Development of a Charge Adjustment Model for Cardiac Catheterization

Andrew Brennan · Kimberlee Gauvreau · Jean Connor · Cheryl O’Connell · Sthuthi David · Melvin Almodovar · James DiNardo · Puja Banka · John E. Mayer Jr. · Audrey C. Marshall · Lisa Bergersen

Received: 1 May 2014 / Accepted: 23 July 2014 / Published online: 12 August 2014 © The Author(s) 2014. This article is published with open access at Springerlink.com

Abstract A methodology that would allow for comparison of charges across institutions has not been developed for catheterization in congenital heart disease. A single institution catheterization database with prospectively collected case characteristics was linked to hospital charges related and limited to an episode of care in the catheterization laboratory for fiscal years 2008–2010. Catheterization charge categories (CCC) were developed to group types of catheterization procedures using a combination of empiric data and expert consensus. A multivariable model with outcome charges was created using CCC and additional patient and procedural characteristics. In 3 fiscal years, 3,839 cases were available for analysis. Forty catheterization procedure types were categorized into 7 CCC yielding a grouper variable with an $R^2$ explanatory value of 72.6 %. In the final CCC, the largest proportion of cases was in CCC 2 (34 %), which included diagnostic cases without intervention. Biopsy cases were isolated in CCC 1 (12 %), and percutaneous pulmonary valve placement alone made up CCC 7 (2 %). The final model included CCC, number of interventions, and cardiac diagnosis ($R^2 = 74.2 %$). Additionally, current financial metrics such as APR-DRG severity of illness and case mix index demonstrated a lack of correlation with CCC. We have developed a catheterization procedure type financial grouper that accounts for the diverse case population encountered in catheterization for congenital heart disease. CCC and our multivariable model could be used to understand financial characteristics of a population at a single point in time, longitudinally, and to compare populations.

Keywords Resource utilization · RVU · Congenital heart disease · Catheterization · Outcomes

Introduction

Congenital heart disease (CHD) accounts for a substantial amount of health care spending in the USA, with acute care expenditures estimated to be 6 billion dollars annually [11, 13, 14]. This large amount of healthcare expenditures is the result of the variable anatomical and physiological anomalies seen in these patients, the requirement for multiple hospitalizations for surgical and interventional therapies, and lifelong follow-up with multidisciplinary medical professionals [11]. Marelli et al. [8] in a study of the population in Quebec over the past several decades showed that mortality rates have decreased for patients with CHD. As CHD patients’ life expectancy increases so does the prevalence of CHD in the general population, leading to a greater need to understand the financial characteristics of this diverse population so that potential areas to reduce and standardize charges are identified.

We hypothesized that examining charges derived from Current Procedural Terminology (CPT) billing codes of catheterization procedures would provide a more accurate assessment of patient resource utilization than widely used current financial metrics such as the All Patient Refined Diagnosis Related Groups (APR-DRG) diagnostic classification system, severity of illness (SOI), and case mix index (CMI). Recent analysis has shown that the APR-DRG system inaccurately classifies patients admitted for congenital
heart surgery, which may have an impact on the accuracy of outcome reporting and resource allocation planning [10]. We sought to create a procedure type financial grouper as well as consider other clinical or procedural characteristics known a priori to predict resource utilization using charges in CHD populations undergoing cardiac catheterization. Total procedure-related values based on CPT codes were chosen as the outcome for resource utilization to provide generalizability to other institutions as procedures are generally billed based on CPT codes.

Methods

The study methods were reviewed and approved by the Institutional Review Board at Children’s Hospital Boston.

Database Source

Our catheterization laboratory reporting and billing database include patient and procedural characteristics on all procedures performed at Children’s Hospital Boston. Hospital charges were matched to all catheterization cases in the clinical database. As total hospital charges for the majority of catheterization cases may reflect other aspects of care unrelated to the catheterization procedure, such as elective and surgical interventions during the same hospitalization, the outcome charges chosen by the group were total procedure-related values from the catheterization laboratory, comprising of procedure codes (CPT with associated charge), supplies, and recovery-related expenses. Recovery-related expenses were expenses accumulated during the patient’s recovery and observation time in the catheterization laboratory department and excluded any other aspects of in-hospital care, such as recovery time as an inpatient in the Intensive Care Unit or general floor. Cases were linked to an APR-DRG Version 20.0 value based on International Classification of Diseases, 9th revision, Clinical Modification (ICD-9-CM) procedure and diagnosis codes assigned in the reporting and billing database.

Population

All cases classified as diagnostic, interventional, or biopsy only were identified in the catheterization database and included. Few common case types such as hybrids or cases recorded as pericardiocentesis, pleuracentesis, or fluoroscopy only were excluded. The fiscal years 2008, 2009, and 2010 comprised the cohort. In the data set, 3,978 cases met inclusion criteria of which 3,940 cases were matched in the hospital database and of these 3,883 had an associated charge recorded. Outliers with total charges less than $10,000 and greater than $100,000 were examined in detail. Based on this review, we excluded 16 cases with incomplete billing and a total charge less than $5,000 ($N = 3,867) and excluded 28 with no procedure charge for a final cohort of 3,839 cases.

