resulting in the final SCC grouper variable containing seven categories. Any surgical procedure type near the

threshold of a category or with limited empiric data was grouped according to expert consensus. The distribution of cases by SCC is summarized in Table 2 and Figure 2, with the largest proportion of cases assigned to SCC 2 (33%). The univariate linear regression model of SCC demonstrated a moderately strong explanatory value ($R^2 \approx 47.3\%$) of outcome charge (Table 2).

All Patient Refined Diagnosis Related Groups Correlation With Surgical Charge Categories

An APR-DRG value was linked to 2,101 cases in the derivation cohort. Surgical charge categories correlated well with APR-DRG SOI and case mix index (Figs 3, 4). Mean SOI increased with SCC except for a deviation between SCC 6 (3.8) and SCC 7 (3.7), possibly owing to the small number of cases in SCC 7. In the lower SCCs, a higher percentage of cases were categorized into SOI subclass 1 (minor) or 2 (moderate), whereas a higher percentage of cases in SCCs 4 through 7 were categorized into SOI subclass 3 (major) or 4 (extreme). Geometric mean case mix index increased between SCC 1 (3.6) and SCC 7 (32.2).

Multivariable Model

A multivariable linear regression model was built for outcome charge starting with SCC (Table 3). Explanatory value increased with addition of the created patient preoperative status ($R^2 \approx 59.4\%$). Additional a priori patient factors including weight at surgery, noncardiac abnormality, and nontrisomy 21 genetic syndrome further improved predictive performance of the model ($R^2 \approx 61.5\%$). When the panel examined postadmission factors by SCC (Table 4), the incidence of ECMO utilization differed significantly from SCC 1 (0%) to SCC 7 (27%). Similarly, the incidence of more than one visit to the OR during an EOC varied from SCC 1 (3%) to SCC 7 (55%). When added to the model, ECMO utilization and more than one OR visit during the EOC further increased explanatory value ($R^2 \approx 74.3\%$).

Contemporary Validation Cohort

In fiscal years 2010 to 2012, 2,595 CHS hospital admissions were analyzed. When applied to the validation set, the univariate predictors remained applicable and geometric

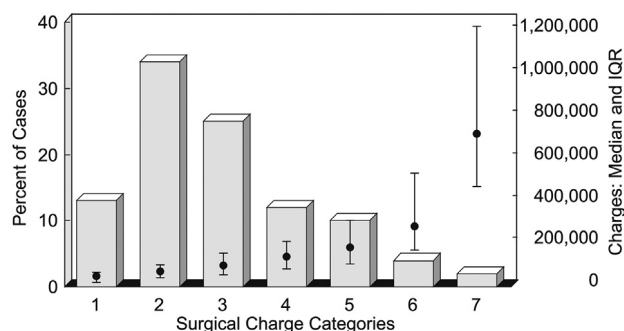


Fig 2. The distribution of cases types by surgical charge categories is represented by the columns, and the calculated median and inter-quartile range charge for each surgical charge category is represented by the scatter plot.

mean charge increased significantly by SCC ($p < 0.01$). The univariate linear regression model yielded an R^2 of 40% (Table 3). A multivariable linear regression model was built starting with SCC. The predictive performance of the outcome charge further improved when the same a priori characteristics were added ($R^2 \approx 58.1\%$) and then both ECMO utilization and more than one OR visit during the EOC ($R^2 \approx 67.7\%$).

Comment

The results of this study demonstrate it is feasible to develop a procedure-based financial grouper and multivariable model accounting for variation in CHS charges and that inclusion of additional nonprocedural clinical variables significantly increased the predictive power. Similar to other risk-adjustment models, this model can be used to compare resource utilization and charges of patients admitted for CHS [10–12]. The defined surgical procedure types and a priori patient characteristics added to the multivariable model can be used before admission to prospectively predict resource utilization, patient risk, and potential patient outliers at risk for higher resource utilization. The composite preoperative status variable that was created is a useful predictor of resource utilization and demonstrates the potential benefits of integrating expert clinical consensus with empiric resource

Table 2. Surgical Charge Category Distribution of Derivation Cohort

Surgical Charge Category	n (%)	Geometric Mean (\$)	IQR		p Value	R^2
			25th	75th		
1	265 (13)	49,813	40,764	57,254	<0.001	47.3%
2	701 (33)	80,160	60,770	90,408		
3	532 (25)	119,838	78,864	149,023		
4	257 (12)	158,642	105,368	200,410		
5	195 (9)	207,632	123,269	296,284		
6	109 (5)	324,233	183,918	438,006		
7	44 (2)	768,942	506,590	1,213,196		

IQR $\approx$ interquartile range.

