Journal of the American Heart Association

ORIGINAL RESEARCH

Resource Use and Outcomes of Pediatric Congenital Heart Disease Admissions: 2003 to 2016

Jonathan B. Edelson, MD; Joseph W. Rossano, MD, MS; Heather Griffis, PhD; William O. Quarshie, MS; Chitra Ravishankar, MD; Matthew J. O'Connor, MD; Christopher E. Mascio, MD; Laura Mercer-Rosa, MD, MSCE; Andrew C. Glatz, MD, MSCE; Kimberly Y. Lin, MD

BACKGROUND: Children with congenital heart disease (CHD) are known to consume a disproportionate share of resources, yet there are limited data concerning trends in resource use and mortality among admitted children with CHD. We hypothesize that charges in CHD-related admissions increased but that mortality improved over time.

METHODS AND RESULTS: This study, including patients <18 years old with CHD, examined inpatient admissions from the nationally representative Kids' Inpatient Database from 2003 to 2016 in order to assess the frequency, medical complexity, and outcomes of CHD hospital admissions. A total of 859 843 admissions of children with CHD were identified. CHD admissions increased by 31.8% from 2003 to 2016, whereas overall pediatric admissions decreased by 13.4%. Compared with non-CHD admissions, those with CHD were more likely to be <1 year of age (80.5% versus 63.3%), and to have ≥1 complex chronic condition (39.7% versus 9.3%). For CHD admissions, mortality was higher (2.97% versus 0.31%) and adjusted median charges greater ($48 426 [interquartile range (IQR), $11.932–$161 048] versus $4697 [IQR, $2551–$12 301]) (*P*<0.0001 for all). Among CHD admissions, whereas adjusted median charges increased from $35 577 (IQR, $9303–$110 439) to $61 696 (IQR, $15 212–$219 237), mortality decreased from 3.2% to 2.7% (*P for trend* <0.0001). CHD admissions accounted for an increased proportion of all inpatient deaths, from 18.0% in 2003 to 24.5% in 2016.

CONCLUSIONS: Children admitted with CHD are 10 times more likely to die than those without CHD and have higher charges. Although the rate of mortality in CHD admissions decreased, children with CHD accounted for an increasing proportion of all pediatric inpatient deaths. Effective resource allocation is critical to optimize outcomes in these high-risk patients.

Key Words: congenital heart disease ■ mortality ■ resource utilization

Although congenital heart disease (CHD) affects only 1 in 100 live births,[1] children with CHD consume a disproportionate share of healthcare resources[2,3]; yearly expenditures in the United States approach $6 billion, with recent increases in both hospital costs and charges to the patient.[4,5] Within the pediatric CHD population, investigators have focused on issues such as the measurement of the value of care provided,[6,7] as well as age- and disease-specific risk factors for increased charges.[4,5,8–10] Critical CHD, the presence of trisomy 21, and clinical presentation in infancy are associated with higher costs.[9,10] Whereas adults with CHD have shown a progressive increase in both overall hospitalizations and admission costs,[11–13] there are limited data on longitudinal resource use and outcomes in the pediatric CHD population.

Trends in resource use among admitted children with CHD are largely undescribed in a contemporary

Correspondence to: Jonathan B. Edelson MD, Division of Cardiology, The Children's Hospital of Philadelphia, 3400 Civic Center Boulevard, Suite 8NW90, Philadelphia, PA 19104, USA. Email: edelsonj@email.chop.edu.

Supplementary Material for this article is available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.120.018286

For Sources of Funding and Disclosures, see page 11.

Data from this article were presented as an abstract at the American Heart Association Scientific Sessions November 16-18, 2019, in Philadelphia, PA

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- In this study we evaluate 31 million national pediatric admissions and describe nearly 1 million admissions of children with congenital heart disease (CHD).
- Children with CHD comprise nearly 2.5% of all pediatric admissions, and this proportion is increasing.
- Although the rate of mortality in CHD admissions is improving, children with CHD account for an increasing proportion of all pediatric inpatient deaths and resource use.

What Are the Clinical Implications?

- This study demonstrates that children with CHD are at high risk of death and are a growing proportion of the inpatient population, emphasizing the need for effective resource allocation and strategies designed to identify and care for those patients at the highest risk of death.

Nonstandard Abbreviations and Acronyms

CCC	complex chronic condition
HCUP	Healthcare Cost and Utilization Project
KID	Kids' Inpatient Database

cohort, as are the impact of noncardiac comorbidities on resource use and outcomes. Our group's recent work demonstrated that children with CHD presenting to the emergency department are medically complex, with higher resource use and mortality than their non-CHD peers. Although resource use among emergency department visits has increased over time, mortality has decreased, suggesting that the overall care of children with CHD may be improving.[14] However, the inpatient population of children with CHD may be different, with respect to both clinical characteristics and outcomes, and has not been as well studied, particularly with respect to changes over time. The purpose of the current study is to describe nationwide estimates of CHD-related hospital admissions over a 14-year period, to detail their medical complexity, to evaluate the burden that CHD places on the inpatient system with respect to admissions and mortality, and ultimately to test the hypothesis that over the study period mortality in CHD-related admissions mirrored the improvement previously shown in the National Emergency Department Sample.[14]

METHODS

The data sets generated and analyzed for the current study were obtained, and can be similarly purchased, from the Healthcare Cost and Utilization Project (HCUP).

Data Source

We used the discharge encounters from the Kids' Inpatient Database (KID), a survey-designed database that contains a nationally representative sample of discharge data from approximately 3 million annual pediatric inpatient discharges from across the United States. KID is provided by the HCUP, Agency for Healthcare Research and Quality,[15,16] and uses systematic random sampling to generate the data set. Systematic sampling is a method of probability sampling where elements are chosen from a target population by selecting a random starting point and then selects sample members after a fixed sampling interval. The KID database is generated by using systematic random sampling to select 10% of uncomplicated in-hospital births and 80% of complicated births and other pediatric discharges. Data from these patients are then weighted and extrapolated to generate national estimates. The hospitals included in the database are specialty hospitals, public hospitals, and academic medical centers. KID includes information with respect to both hospital and patient variables. As no patient identifying information is available in KID, the study was exempt from review by the institutional review board.