Predictor Variables

We considered both patient and procedural characteristics as potential predictor variables of the outcome charges. Patient characteristics included the following: age, weight, diagnosis, genetic syndrome, non-cardiac problem, previous catheterization, previous catheterization within 30 days, previous surgery, previous surgery within 30 days, admit source, mechanical circulatory support including ECMO, continuous supportive intravenous (IV) medications including vasoactive medications and inotropes, intubation status, known vascular occlusion, and indicators of hemodynamic vulnerability. Procedural characteristics included the following: year of procedure, case type (diagnostic, interventional, or biopsy only), intervention type (balloon angioplasty, valvotomy, stent placement, stent redilation, device implant, or coil implant), number of interventions, and procedure type risk category as designated by Catheterization for Congenital Heart Disease Adjustment for Risk Method (CHARM) [2].

Development of Procedure Types and Catheterization Charge Categories (CCC)

Since cardiac catheterization for CHD includes a wide variety of case types, a multidisciplinary panel comprising of the authors was established to develop procedure types \(n = 35\) with empiric analysis followed by expert consensus to group case types into categories with similar charges. Charges were summarized by mutually exclusive catheterization procedure types. To identify procedure types with potential modifying factors, procedure types were ranked from high to low distribution of charges within the procedure type designation. The procedure types were grouped into different combination of numbers of categories according to empiric similarity in order to minimize the variation within a group while maximizing discrimination between groups.

Statistical Methods and Development of the Multivariable Model

Patient and procedural characteristics were summarized by median and interquartile range charges. The coefficient of determination \(R^2\) was calculated by univariate and multivariable linear regression models for the outcome charges. A multivariable model was built using stepwise forward regression for the outcome charges to normalize
Table 1  Summary of charges for catheterization by patient characteristics

| Age                      | N (%) | Median ($) | Percentiles | P value | R² |
|--------------------------|-------|------------|-------------|---------|----|
|                          |       |            | 25th        | 75th    |    |
| <1 month                 | 227 (6)| 26,843     | 17,136      | 33,839  | <0.001 | 0.029 |
| ≥1 month, <1 year        | 659 (17)| 32,351    | 20,538      | 44,909  |        |    |
| ≥1 year, <5 years        | 913 (24)| 33,540    | 19,617      | 45,392  |        |    |
| ≥5 years, <18 years      | 1,340 (35)| 22,846   | 15,782      | 37,942  |        |    |
| ≥18 years                | 700 (18)| 23,246     | 16,692      | 37,727  |        |    |
| Weight (kg)              |       |            |             |         |    |
| <4                       | 321 (8)| 28,759     | 17,646      | 35,660  | <0.001 | 0.034 |
| 4–9                      | 830 (22)| 32,868    | 20,350      | 45,038  |        |    |
| 10–19                    | 815 (21)| 33,787    | 19,818      | 45,769  |        |    |
| ≥20                      | 1,872 (49)| 22,636   | 15,834      | 37,134  |        |    |
| Diagnosisa               |       |            |             |         |    |
| No structural defects    | 150 (4)| 16,676     | 11,949      | 23,039  | <0.001 | 0.298 |
| Heart transplant         | 743 (19)| 15,126    | 13,335      | 20,632  |        |    |
| Isolated defects         | 635 (17)| 31,337    | 21,636      | 36,807  |        |    |
| Pulmonary hypertension   | 107 (3)| 16,784     | 10,086      | 21,724  |        |    |
| Complex two ventricle    | 1,491 (39)| 34,235   | 21,006      | 48,927  |        |    |
| Single ventricle         | 711 (19)| 37,014    | 24,004      | 50,281  |        |    |
| Genetic syndromeb        |       |            |             |         |    |
| Yes                      | 502 (13)| 30,046    | 18,516      | 43,876  | 0.02   | 0.001 |
| No                       | 3,330 (87)| 27,896   | 17,621      | 41,025  |        |    |
| Non-cardiac problemc     |       |            |             |         |    |
| Yes                      | 1,372 (36)| 25,696   | 17,448      | 40,602  | 0.03   | 0.002 |
| No                       | 2,454 (64)| 29,195   | 18,018      | 41,577  |        |    |
| Previous catheterization |       |            |             |         |    |
| Yes                      | 2,058 (54)| 35,819   | 21,406      | 50,322  | <0.001 | 0.151 |
| No                       | 1,781 (46)| 20,605   | 15,069      | 31,832  |        |    |
| Previous catheterization within 30 days |       |            |             |         |    |
| Yes                      | 207 (5) | 34,474     | 21,785      | 54,199  | <0.001 | 0.008 |
| No                       | 3,632 (95)| 27,573   | 17,676      | 40,899  |        |    |
| Previous surgery         |       |            |             |         |    |
| Yes                      | 2,064 (54)| 35,099   | 21,340      | 48,898  | <0.001 | 0.143 |
| No                       | 1,775 (46)| 20,549   | 14,854      | 32,239  |        |    |
| Previous surgery within 30 days |       |            |             |         |    |
| Yes                      | 229 (6) | 29,451     | 18,708      | 43,172  | 0.11   | 0.001 |
| No                       | 3,610 (94)| 27,955   | 17,757      | 41,173  |        |    |
| Admit source             |       |            |             |         |    |
| Elective                 | 3,038 (79)| 28,269   | 18,037      | 41,754  | 0.04   | 0.002 |
| Non elective             | 801 (21)| 28,046     | 17,103      | 40,068  |        |    |
| Mechanical circulatory supportd |       |            |             |         |    |
| Yes                      | 88 (2)  | 28,323     | 17,408      | 39,615  | 0.98   | 0.000 |
| No                       | 3,724 (97)| 28,266   | 17,850      | 41,305  |        |    |
| Continuous supportive IV medicationsd |       |            |             |         |    |
| Yes                      | 421 (11)| 29,451     | 18,142      | 41,446  | 0.15   | 0.001 |
| No                       | 3,392 (88)| 27,896   | 17,731      | 41,213  |        |    |
| Intubation statusd       |       |            |             |         |    |
| Spontaneous              | 1,393 (36)| 20,216   | 15,094      | 32,173  | <0.001 | 0.101 |
for skewed distributions. Starting with CCC, all of the patient and procedural characteristics were considered for inclusion in the multivariable model until no additional explanatory value could be found by adding a variable to the model. The proportion of cases in each of the 4 sub-classes of APR-DRG SOI was summarized by CCC, and the weighted mean SOI was calculated by CCC. Geometric mean APR-DRG CMI was calculated by CCC.