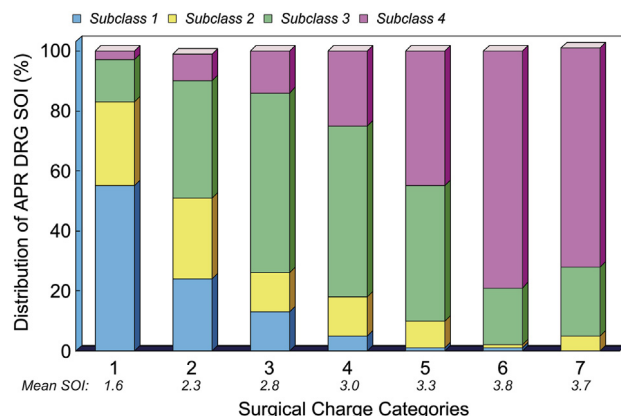


Fig 3. The distribution of surgical cases linked to an associated all patient refined diagnosis related groups (APR-DRG) value were matched to their associated severity of illness (SOI) subclass and summarized by surgical charge categories. Mean severity of illness was calculated by surgical charge category. Subclass 1 is designated by light blue; subclass 2 by yellow; subclass 3 by green; and subclass 4 by purple.

utilization data. In an exploratory analysis, two post-admission factors, ECMO utilization and more than one OR visit for a cardiac surgery during the EOC, were more prevalent in the higher SCCs, indicating that reducing multiple operative events during an EOC may improve outcomes and reduce resource utilization (charges). In reimbursement negotiations, “weighted” insurance or patient outlier protection should be considered to account for the increased financial risk associated with higher SCCs secondary to ECMO utilization and additional OR visits for cardiac surgery during an EOC.

As our methodology prospectively designates surgical procedure types according to CPT codes and considers a priori characteristics to reflect the patient’s health status on admission, it may represent a more accurate tool than the APR-DRG diagnostic classification system in measuring and predicting resource utilization before

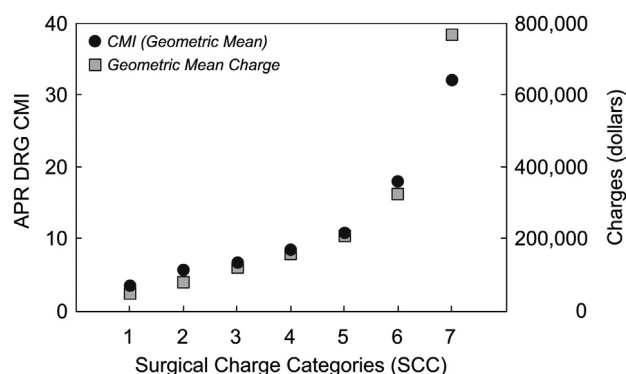


Fig 4. The distribution of surgical cases linked to an associated all patient refined diagnosis related groups (APR-DRG) value were matched to their associated case mix index (CMI; solid circles) subclass and summarized by surgical charge categories. Geometric mean charge (shaded squares) was calculated by surgical charge category.

admission as well as in calculating reimbursement for CHS. The APR-DRG diagnostic classification system is based on hospital discharge data and therefore cannot serve as a prospective predictor of resource utilization. Recent studies have found that certain patient populations admitted for a CHS were misclassified into noncardiac APR-DRG and that International Classification of Disease, 9th revision, Clinical Modification coding may result in differential case ascertainment [13, 14].

The variation in resource utilization that is attributable to a priori patient characteristics among patients undergoing procedures described by a single CPT code also has implications for physician reimbursement. The majority of payors base physician payments on the Medicare RBRVS system, which assigns relative value units to CPT codes to account for physician work, practice expense, and malpractice expense [8, 15, 16]. Relative value units assigned to CHS procedures have previously been shown to correlate reasonably with physician work and resource consumption [17]. More recently the applicability of relative value units in pediatrics, surgery, and cardiac catheterization has been questioned [8, 9, 18, 19]. Similar to the RBRVS system, the developed surgical procedure types were designated according to CPT codes; however, our group stratified the developed surgical procedure types by modifying factors. This revealed important differences in resource utilization that the RBRVS system does not measure and points out the potential pitfall in assigning relative value units based only on procedural service without considering other clinical factors. Assuming that patients undergoing the same procedure will be normally distributed on a statistical basis and thus form a bell-shaped curve is not reflected in our data (Fig 2), particularly in certain complex patient groups. Similar findings have been noted in adult cardiac surgery [20].