Study Population

For this study, we used KID data from 2003 to 2016 and limited analyses to admission encounters of patients <18 years of age. The KID database is typically produced every 3 years (including 2003, 2006, 2009, and 2012). Because 2015 contains both *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) and *Tenth Revision, Clinical Modification* (*ICD-10-CM*) data, KID was not released for 2015 and instead released in 2016. The unit of analysis is the admission encounter; therefore, a patient may be represented by multiple encounters in any given year or multiple years. For each visit in KID, up to 25 *ICD-9-CM* diagnostic codes before 2016, and up to 30 *ICD-10-CM* diagnostic codes in 2016 were used. We used *ICD-9/10-CM* to identify CHD-related admissions as well as to identify acute CHD-associated comorbidities that included heart failure, cyanosis, arrhythmia, pulmonary hypertension, acute respiratory disease, acute gastrointestinal disease, acute neurologic disease, sepsis, and acute kidney injury. We classified CHD into 3 groups hierarchically:

single ventricle (SV) complex CHD, non-SV complex CHD, and simple CHD, using *ICD-9/10-CM* and our previously reported classification scheme[14] (Figure S1).

Covariates

We examined patient and hospital characteristics as covariates. These included age in years (<1, 1–4, 5–9, 10–14, 15–17, >17), sex, insurance status (government, private, other), residence (urban versus rural), and day of admission (weekday versus weekend). Hospital characteristics included geographic region (Northeast, Midwest, South, West), bed size (small, medium, large), and location/teaching status (metropolitan/teaching, metropolitan/nonteaching or nonmetropolitan area).

Clinical characteristics include heart failure, cyanosis, arrhythmia, pulmonary hypertension, acute respiratory disease, acute gastrointestinal disease, and others, as listed in Table 2.

Complex chronic conditions (CCC) were defined as medical conditions that can be reasonably expected to last at least 12 months and that involve either several different organ systems or 1 organ system severely affected enough to require specialty pediatric care and some period of hospitalization in a tertiary care center, and included categories such as gastrointestinal, immunologic, and genetic. Given that the majority of patients with CHD should have a CCC for cardiovascular disease, the CCC for cardiovascular disease was not included in this analysis. To identify whether an individual was diagnosed with a CCC, we used the previously published classification scheme based on *ICD-9-CM* and revalidated using *ICD-10-CM*.[17]

Outcomes of Interest

We examined the following outcomes of interest within each encounter: (1) hospital length of stay in days, (2) mortality, and (3) total inflation-adjusted charges. Total inpatient charges were inflated to 2016 US dollars using the medical care services component of the Consumer Price Index.[18]

Statistical Analysis

All analyses accounted for KID's complex survey designs using appropriate survey weights and as recommended by HCUP. Discharge weights were calculated for KID data by stratifying the hospitals on the same variables that were used for creating the sample and then creating weights by stratum. The stratifying variables were geographic region, urban/rural location, teaching status, bed size, ownership, and children's hospital. National estimates of inpatients, with CHD and without CHD, by year in 2003, 2006, 2009, 2012, and 2016 were calculated. Demographic and clinical characteristics inpatient visits with CHD and without CHD were compared using chi-square tests. Cochran-Armitage tests of trend were used to assess a relationship with admissions and outcomes by year, for all pediatric admissions, those with any type of CHD, and among SV, other complex, and simple CHD, and a simple linear regression for the median charges with year as an ordered covariate.

To explore the association between visits with and without CHD and outcomes, unadjusted analyses were conducted via chi-square (mortality) and Wilcoxon signed rank tests of (length of stay and inflation-adjusted charges). Multivariable logistic regression models were used to assess the relationship between demographic/clinical characteristics and mortality. Unadjusted and adjusted odds ratios and 95% CIs as well as estimated adjusted marginal probabilities (margins) are presented.

All data management and statistical analyses were performed using SAS (version 9.4, SAS Institute, Inc.) and R statistical software. National estimates, 95% CIs, or interquartile range (IQR), and trend tests were conducted by using SAS survey procedures, as recommended by HCUP to compute accurate variances.[19] A 2-sided P value<0.05 was used as the threshold for statistical significance.

RESULTS

Demographics and Clinical Characteristics

Among approximately 31 million national pediatric admissions over the 5 years sampled, there were 859,843 admissions of children with CHD (2.44% of all pediatric admissions). Slightly less than half of patients had complex CHD, including 5% with SV disease. (Figure 1) The majority of admitted patients with CHD were <4 years of age (90.4%) and were more often male (52.9%). (Table 1) Compared with admitted patients without CHD, patients with CHD were more likely to be <1 year old (80.5% versus 63.3%), to have Medicaid (50.4% versus 47%), and to present to a metropolitan teaching hospital (74.9% versus 53.8%) (P<0.0001 for all).