**Results**

**Patient Characteristics**

Charges were summarized according to patient characteristics based on the final cohort of 3,839 cases in Table 1. The majority of the patients was between the ages of 1–18 (82 %) and had a diagnosis of complex CHD with two ventricles (39 %) or single ventricle physiology (19 %). For most cases, the patient had a previous catheterization (54 %) or a previous surgery (54 %). In univariate analysis although diagnosis alone explained some variation in charge ($R^2 = 27.2 \%$), we noted that, as a population, the majority of patient characteristics that anecdotal experience suggests may be important in determining the intensity of resources needed to perform a case, such as age ($R^2 = 2.9 \%$), admit source ($R^2 = 0.2 \%$), intubation status ($R^2 = 10.1 \%$), continuous supportive IV medications ($R^2 = 0.1 \%$), and indicators of hemodynamic vulnerability ($R^2 = 2.4 \%$), did not individually explain the variability in charges despite having a significant association with charge ($P < 0.01$).

**Procedure Types**

For some procedure types, such as pulmonary artery angioplasty, discrimination improved when stratified by the number of interventions, while for other procedure types, such as pulmonary valve dilation, the number of interventions had less effect. Procedure types that led to improved discrimination were stratified into the number of interventions, leading to the final 40 procedure types based on expert clinical consensus and empiric analysis summarized in Table 3.

**Catheterization Charge Categories**

With the procedure types defined, the multidisciplinary panel looked for a categorization number that had face validity, with the final CCC containing 7 categories as summarized in Table 3. Although similar in charges to diagnostic cases, biopsy cases were forced as a separate group in the CCC for better potential future generalizability of the final model when applying to institutions that perform diagnostic, but few if any biopsy cases.

Table 1 continued

|                     | N (%) | Median ($) | Percentiles 25th | Percentiles 75th | P value | $R^2$ |
|---------------------|-------|------------|------------------|------------------|---------|-------|
|                     |       |            |                  |                  |         |       |
| Prior to transfer   | 507 (13) | 31,079 | 18,794 | 43,262 | 0.002 | 0.003 |
| Before case         | 1,886 (49) | 33,565 | 20,476 | 47,682 |         |       |
| During case         | 40 (1) | 37,359 | 18,727 | 53,733 |         |       |
| Known vascular occlusion | Yes | 507 (13) | 30,548 | 18,660 | 48,133 | <0.001 | 0.024 |
|                     | No    | 3,332 (87) | 27,914 | 17,716 | 40,716 |         |       |
| Indicators of hemodynamic vulnerability | 0 | 2,055 (54) | 23,416 | 16,050 | 36,775 |         |       |
|                     | 1     | 1,018 (27) | 31,416 | 19,123 | 45,050 |         |       |
|                     | ≥2    | 766 (20) | 32,376 | 19,274 | 47,319 |         |       |

*Not entered N = 2; †Not entered N = 7; ‡Not entered N = 13; §Not entered N = 27; ‡Not entered N = 26; †Not entered N = 13
Percutaneous pulmonary valve placement was forced into a separate category for similar reasons. Additionally, the total procedure-related charges for percutaneous pulmonary valve placement, for which a high percentage is associated with the cost of the valve device, were significantly higher than those associated with any other procedure type.