Our methodology may provide a generalizable tool for linking multiinstitutional clinical and administrative databases in comparative analysis of charges and resource utilization at a single point in time, longitudinally, and across institutions. The STS-CHSD collects indirect identifiers, enabling linkage with databases such as the Pediatric Health Information Systems administrative database [21]. Clinical data from the STS-CHSD can be used to designate procedures into our surgical procedure types and corresponding SCCs by developing cross-bridges between STS-CHSD codes and CPT codes. Methods exist to then link cases in the STS-CHSD with those in the Pediatric Health Information Systems database to summarize charges for mutually exclusive surgical procedure types [21]. The recent linkage of the STS adult cardiac database to the Centers for Medicare and Medicaid Services Medicare database has allowed assessment of longitudinal resource utilization, but there is no comparable all-payor database for non-Medicare patients [22]. If such data could be acquired, prospective data collection and linkage to SCCs could be used to follow financial trends within the CHS population.

As this analysis is based on databases and case mix from a single institution, further evaluation at other sites is required to validate our methodology. Our outcome

Table 3. Final Multivariable Log Model of Derivation and Contemporary Cohort

Variable	2007–2009 n (%)	R ² (%)	2010–2012 n (%)	R ² (%)
Surgical charge category		47.3		40.0
1	265 (13)		342 (13)	
2	701 (33)		929 (36)	
3	532 (25)		723 (28)	
4	257 (12)		222 (9)	
5	195 (9)		206 (8)	
6	109 (5)		107 (4)	
7	44 (2)		66 (3)	
Preoperative status consisting of age, ventilator status, and admission status		59.4		56.9
< 30 days and ventilator	190 (9)		73 (3)	
30 days to < 1 year and ventilator	83 (4)		45 (2)	
□ 1 year and ventilator	31 (1)		15 (1)	
< 30 days and no ventilator	204 (10)		335 (13)	
□ 30 days, no ventilator, and inpatient	296 (14)		324 (12)	
□ 30 days, no ventilator, and not inpatient	1,301 (62)		1,803 (69)	
Noncardiac abnormality		60.5		57.0
Yes	262 (12)		352 (14)	
No	1,843 (88)		2,243 (86)	
Weight at surgery (kg)		61.1		57.5
< 3	152 (7)		180 (7)	
3–9.9	1,002 (48)		1,067 (41)	
□ 10	950 (45)		1,346 (52)	
Genetic syndrome other than trisomy 21		61.5		58.1
Yes	151 (7)		363 (14)	
No	1,954 (93)		2,232 (86)	
Adding in ECMO utilization		66.5		60.2
Adding in > 1 OR visit during admission		72.3		67.3
Adding in both		74.3		67.7

ECMO = extracorporeal membrane oxygenation; OR = operating room.

variable, total hospital charges, is known to vary by region, but this can be adjusted by using the Centers for Medicare and Medicaid Services regional price and wage index [7, 23]. Our group may not have taken into consideration other clinically relevant patient and procedural characteristics and postadmission factors that further explain the variability in charge or could have been used to further stratify the surgical procedure types. Like the RBRVS system, the developed surgical

procedure types were designated according to CPT codes and therefore may contain similar limitations. However, this limitation is mitigated in our methodology through the development of surgical procedure types stratified by modifying factors and the addition of a priori characteristics to the multivariable model.

Using a multidisciplinary panel, we have developed and validated a surgical procedure financial grouper, SCC, and an associated multivariable model to predict resource

Table 4. Incidence of Extracorporeal Membrane Oxygenation and Greater Than One Operating Room Visit During Episode of Care of Derivation Cohort

Surgical Charge Category	Cases (n)	ECMO (n)	ECMO/100 EOC	> 1 OR Visit (n)	> 1 OR Visit/100 EOC
1	265	0	0	8	3
2	701	1	0	24	3
3	532	12	2	42	8
4	257	12	5	34	13
5	195	15	8	38	20
6	109	29	27	34	31
7	44	12	27	24	55

ECMO = extracorporeal membrane oxygenation; EOC = episode of care; OR = operating room.

utilization in congenital heart surgery at a single institution. Given the components of this model, we believe it is likely that with additional study this tool could be used to inform institutions, payors, and patients for appropriate budgeting and resource planning. This model may also be useful in developing and setting reference values for payors and patients in prospective global payment proposals for CHS admissions. In addition, our group identified that patients placed on ECMO or requiring additional OR visits for a cardiac surgery during an EOC had significant increases in resource utilization, which could provide a basis for developing “outlier” prediction and financial protection. Surgical charge categories and our multivariable model can lead to improved understanding of patients at risk for high resource utilization in CHS and could be an important tool for the next generation of institutional reimbursement.

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