The most common associated diagnosis among CHD admissions was sepsis (13.7%), followed by acute respiratory distress (8.3%). Among cardiac associated comorbidities, the most frequent diagnosis was heart failure (5.1%) followed by arrhythmia (3.9%) and pulmonary hypertension (2.3%). Patients with CHD who were admitted were significantly more

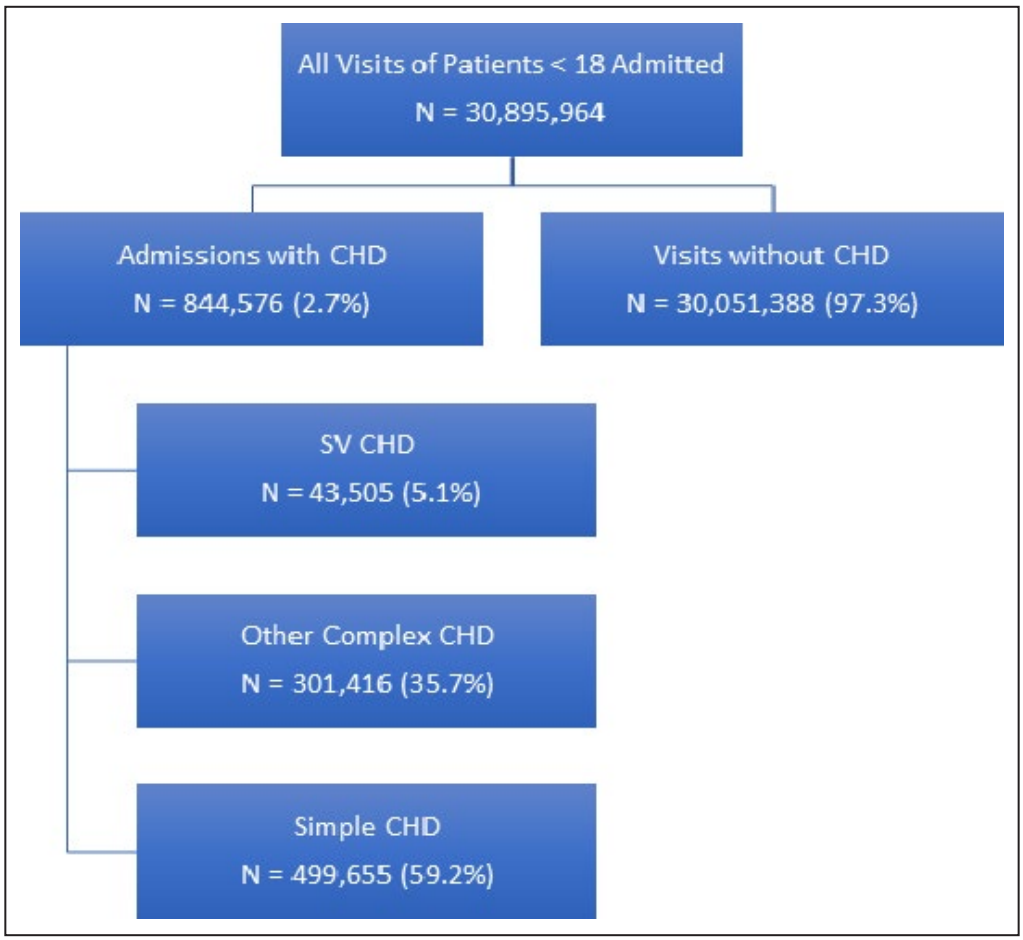

Figure 1. Study Cohort.
CHD indicates congenital heart disease; and SV, single ventricle.

likely to have ≥1 CCC (39.1% versus 9.3%) and 14.5% of patients with CHD had 2 or more CCCs compared with only 2.4% in patients without CHD. The most common CCCs among CHD admissions were prematurity (14.2%) followed by genetic (13.4%) and gastrointestinal (9.9%) (*P*<0.0001 for all). (Table 2).

Children with CHD admitted to the hospital were 10 times more likely to die than those admitted without CHD (2.97% versus 0.31%). Length of stay was longer (4.97 days [IQR 1.91–18.32] versus 1.67 days [1.09–2.62]) and inflation-adjusted charges were 10-fold higher ($48 436 [IQR $11 932–$161 048] versus $4697 [IQR $2551–$12 301]). (*P*<0.0001 for all). (Table 3).

Temporal Trends in CHD-Related Admissions

Between 2003 and 2016, total pediatric admissions decreased by 13.4% and CHD-related admissions increased by 32%, resulting in a proportionate increase of CHD admissions from 2.2% to 3.3% of all pediatric admissions. The most notable changes were in SV disease admissions, which increased by 39.4%, and simple CHD admissions, which increased by 50.2% (*P for trend* <0.0001). (Tables S1-S3).

The overall mortality rate of admitted pediatric patients decreased by 5.5%, whereas CHD mortality decreased by 15.4%, from 3.2% in 2003 to 2.7% in 2016. However, CHD admissions accounted for an increased proportion of all deaths, from 18.0% in 2003 to 24.5% in 2016. There was a concurrent increase in median adjusted charges for individual CHD admissions from $35 577 (IQR $9303–110 439) in 2003 to $61 696 (IQR $15 212–210 237) in 2016 (*P for trend* <0.0001). (Figure 2, Figure 3).

Factors Associated With Mortality

Factors independently associated with mortality included age <1 year, having nonprivate insurance, presenting on a weekend or in the South region, living in a rural environment, presenting to a metropolitan teaching hospital, having a CCC, and having complex

Table 1. Demographics, Years 2003, 2006, 2009, 2012, and 2016

Characteristic	All Admissions, % (N=35 279 684)	Admissions Without Congenital Heart Disease, % (N=34 419 841)	Admissions with Congenital Heart Disease, % (N=859 843)	*P* Value
Age, y				
<1	63.70	63.28	80.49	<0.0001
1–4	7.38	7.32	9.91	
5–9	4.76	4.79	3.61	
10–14	5.21	5.27	2.61	
15–17	6.52	6.64	1.72	
>17	12.09	12.35	1.56	
Missing	0.34	0.34	0.10	
Sex				
Male	47.38	47.25	52.93	<0.0001
Primary payer				
Government	47.06	46.97	50.43	<0.0001
Private	44.71	44.77	42.28	
Other	4.70	4.74	2.77	
Missing	3.54	3.51	4.52	
Time of visit				
Weekday	79.29	79.22	82.03	<0.0001
Region of hospital				
Northeast	16.80	16.83	15.58	<0.0001
Midwest	21.83	21.86	20.62	
South	38.44	38.39	40.44	
West	22.93	22.92	23.36	
Teaching status of hospital				
Metropolitan nonteaching	32.76	33.09	19.77	<0.0001
Metropolitan teaching	54.35	53.84	74.91	
Nonmetropolitan	11.14	11.35	2.49	
Missing	1.75	1.72	2.83	
Location of patient				
Urban	83.52	83.46	86.28	<0.0001
Rural	15.73	15.80	12.75	
Missing	0.75	0.74	0.97	
Bed size of hospital				
Small	11.83	11.89	9.63	<0.0001
Medium	25.83	25.87	24.22	
Large	60.59	60.52	63.32	
Missing	1.75	1.72	2.83	