The distribution of cases by CCC and the median and interquartile range of associated charges by CCC are shown in Fig. 1. The largest proportion of cases were ranked in CCC 2 (34%), containing mostly diagnostic cases without intervention. A summary of univariate comparison of catheterization charges by CCC is detailed in Table 4, with a statistically significant \( p \) value for all categories \((P < 0.01)\). The univariate linear regression model for the outcome charges demonstrated a moderately strong relationship \( R^2 = 72.6\% \) between variability in charges by CCC.

| Table 2 | Summary of charges for catheterization by procedural characteristics |
|---------|------------------|-------------------|------------------|------------------|
|         | N (%) | Median ($) | Percentiles | P value | R² |
|         |        |            | 25th | 75th |            |        |
| **Year of procedure** | | | | | |
| 2008 | 1,238 (32) | 25,952 | 16,584 | 38,219 | <0.001 | 0.007 |
| 2009 | 1,363 (36) | 28,854 | 18,454 | 42,839 | |
| 2010 | 1,238 (32) | 30,001 | 18,211 | 41,734 | |
| **Case type** | | | | | |
| Diagnostic | 915 (24) | 18,180 | 16,021 | 20,281 | <0.001 | 0.544 |
| Intervventional | 2,196 (57) | 38,084 | 31,264 | 51,303 | |
| Biopsy | 728 (19) | 15,059 | 13,253 | 20,468 | |
| **Balloon angioplasty** | | | | | |
| Yes | 1,021 (27) | 43,895 | 33,830 | 57,876 | <0.001 | 0.255 |
| No | 2,818 (73) | 21,086 | 15,899 | 33,844 | |
| **Valvotomy** | | | | | |
| Yes | 242 (6) | 34,947 | 31,457 | 40,980 | <0.001 | 0.017 |
| No | 3,597 (94) | 25,822 | 17,394 | 41,270 | |
| **Stent placement** | | | | | |
| Yes | 497 (13) | 47,745 | 37,988 | 62,663 | <0.001 | 0.154 |
| No | 3,342 (87) | 23,396 | 16,868 | 36,682 | |
| **Stent redilation** | | | | | |
| Yes | 262 (7) | 45,456 | 34,109 | 61,780 | <0.001 | 0.061 |
| No | 3,577 (93) | 25,698 | 17,353 | 39,725 | |
| **Device implant** | | | | | |
| Yes | 348 (9) | 35,161 | 30,542 | 48,147 | <0.001 | 0.028 |
| No | 3,491 (91) | 25,545 | 17,183 | 40,731 | |
| **Coil implant** | | | | | |
| Yes | 445 (12) | 47,199 | 37,130 | 61,359 | <0.001 | 0.120 |
| No | 3,394 (88) | 23,801 | 16,972 | 37,446 | |
| **Number of interventions** | | | | | |
| None | 937 (24) | 18,206 | 15,984 | 20,315 | <0.001 | 0.498 |
| 1 | 1,730 (45) | 24,309 | 15,374 | 33,611 | |
| 2 | 493 (13) | 40,980 | 34,491 | 48,976 | |
| 3 | 283 (7) | 49,344 | 41,211 | 61,501 | |
| 4 | 184 (5) | 55,190 | 47,080 | 67,397 | |
| ≥5 | 212 (6) | 61,731 | 49,073 | 72,145 | |
| **Procedure type risk category** | | | | | |
| 1 | 1,403 (36) | 16,764 | 13,785 | 20,419 | <0.001 | 0.490 |
| 2 | 930 (24) | 31,418 | 22,369 | 36,875 | |
| 3 | 883 (23) | 39,251 | 30,848 | 53,035 | |
| 4 | 594 (16) | 45,409 | 36,280 | 59,944 | |