congenital heart disease. Children with SV were at particular risk of death, with an odds of mortality more than 3.5 times higher than those with simple CHD and more than twice as high as those with other forms of complex CHD. Associated diagnoses of heart failure, arrhythmia, pulmonary hypertension, respiratory disease, neurologic disease, sepsis, and acute kidney disease were also all independently associated with death. The adjusted marginal probability for mortality in patients with CHD who have 1 CCC was 4.6% (95% CI, 4.5–4.7), and increased to 6.5% (95% CI, 6.3–6.7) for those with ≥2 CCCs. (Table 4).

DISCUSSION

This is the largest known longitudinal evaluation of pediatric CHD admissions to date and has several notable findings that are of interest to clinicians, hospital administrators, and policymakers. First, our study

Table 2. Clinical Characteristics of the Study Population Years 2003, 2006, 2009, 2012, and 2016 (Restricted to Ages 0–17 Years)

Characteristic	All Admissions, % (N=30 895 967)	Admission Without Congenital Heart Disease, % (N=30 051 388)	Admissions with Congenital Heart Disease, % (N=844 576)	*P* value
Heart failure	0.20	0.06	5.09	<0.0001
Cyanosis	0.13	0.12	0.81	<0.0001
Arrhythmia	0.52	0.42	3.93	<0.0001
Pulmonary Hypertension	0.12	0.06	2.33	<0.0001
Acute respiratory disease	3.98	3.86	8.28	<0.0001
Acute gastrointestinal disease	1.94	1.91	3.07	<0.0001
Acute neurologic disease	1.47	1.44	2.65	<0.0001
Sepsis	2.27	1.95	13.67	<0.0001
Acute kidney injury	0.26	0.22	1.68	<0.0001
Complex chronic conditions				
Neurologic and neuromuscular	2.28	2.19	5.59	<0.0001
Respiratory	1.00	0.85	6.16	<0.0001
Renal and urologic	1.20	1.11	4.36	<0.0001
Gastrointestinal	2.03	1.81	9.87	<0.0001
Hematologic or immunologic	1.41	1.37	2.75	<0.0001
Metabolic	1.01	0.96	2.97	<0.0001
Other congenital or genetic	1.63	1.30	13.39	<0.0001
Malignancy	1.69	1.72	0.92	<0.0001
Premature and neonatal	1.53	1.17	14.24	<0.0001
Number of complex chronic conditions				
0	89.89	90.70	60.87	<0.0001
1	7.41	6.93	24.59	
2+	2.70	2.37	14.54	

demonstrates the significant and increasing burden that patients with CHD place on the inpatient hospital system. Second, these results parallel those seen in our evaluation of emergency department encounters, with increasing charges occurring in tandem with improving mortality rates, suggesting that increased allocation of resources may be having a positive effect on outcomes. Finally, our study demonstrates the high-risk nature of children with CHD admitted to the hospital with a mortality rate 10-fold higher than children admitted without CHD.

Despite making up less than 1% of the pediatric population, children with CHD comprise nearly 2.5% of all pediatric admissions, with greater than 170 000 per year, and this proportion increased over the course of the study. Our data support other studies, which have shown that advances in the care of children with CHD have shifted mortality away from childhood and toward adulthood.[20] This increase in the prevalence of complex CHD has in turn likely contributed to the growing number of CHD admissions.[1] Interestingly, the increase in admissions was most notable in the SV cohort, which may be a result of both improvements in the survival of children with SV disease[21–23] and the spread of interstage monitoring programs, which has improved mortality but may also be leading to increased referrals for admission.[24–27] Each hospitalization of a patient with CHD, on average, resulted in more than 10 times

Table 3. Outcomes of the Congenital Heart Disease Related Admissions in Patients <18 Years Old

Characteristic	All Admissions, % (N=30 895 967)	Admission Without Congenital Heart Disease, % (N=30 051 388)	Admissions with Congenital Heart Disease, % (N=844 576)	*P* value
Mortality, % (95% CI)	0.38 (0.37, 0.38)	0.31 (0.30, 0.31)	2.97 (2.92, 3.01)	<0.0001
Length of stay in hospitalization, days median (interquartile range)	1.68 (1.10–2.69)	1.67 (1.09–2.62)	4.97 (1.91–18.32)	<0.0001
Inflated-adjusted charges, $, median (interquartile range)	4864 (2590 –13 161)	4697 (2551–12 301)	48 436 (11 932–161 048)	<0.0001