*N = 29*
| Category 1                           | N   | Median ($) | Percentiles  |
|-------------------------------------|-----|------------|--------------|
| Heart biopsy after transplant       | 451 | 13,880     | 12,744       |
| Heart biopsy and diagnostic catheterization | 990 | 18,243     | 15,909       |
| Heart biopsy and coronary angiography | 263 | 20,860     | 16,800       |
| Diagnostic catheterization including transseptal puncture | 43  | 23,018     | 19,744       |
| Category 2                          |     |            |              |
| PDA device or coil closure           | 86  | 27,123     | 21,457       |
| Atrial septum stent, dilation, or septostomy | 62  | 28,961     | 22,155       |
| PDA stent                           | 4   | 28,439     | 27,304       |
| Aorta dilation and/or stent (one intervention) | 69  | 29,121     | 26,482       |
| Aorta stent redilation              | 32  | 29,515     | 27,829       |
| Pulmonary valvotomy (isolated intervention) | 95  | 31,982     | 29,421       |
| RVOT dilation and/or stent (no PA angioplasty or stent) (one intervention) | 58  | 32,829     | 30,110       |
| Proximal or distal right or left PA angioplasty and/or stent (excluding RVOT intervention) (one intervention) | 116 | 32,868     | 29,380       |
| Category 3                          |     |            |              |
| Systemic vein dilation or stent     | 72  | 33,007     | 25,069       |
| ASD or PFO closure (isolated intervention) | 164 | 33,696     | 30,790       |
| Aortic valvotomy (isolated intervention) | 79  | 35,453     | 32,849       |
| Coil/device systemic collateral (one intervention) | 62  | 35,864     | 32,512       |
| Systemic pulmonary shunt dilation or stent | 16  | 37,746     | 28,365       |
| Fenestration device closure (isolated intervention) | 21  | 36,197     | 34,296       |
| Coronary fistula closure            | 6   | 38,282     | 35,819       |
| Systemic artery angioplasty and/or stent (not aorta) | 22  | 40,210     | 27,898       |
| RVOT dilation and/or stent and proximal or distal right or left PA angioplasty and/or stent (two interventions) | 34  | 37,936     | 35,168       |
| Fontan baffle dilation              | 21  | 36,643     | 32,903       |
| Category 4                          |     |            |              |
| RVOT dilation and/or stent (no PA angioplasty or stent) (plus at least one additional intervention) | 37  | 43,702     | 34,967       |
| Any pulmonary vein dilation and/or stent intervention | 105 | 41,032     | 35,017       |
| Aortic valvotomy (plus at least one additional intervention) | 7   | 41,350     | 29,957       |
| RVOT dilation and/or stent and proximal or distal right or left PA angioplasty and/or stent (excluding RVOT intervention) (two interventions) | 124 | 41,870     | 36,338       |
| Aorta dilation and/or stent (plus at least one additional intervention) | 53  | 42,822     | 37,652       |
| Systemic collateral coil or device closure (plus at least one additional intervention) | 122 | 42,859     | 37,130       |
| Pulmonary valvotomy (plus at least one additional intervention) | 7   | 46,151     | 39,433       |
| Systemic venous collateral coil or device closure | 24  | 40,142     | 36,733       |
| Mitral valvotomy                    | 24  | 43,129     | 40,464       |
| RVOT dilation and/or stent and proximal or distal right or left PA angioplasty and/or stent (three interventions) | 32  | 49,014     | 40,553       |
| VSD device placement                | 15  | 44,904     | 42,908       |
| Systemic pulmonary collateral dilation or stent | 4   | 49,382     | 39,240       |
| Category 5                          |     |            |              |
| Proximal or distal right or left PA angioplasty and/or stent (excluding RVOT intervention) (three interventions) | 109 | 50,821     | 43,451       |
| Fenestration device closure (plus at least one additional intervention) | 39  | 53,480     | 48,161       |
| ASD or PFO closure (plus at least one additional intervention) | 9   | 57,114     | 43,846       |
Multivariable Model

A multivariable linear regression model was developed for the outcome, procedure-related values, starting with CCC and including patient and procedural characteristics from the univariate model. The addition of number of interventions ($R^2 = 73.7\%$) and number of interventions and diagnosis ($R^2 = 74.2\%$) minimally improved explanation of the variability in charges, while all other characteristics added such as case type, age, and admit source did not result in a significant increase in explanatory value.

Catheterization Charge Category and APR-DRG Relationship

We were able to link 76\% ($N = 2,919$) of cases performed as inpatients to an APR-DRG SOI and CMI value. These values were examined to determine whether they correlated with CCC, and the final results are summarized in Table 5 and Fig. 2. The total number of cases linked to an APR-DRG value was grouped into the corresponding CCC, and the median charge for each CCC was calculated. The weighted mean SOI for CCC 1 (3.3) when compared to CCC 7 (2.4) demonstrated no relationship between CCC and SOI subclasses. Furthermore, the percentage of all cases classified as SOI subclass 4, the highest SOI subclass, was 44\% in CCC 1 compared to 2\% in CCC 7. Similarly, CMI proved to have little association with CCC. Instead of a direct relationship between geometric mean CMI and CCC, CCC 1 (5.8) had a higher geometric mean CMI than any other CCC, including CCC 7 (4.1) (Fig. 2).

Discussion

To more accurately account for the variability of charges in CHD patients undergoing a catheterization procedure, our multidisciplinary group developed a metric based on catheterization charges from the reporting and billing database at Children’s Hospital Boston for fiscal years 2008–2010. The outcome chosen to account for resource utilization was total procedure-related values, which comprised of procedure codes (CPT with associated charge), supplies, and recovery-related expenses. Procedure-related values were chosen in order to exclude charges and aspects of in-hospital care during the episode of care unrelated to the catheterization laboratory. Catheterization cases were defined into 40 procedure types by empiric analysis followed by

Table 3 continued

| $N$ ($\%$) | Median ($\) | Percentiles | $P$ value | $R^2$ |
|-----------|-------------|-------------|-----------|-------|
| $25th$    | $75th$      |             |           |       |
| RVOT dilation and/or stent and proximal or distal right or left PA angioplasty and/or stent (four or more interventions) | 36 | 62,001 | 55,281 | 69,004 |
| Proximal or distal right or left PA angioplasty and/or stent (excluding RVOT intervention) (four or more interventions) | 198 | 60,347 | 50,675 | 70,345 |
| Category 7 | | | | |
| Percutaneous pulmonary valve placement | 89 | 83,095 | 75,848 | 90,434 |

$PDA$ patent ductus arteriosus, $RVOT$ right ventricular outflow tract, $PA$ pulmonary artery, $ASD$ atrial septal defect, $PFO$ patent foramen ovale, $VSD$ ventricular septal defect

Fig. 1 Distribution of cases and associated charges by CCC. The distribution of catheterization cases by CCC is represented by the columns, and the calculated median and interquartile range charge for each CCC is represented by the scatter plot.