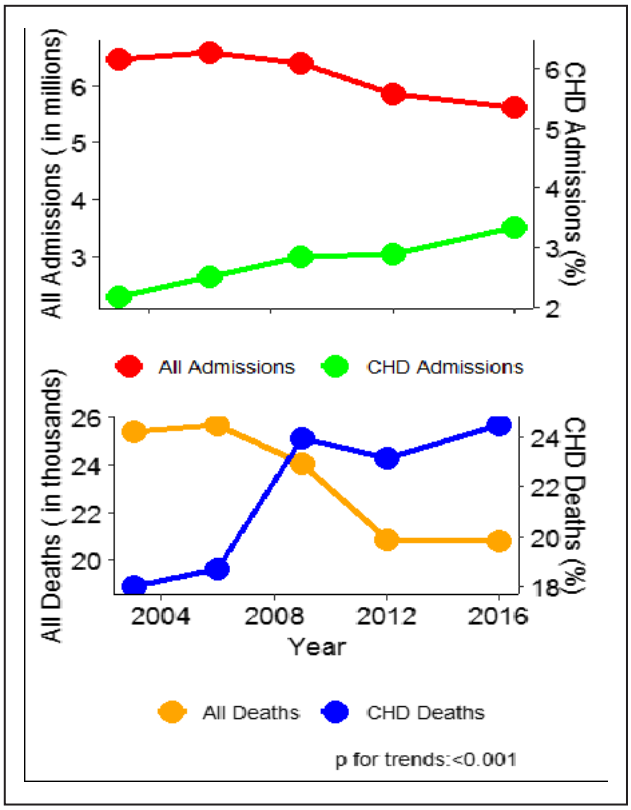

Figure 2. Trends in Admissions and Mortality.
Whereas overall pediatric admissions and overall mortality decreased, the proportion of those admissions, and of inpatient deaths, that were children with CHD, increased. CHD indicates congenital heart disease.

the charge of a patient without CHD. These higher charges are likely multifactorial, with longer length of stay, increased surgical procedures, and higher acuity all contributing.[9,10,14,28] There was a significant increase in median charge per admission, which outpaced changes seen in all pediatric admissions, even after taking inflation into account. Given that CHD admissions increased significantly over the period studied, despite a national trend toward decreasing pediatric hospital admissions, the increase in per admission charge is further magnified with respect to total resource use. By 2016, annual charges for CHD-related admissions exceeded $11.5 billion. These findings, with CHD-related admissions accruing higher charges and comprising an increasing proportion of total pediatric admissions, have important implications for the future of the inpatient care model.

These data support other studies showing that with improvements in medical care and technologic support, children whose illnesses would have at one point been fatal are now surviving, often accompanied by substantial comorbidities.[29,30] This changing disease course comes at a time when there is a determined effort to increase the evidence-based care of common pediatric illnesses like asthma and bronchiolitis and to keep those children from being unnecessarily admitted.[31,32] In concert this has led to a population of pediatric inpatients that is increasingly composed of children with chronic diseases.[33–35]

This study also reinforces the findings from our prior work evaluating outcomes of emergency department visits among children with congenital heart disease, which showed that whereas the charge per encounter of CHD-related visits was increasing, mortality was improving. In that study we posited that increased resource use was having a positive effect on mortality, yet we could not rule out the possibility that mortality had been shifted from the emergency department to patients admitted to the hospital by other means or who were never discharged. The findings in this study of inpatients, however, show a similar increase in charges concurrent with an improvement in mortality in the CHD population. These studies together suggest that the overall care of patients with CHD is improving across emergency care and inpatient domains and that although resource use has increased significantly over the 14 years studied, it is having an important impact on mortality.

Finally, and most important, our findings demonstrate that despite improvements in care, patients with CHD who are admitted to the hospital are at high risk of mortality, with 1 in 33 admissions resulting in death and 1 in 4 inpatient deaths occurring in a child with CHD. Our findings reinforce other studies, which have shown that infants and those with SV are at particularly high risk of death, while also highlighting other less recognized risk factors. Nearly a quarter of admitted patients with CHD have at least 1 CCC, with the degree of medical complexity predicting an increased probability of death. Increased survival in children with CHD has been accompanied by a new set of comorbidities and complications.[20,36–38] Studies in adults with CHD have shown that that noncardiac comorbidities incur worse outcomes and higher resource use.[13,39–41] Our findings show that noncardiac CCCs have a prominent effect on mortality of hospitalized children with CHD and raise the possibility that one method by which to improve outcomes may be to provide greater attention to the care of noncardiac comorbidities.

It is notable that these data showed that government insurance was independently associated with death. Other studies have also demonstrated that the presence of Medicaid is associated with worse outcomes for patients with CHD[42] and other forms of chronic disease including cystic fibrosis.[43] This may be in part because pediatric patients with more significant disease use Medicaid as a secondary form of insurance, and it is difficult to entirely control for illness severity. However, this finding also raises the possibility

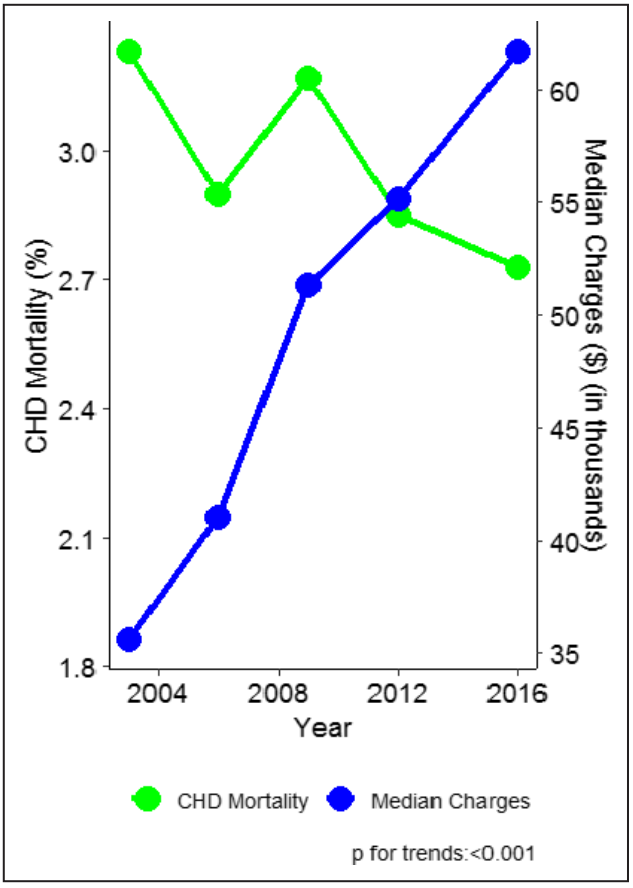

Figure 3. Changes in Charge and Mortality Over Time.
Median inflation-adjusted charges increased over the course of the study; there was a concurrent decrease in mortality. CHD indicates congenital heart disease.

that lower socioeconomic status, which is associated with the increased use of government insurance, has an important negative effect on survival, thus highlighting a group of patients deserving of increased attention. Patients who live in a rural environment also had an increased risk of death, which we hypothesize may be owing to reduced proximity to tertiary care hospitals. Higher mortality was also seen in patients cared for at metropolitan teaching hospitals, a result that may be owing to a combination of underappreciated disease complexity or a reflection of the number of unwell children who get transferred to these hospitals in times of extremis or in anticipation of a high-risk procedure. Although this study was not designed to evaluate regional differences, it is important to mention that the risk of death did differ by region, a finding that deserves further investigation in future studies.

Heart failure, an independent risk factor for death, was seen in 1 in 20 admissions, and we suspect that this may underestimate the size of this population as heart failure related symptoms may have been coded as either acute respiratory or gastrointestinal disease. Prior studies have shown that patients with CHD and heart failure are a growing population who carry significantly increased risk of mortality and resource use.[44,45] Arrhythmia was also relatively prevalent in our cohort and another independent risk factor for death. These findings reinforce prior studies that have shown that over time there has been a shift in mortality in children with CHD from postoperative complications and cardiac arrests to subacute comorbidities like heart failure and rhythm disturbances[46] and illustrate high-risk subgroups that deserve increased attention.

LIMITATIONS

The present study has several limitations associated with the design of retrospective studies. It is a retrospective analysis and the findings may differ from a prospectively enrolled cohort. Identification of patients was made by *ICD-9/10* codes, thus excluding, and including, patients who were either misdiagnosed or miscoded. We think that it more likely that patients with CHD would be misclassified as not having CHD, thus biasing our results to the null. The de-identification of data limits our ability to assess patients longitudinally or assess for repeat hospital admissions. As such, a small number of patients could be accounting for a disproportionate number of encounters. Although HCUP performs several analyses to ensure internal consistency and data validity, some of the cases may have misclassified information. Furthermore, this analysis is limited to those hospitals included in the KID database, which necessarily excludes those patients admitted to other hospitals, and does not contain data on admissions for observation that lasted less than 24 hours. In a sample of this size statistically significant differences may be detected that do not have clinical pertinence, and as such we have focused on those differences that have relevance, either clinically or economically. Finally, we have evaluated charges, which serves as a proxy for resource use over time but does not give us information on actual cost.

CONCLUSIONS

In conclusion, children with CHD admitted to the hospital are placing an increasingly large demand on the healthcare system and are becoming an increasing proportion of all pediatric admissions and deaths. Increased resource use has coincided with an improvement in mortality, suggesting that increased resource devotion to admitted patients with CHD are having a positive impact on outcomes. Given that this high-risk cohort is a growing proportion of the inpatient population, strategies designed to identify and care for those patients at the highest risk of death are urgently needed.

Table 4. Factors Associated With Mortality Among Children With Congenital Heart Disease in the United States