Table 4 Catheterization charge category distribution

| $N$ ($\%$) | Median ($\) | Percentiles | $P$ value | $R^2$ |
|-----------|-------------|-------------|-----------|-------|
| $25th$    | $75th$      |             |           |       |
| Catheterization charge category | | | | |
| 1 | 451 (12) | 13,880 | 12,744 | 15,213 | <0.001 | 0.726 |
| 2 | 1,296 (34) | 18,786 | 16,170 | 21,628 |
| 3 | 522 (14) | 30,869 | 26,966 | 34,811 |
| 4 | 497 (13) | 35,222 | 31,368 | 39,925 |
| 5 | 554 (15) | 42,773 | 36,884 | 51,695 |
| 6 | 391 (10) | 56,926 | 48,966 | 67,523 |
| 7 | 89 (2) | 83,095 | 75,848 | 90,434 |

Multivariable Model

A multivariable linear regression model was developed for the outcome, procedure-related values, starting with CCC and including patient and procedural characteristics from the univariate model. The addition of number of interventions ($R^2 = 73.7\%$) and number of interventions and diagnosis ($R^2 = 74.2\%$) minimally improved explanation of the variability in charges, while all other characteristics added such as case type, age, and admit source did not result in a significant increase in explanatory value.

Catheterization Charge Category and APR-DRG Relationship

We were able to link 76\% ($N = 2,919$) of cases performed as inpatients to an APR-DRG SOI and CMI value. These values were examined to determine whether they correlated with CCC, and the final results are summarized in Table 5 and Fig. 2. The total number of cases linked to an APR-DRG value was grouped into the corresponding CCC, and the median charge for each CCC was calculated. The weighted mean SOI for CCC 1 (3.3) when compared to CCC 7 (2.4) demonstrated no relationship between CCC and SOI subclasses. Furthermore, the percentage of all cases classified as SOI subclass 4, the highest SOI subclass, was 44\% in CCC 1 compared to 2\% in CCC 7. Similarly, CMI proved to have little association with CCC. Instead of a direct relationship between geometric mean CMI and CCC, CCC 1 (5.8) had a higher geometric mean CMI than any other CCC, including CCC 7 (4.1) (Fig. 2).

Discussion

To more accurately account for the variability of charges in CHD patients undergoing a catheterization procedure, our multidisciplinary group developed a metric based on catheterization charges from the reporting and billing database at Children’s Hospital Boston for fiscal years 2008–2010. The outcome chosen to account for resource utilization was total procedure-related values, which comprised of procedure codes (CPT with associated charge), supplies, and recovery-related expenses. Procedure-related values were chosen in order to exclude charges and aspects of in-hospital care during the episode of care unrelated to the catheterization laboratory. Catheterization cases were defined into 40 procedure types by empiric analysis followed by
expert consensus. The procedure types were further grouped into 7 CCC stratified by charge outcomes. The CCC demonstrated a moderately strong explanation of the variability in outcome charges ($R^2 = 72.6\%$). Factors typically associated with resource utilization such as number of interventions ($R^2 = 73.7\%$) and number of interventions and diagnosis ($R^2 = 74.2\%$) slightly improved discrimination when added to the CCC.

The APR-DRG diagnostic classification system, a widely used financial metric that evaluates resource intensity and outcomes, is coded based on hospital discharge data and is therefore inadequate in serving as a prospective predictor of resource utilization. As APR-DRG is based on the accumulation of a patient’s characteristics including all cardiac and non-cardiac diagnoses, comorbidities, and past procedures, this metric may be less adequate in measuring patient resource utilization than CCC, which is based on procedure-related charges and modifiers derived from a priori patient and procedural characteristics reflecting the patient’s health status at the time of the catheterization. In our analysis, geometric mean CMI was highest in CCC 1, comprised of heart biopsy after transplant, although this was the procedure type with the lowest associated median charge. This finding may be due to this patient population’s significant past cardiac diagnoses and procedures rather than the resource utilization required at the time of a heart biopsy catheterization. Neither SOI or CMI demonstrated a relationship with CCC and as SOI and CMI are intended to capture the financial complexity of patients we expected that these metrics would correlate with CCC as we have shown CCC measures the variation in charges and resource utilization for catheterization procedures reasonably well.

The majority of Medicare and non-Medicare payers report current use of a system of physician reimbursement based on the Medicare Resource-Based Relative Value Scale (RBRVS), with 77% of private plans based on this payment system according to an American Medical Association (AMA) survey in 2006 [1, 4, 6]. Physician payment through the RRBVS system is determined by total relative value units (RVUs), which are based on physician work, professional expenses, and professional liability insurance, and are assigned to procedures identified by the AMA’s CPT codes [1, 6]. In the field of congenital heart surgery, CPT codes and subsequently work RVUs were assigned to 81 congenital heart operations in 1993–1994 as they previously did not exist for these procedures. Jenkins et al. [7] validated that the work RVU scale for congenital heart operations correlated reasonably with measuring physician work and resource consumption.