Predictor Variables	Mortality During Admission			
	Died During Admission, % N=25 061	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Adjusted Marginal Probability of Mortality %
Age, y				
<1	3.38 (3.33,3.43)	Ref	Ref	3.46 (3.41, 3.52)
1–4	1.18 (1.09, 1.27)	0.342 (0.316, 0.370)	0.236 (0.217, 0.257)	0.95 (0.88, 1.02)
5–9	0.91 (0.78, 1.04)	0.262 (0.277, 0.304)	0.200 (0.171, 0.233)	0.81 (0.70, 0.93)
10–14	0.99 (0.82, 1.15)	0.284 (0.240, 0.337)	0.227 (0.190, 0.270)	0.92 (0.77, 1.07)
15–17	1.22 (1.00, 1.44)	0.354 (0.295, 0.425)	0.275 (0.226, 0.334)	1.09 (0.90, 1.29)
Sex				
Male	3.05 (2.99, 3.11)	Ref	Ref	2.91 (2.86, 2.97)
Female	2.87 (2.80, 2.94)	0.941 (0.912, 0.970)	1.013 (0.979, 1.048)	2.94 (2.88, 3.01)
Primary payer				
Government	3.18 (3.12, 3.25)	Ref	Ref	2.95 (2.89, 3.01)
Private	2.62 (2.56, 2.69)	0.819 (0.793, 0.847)	0.943 (0.909, 0.978)	2.80 (2.73, 2.87)
Other	3.95 (3.64, 4.25)	1.250 (1.149, 1.360)	2.071 (1.887, 2.274)	5.41 (5.02, 5.81)
Time of visit				
Weekday	2.88 (2.83, 2.92)	Ref	Ref	2.90 (2.85, 2.95)
Weekend	3.39 (3.28, 3.50)	1.184 (1.140, 1.230)	1.066 (1.022, 1.021)	3.06 (2.96, 3.16)
Region of hospital				
Northeast	2.59 (2.49, 2.70)	Ref	Ref	2.79 (2.69, 2.90)
Midwest	3.21 (3.11, 3.31)	1.245 (1.181, 1.313)	1.046 (0.986, 1.109)	2.90 (2.81, 3.00)
South	2.96 (2.89, 3.03)	1.146 (1.092, 1.203)	1.089 (1.032, 1.148)	3.01 (2.94, 3.08)
West	3.02 (2.93, 3.11)	1.169 (1.110, 1.231)	1.052 (0.994, 1.115)	2.92 (2.83, 3.01)
Teaching status of hospital				
Metropolitan nonteaching	1.51 (1.44, 1.58)	Ref	Ref	2.25 (2.15, 2.35)
Metropolitan teaching	3.37 (3.31, 3.42)	2.273 (2.163, 2.388)	1.426 (1.352, 1.504)	3.07 (3.02, 3.11)
Nonmetropolitan	1.11 (0.92, 1.30)	0.732 (0.613, 0.875)	0.921 (0.763, 1.113)	2.09 (1.75, 2.43)
Location of patient				
Rural	3.25 (3.12, 3.38)	Ref	Ref	3.08 (2.95, 3.20)
Urban	2.92 (2.87, 2.97)	0.895 (0.856, 0.935)	0.936 (0.888, 0.987)	2.91 (2.86, 2.95)
Congenital heart disease group				
Single ventricle disease	7.01 (6.72, 7.31)	2.840 (2.700, 2.987)	3.669 (3.438, 3.915)	7.16 (6.82, 7.49)
Other complex CHD	3.02 (2.94, 3.09)	1.170 (1.132, 1.210)	1.465 (1.413, 1.520)	3.36 (3.28, 3.44)
Simple CHD	2.59 (2.53, 2.64)	Ref	Ref	2.40 (2.36, 2.45)
Heart failure				
No	2.82 (2.78, 2.87)	Ref	Ref	2.90 (2.85, 2.94)
Yes	5.73 (5.45, 6.00)	2.094 (1.986, 2.209)	1.180 (1.04, 1.261)	3.34 (3.16, 3.52)
Cyanosis				
No	2.98 (2.93, 3.02)	Ref	Ref	2.94 (2.90, 2.99)
Yes	1.99 (1.59, 2.38)	0.663 (0.540, 0.813)	0.531 (0.424, 0.665)	1.69 (1.35, 2.03)
Arrhythmia				
No	2.74 (2.69, 2.78)	Ref	Ref	2.76 (2.72, 2.80)
Yes	8.60 (8.22, 8.98)	3.342 (3.176, 3.516)	2.616 (2.449, 2.795)	6.19 (5.88, 6.51)
Pulmonary hypertension				
No	2.89 (2.85, 2.94)	Ref	Ref	2.90 (2.86, 2.94)
Yes	6.18 (5.76, 6.60)	2.213 (2.055, 2.383)	1.404 (1.287, 1.531)	3.87 (3.59, 4.14)

(*Continued*)

Table 4. Continued

Predictor Variables	Mortality During Admission			
	Died During Admission, % N=25 061	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Adjusted Marginal Probability of Mortality %
Acute respiratory disease				
No	2.49 (2.45, 2.53)	Ref	Ref	2.72 (2.68, 2.77)
Yes	8.27 (8.02, 8.52)	3.528 (3.399, 3.662)	1.628 (1.556, 1.702)	4.14 (4.00, 4.28)
Acute gastrointestinal disease				
No	3.02 (2.97, 3.06)	Ref	Ref	3.01 (2.97, 3.06)
Yes	1.37 (1.20, 1.55)	0.447 (0.393, 0.508)	0.296 (0.258, 0.340)	1.02 (0.89, 1.15)
Acute neurologic disease				
No	2.82 (2.78, 2.87)	Ref	Ref	2.87 (2.83, 2.92)
Yes	8.28 (7.84, 8.73)	3.108 (2.925, 3.301)	1.542 (1.431, 1.661)	4.15 (3.90, 4.40)
Sepsis				
No	2.07 (2.03, 2.11)	Ref	Ref	2.28 (2.24, 2.32)
Yes	8.66 (8.46, 8.85)	4.490 (4.349, 4.635)	2.701 (2.602, 2.804)	5.41 (5.28, 5.55)
Acute kidney injury				
No	2.53 (2.49, 2.58)	Ref	Ref	2.61 (2.57, 2.65)
Yes	28.53(27.63, 29.44)	15.365 (14.651,16.114)	5.171 (4.868, 5.493)	10.35 (9.89, 10.80)
Number of complex chronic conditions				
0	0.79 (0.75, 0.82)	Ref	Ref	0.91 (0.88, 0.95)
1	5.26 (5.14, 5.37)	7. 008 (6.696, 7.333)	5.693 (5.426, 5.974)	4.61 (4.50, 4.71)
≥2	8.24 (8.05, 8.43)	11.340 (10.830, 11.875)	8.402 (7.973, 8.855)	6.49 (6.31, 6.66)

CHD indicates congenital heart disease; OR, odds ratio; and Ref, Reference.

ARTICLE INFORMATION

Received June 29, 2020; accepted December 14, 2020.

Affiliations

From the Division of Cardiology, Cardiac Center, the Children's Hospital of Philadelphia, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA (J.B.E., J.W.R., C.R., M.J.O., L.M., A.C.G., K.Y.L.); Cardiovascular Outcomes, Quality and Evaluative Research Center, University of Pennsylvania, Philadelphia, PA (J.B.E., J.W.R.); Leonard Davis Institute of Health Economics, University of Pennsylvania, Philadelphia, PA (J.B.E., J.W.R.); Department of Biomedical Health Informatics, Healthcare Analytics Unit, the Children's Hospital of Philadelphia, PA (H.G., W.O.Q.); and Division of Cardiothoracic Surgery, Cardiac Center, the Children's Hospital of Philadelphia, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA (C.E.M.).

Acknowledgments

The authors would like to acknowledge the Cardiac Center Clinical Research Core at the Children's Hospital of Philadelphia for providing statistical support for this article.