The catheterization procedure types and CCC developed by our group are derived from CPT-associated billing codes similar to the CPT-based RVU system. Our multi-disciplinary panel believes that our developed metric presents an easily generalizable tool to assess catheterization charges among institutions as many institutions bill for procedures based on CPT codes. Catheterization cases can be linked from reporting and billing databases to one of the 40 developed procedure types and the corresponding CCC.

| Catheterization charge category | Cases | Median Charge ($) | APR-DRG v20 SOI | APR-DRG v20 CMI |
|--------------------------------|-------|-------------------|----------------|----------------|
| 1                              | 119 (4) | 13,989            | 2 (2) | 18 (15) | 47 (40) | 52 (44) | 3.3 | 5.8 |
| 2                              | 863 (30) | 18,404           | 78 (9) | 278 (32) | 270 (31) | 237 (27) | 2.8 | 3.4 |
| 3                              | 434 (15) | 30,301           | 53 (12) | 169 (39) | 125 (29) | 87 (20) | 2.6 | 3.8 |
| 4                              | 456 (16) | 35,838           | 136 (30) | 130 (29) | 116 (25) | 74 (16) | 2.3 | 3.9 |
| 5                              | 532 (19) | 43,847           | 16 (3) | 208 (39) | 207 (39) | 101 (19) | 2.7 | 3.8 |
| 6                              | 382 (13) | 57,692           | 10 (3) | 160 (42) | 160 (42) | 52 (14) | 2.7 | 3.7 |
| 7                              | 85 (3) | 82,746           | 3 (4) | 44 (52) | 36 (42) | 2 (2) | 2.4 | 4.1 |

CMI case mix index, SOI severity of illness

Fig. 2 APR-DRG CMI and associated charges. Catheterization cases with an associated APR-DRG value were linked to CMI subclass and grouped into corresponding CCC to allow for median charge as well as geometric mean CMI to be calculated by CCC.
to calculate the median charge of each CCC at various institutions. This is especially pertinent as the APR-DRG system has been found to inaccurately classify patients admitted for congenital heart surgery, which can present inaccurate outcome reporting in center comparison [10].

Recently, the CPT-based RVU system’s ability to accurately reflect physician work has been examined and found to be inadequate in several surgical fields [9, 12]. One concern is whether work RVUs accurately measure pediatric CHD catheterization procedures as the RBRVS was developed to estimate work on standard adult Medicare patients [4]. The CPT-based RVU system assigned to pediatric CHD catheterization procedures has also been found to be inadequate in reflecting required physician work in a study by Bergersen et al. [3]. This study concluded that many of the pediatric catheterization CPT codes did not exist or were deduced from procedures performed in adults [3]. Thus, this system does not adjust for the variable age range or the variable complexity within and between catheterization procedures [3]. For instance within diagnostic catheterizations, CPT codes (93530–93533), a routine angiogram of an otherwise healthy patient is reimbursed at a similar rate as an angiogram for an inpatient infant following surgery although the resources, length of procedure, and number of full-time equivalent (FTE) ancillary personnel required differ significantly. Likewise, the CPT code (93580) for an isolated atrial septal defect (ASD) or patent foramen ovale (PFO) closure, which is typically a short intervention with low adverse event rates, has a much higher RVU than diagnostic catheterizations and is on par with more difficult procedures such as pulmonary vein dilations [3].

The inadequacies inherent in deriving physician work and resource utilization from RVU assigned to CPT codes means our developed metric has similar shortcomings as those described. This led our group to examine potential modifiers based on a priori patient and procedural characteristics that may further strengthen the metric and account for these inadequacies. Stratification via expert consensus by the number of interventions of the catheterization procedure types and the addition of the number of interventions and diagnosis to CCC resulted in a metric that is a moderately strong predictor of charges. However, our metric warrants reevaluation, especially in its ability to measure resource intensity and physician work during a catheterization. In order to add explanatory value, additional characteristics may need to be measured and accounted for such as complexity of care requiring different levels of resources from a staffing perspective. Duration of procedure is a potential characteristic that has been indicated as an area that the current CPT-based RVU system does not reimburse appropriately [9, 12].

The development of the procedure types and CCC was based on catheterization data from a single institution, and after reevaluation, further validation will be required to demonstrate our metric is generalizable to cases at different institutions. The value of absolute hospital charges assigned to procedure types may vary between institutions due to the valuation of an interventional procedure CPT code, hospital location, and local billing patterns; however, relative hospital charges by catheterization procedure type and CCC should be generalizable. Attempting comparative analyses in administrative databases such as the Pediatric Health Information System (PHIS), an inpatient dataset, was determined to not be possible because most catheterization cases are considered outpatient procedures. Therefore, exploration of our hospital finance data revealed that less than 50 % of catheterization cases are captured in PHIS.

The developed procedure type financial grouper shows that it is feasible to create such a predictive model for catheterization. Studies examining the variation in costs among institutions and charge methodologies associated with CHD patients in pediatric cardiology have mostly focused on surgical management up to this point [5, 7, 11, 15]. However, catheterization procedures for CHD patients warrant a separate methodology to compare charges, yet no methodology nor billing standards currently exist. The inadequacies with the current RBRVS system justifies a reevaluation of the current billing system and an expanded set of CPT codes to better capture the variability in age, complexity, and the procedures types performed for CHD patients undergoing catheterization.

**Conclusion**

The results of this study demonstrate that the development of a procedure type financial grouper for CHD catheterization case types is feasible. The metric developed by our group, CCC, is a more accurate tool in assessing patient resource utilization than current financial metrics, such as APR-DRG, case mix index, and severity of illness as both of these financial metrics did not correlate with CCC. Although CCC is a moderately strong predictor of the variability in catheterization procedure type charges, further work is needed to identify additional patient and procedural characteristics that influence resource utilization and physician work as they may strengthen the metric. In the interim, as CCC relies on defining procedures via CPT codes and catheterization procedures at institutions are generally billed based on CPT codes, this developed metric provides an easily generalizable tool to examine charges at a single point in time, longitudinally, and across
institutions to inform negotiation of prices with health care reformers.

Acknowledgments The authors have no financial relationships relevant to this article to disclose. The authors would like to acknowledge the Kostin Family Fund and Farb Family Fund for providing funding for this study.

Conflict of interest The authors declare that they have no conflict of interest.

Open Access This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

References

1. Becker ER, Dunn D, Braun P, Hsiao WC (1990) Refinement and expansion of the Harvard resource-based relative value scale: the second phase. Am J Public Health 80(7):799–803
2. Bergersen L, Gauvreau K, Forder SR, Marshall AC, McElhinney DB, Beekman RH 3rd, Hirsch R, Kreutzer J, Balzer D, Vincent J, Hellenbrand WE, Holzer R, Cheatham JP, Moore JW, Burch G, Armsby L, Lock JE, Jenkins KJ (2011) Catheterization for congenital heart disease adjustment for risk method (CHARM). Cardiovasc Interv 4(9):1037–1046
3. Bergersen L, Gauvreau K, McElhinney D, Fenwick S, Kirshner D, Harding J, Hickey P, Mayer J, Marshall A (2013) Capture of complexity of specialty care in pediatric cardiology by work RVU measures. Pediatrics 131(2):258–267
4. Committee on Coding and Nomenclature (2008) Application of the resource-based relative value scale system to pediatrics. Pediatrics 122(6):1395–1400
5. Connor JA, Gauvreau K, Jenkins KJ (2005) Factors associated with increased resource utilization for congenital heart disease. Pediatrics 116(3):689–695
6. Hsiao WC, Braun P, Yntema D, Becker ER (1988) Estimating physicians’ work for a resource-based relative-value scale. N Engl J Med 319(13):835–841
7. Jenkins KJ, Gauvreau K, Newburger JW, Kyn LB, Iezzoni LI, Mayer JE (1998) Validation of relative value scale for congenital heart operations. Ann Thorac Surg 66(3):860–869
8. Marelli AJ, Mackie AS, Ionescu-Ittu R, Rahme E, Pilote L (2007) Congenital heart disease in the general population: changing prevalence and age distribution. Circulation 115(2):163–172
9. Martin JD, Warble PB, Hupp JA, Mapes JE, Stanziale SF, Weiss LL, Schiller TB, Hanson LA (2010) A real world analysis of payment per unit time in a Maryland vascular practice. J Vasc Surg 52(4):1094–1098
10. Parnell AS, Shultz J, Gaynor JW, Leonard MB, Dai D, Feudtner C (2014) Accuracy of the all patient refined diagnosis related groups classification system in congenital heart surgery. Ann Thorac Surg 97(2):641–650
11. Pasquali SK, Sun JL, d’Almada P, Jaquiss RD, Lodge AJ, Miller N, Kemper AR, Lannon CM, Li JS (2011) Center variation in hospital costs for patients undergoing congenital heart surgery. Circ Cardiovasc Qual Outcomes 4(3):306–312
12. Schwartz DA, Hui X, Velopulos CG, Schneider EB, Selvarajah S, Lucas D, Haut ER, McQuay N, Pawlik TM, Efron DT, Haider AH (2014) Does relative value unit-based compensation short-change the acute care surgeon? J Trauma Acute Care Surg. 76(1):84–92
13. Smith AH, Guy JC, Patel NR (2014) Trends in resource utilization associated with the inpatient treatment of neonatal congenital heart disease. Congenit Heart Dis. 9(2):96–105
14. Ungerleider RM, Kanter RJ, O’Laughlin M, Bengur AR, Anderson PA, Herlong JR, Li J, Armstrong BE, Tripp ME, Garson A, Meliones JN, Jaggers J, Sanders SP, Greeley WJ (1997) Effect of repair strategy on hospital cost for infants with tetralogy of Fallot. Ann Surg 225(6):779–783
15. Ungerleider RM, Bengur AR, Kessenich AL, Liekweg RJ, Hart EM, Rice BA, Miller CE, Lockwood NW, Knauss SA, Jaggers J, Sanders SP, Greeley WJ (1997) Risk factors for higher cost in congenital heart operations. Ann Thorac Surg 64(1):44–48

 Springer