Sources of Funding

This work was supported by the Cardiac Center Clinical Research Core at the Children's Hospital of Philadelphia. Dr. Mercer-Rosa has received support from grant NIH K01HL125521 and from the Pulmonary Hypertension Society.

Disclosures

None.

Supplementary Material

Tables-S1-S3
Figure S1

REFERENCES

1. Marelli AJ, Mackie AS, Ionescu-Ittu R, Rahme E, Pilote L. Congenital heart disease in the general population: changing prevalence and age distribution. *Circulation*. 2007;115:163–172. DOI: 10.1161/CIRCULATIONAHA.106.627224.
2. Pasquali SK, Sun J-L, d'Almada P, Jaquiss RD, Lodge AJ, Miller N, Kemper AR, Lannon CM, Li JS. Center variation in hospital costs for patients undergoing congenital heart surgery. *Circ Cardiovasc Qual Outcomes*. 2011;4:306–312. DOI: 10.1161/CIRCOUTCOMES.110.958959.
3. Simeone RM, Oster ME, Hobbs CA, Robbins JM, Collins RT, Honein MA. Population-based study of hospital costs for hospitalizations of infants, children, and adults with a congenital heart defect, Arkansas 2006 to 2011. *Birth Defects Res Part A Clin Mol Teratol*. 2015;103:814–820. DOI: 10.1002/bdra.23379.
4. Smith AH, Gay JC, Patel NR. Trends in resource utilization associated with the inpatient treatment of neonatal congenital heart disease. *Congenit Heart Dis*. 2014;9:96–105. DOI: 10.1111/chd.12103.
5. Connor JA, Gauvreau K, Jenkins KJ. Factors associated with increased resource utilization for congenital heart disease. *Pediatr*. 2005;116:689–695. DOI: 10.1542/peds.2004-2071.
6. Shin AY, Hu Z, Jin B, Lal S, Rosenthal DN, Efron B, Sharek PJ, Sutherland SM, Cohen HJ, McElhinney DB, et al. Exploring value in congenital heart disease: an evaluation of inpatient admissions. *Congenit Heart Dis*. 2015;10:E278–E287. DOI: 10.1111/chd.12290.
7. Mackie AS, Tran DT, Marelli AJ, Kaul P. Cost of congenital heart disease hospitalizations in Canada: a population-based study. *Can J Cardiol*. 2017;33:792–798. DOI: 10.1016/j.cjca.2017.01.024.
8. Simeone RM, Oster ME, Cassell CH, Armour BS, Gray DT, Honein MA. Pediatric inpatient hospital resource use for congenital heart defects. *Birth Defects Res Part A - Clin Mol Teratol*. 2014;100:934–943. DOI: 10.1002/bdra.23262.
9. Ungerleider RM, Bengur AResai, Kessenich AL, Liekweg RJ, Hart EM, Rice BA, Miller CE, Lockwood NW, Knauss SA, Jaggers J, et al. Risk

factors for higher cost in congenital heart operations. *Ann Thorac Surg*. 1997;64:44–49. DOI: 10.1016/S0003-4975(97)00503-1.
10. Pinto NM, Waitzman N, Nelson R, Minich LLA, Krikov S, Botto LD. Early childhood inpatient costs of critical congenital heart disease. *J Pediatr*. 2018;203:371–379. DOI: 10.1016/j.jpeds.2018.07.060.
11. Bhatt AB, Rajabali A, He W, Benavidez OJ. High resource use among adult congenital heart surgery admissions in adult hospitals: risk factors and association with death and comorbidities. *Congenit Heart Dis*. 2015;10:13–20. DOI: 10.1111/chd.12169.
12. Briston DA, Bradley EA, Sabanayagam A, Zaidi AN. Health care costs for adults with congenital heart disease in the United States 2002 to 2012. *Am J Cardiol*. 2016;118:590–596. DOI: 10.1016/j.amjcard.2016.05.056.
13. Burchill LJ, Gao L, Kovacs AH, Opotowsky AR, Maxwell BG, Minnier J, Khan AM, Broberg CS. Hospitalization trends and health resource use for adult congenital heart disease-related heart failure. *J Am Heart Assoc*. 2018;7:e008775. DOI: 10.1161/JAHA.118.008775.
14. Edelson JB, Rossano JW, Griffis H, Dai D, Faerber J, Ravishankar C, Mascio CE, Mercer-Rosa LM, Glatz AC, Lin KY. Emergency department visits by children with congenital heart disease. *J Am Coll Cardiol*. 2018;72:1817–1825. DOI: 10.1016/j.jacc.2018.07.055.
15. HCUP Nationwide Emergency Department Sample (NEDS). Healthcare Cost and Utilization Project (HCUP). Agency for Healthcare Research and Quality; 2016. http://www.hcup-us.ahrq.gov/nedsoverview.jsp.
16. Healthcare Cost and Utilization Project. Introduction to the HCUP Nationwide Emergency Department Sample (NEDS). Agency for Healthcare Research and Quality; 2014.
17. Feudtner C, Feinstein JA, Zhong W, Hall M, Dai D. Pediatric complex chronic conditions classification system version 2: updated for ICD-10 and complex medical technology dependence and transplantation. *BMC Pediatr*. 2014;14:199. DOI: 10.1186/1471-2431-14-199.
18. US Bureau of Labor Statistics. Consumer Price Index. http://www.bls.gov/cpi/. Accessed February 6, 2018.
19. Healthcare Cost and Utilization Project. Calculating National Inpatient Sample (NIS) Variances for Data Years 2012 and Later. https://www.hcup-us.ahrq.gov/reports/methods/2015-09.pdf.
20. Khairy P, Ionescu-Ittu R, MacKie AS, Abrahamowicz M, Pilote L, Marelli AJ. Changing mortality in congenital heart disease. *J Am Coll Cardiol*. 2010;56:1149–1157. DOI: 10.1016/j.jacc.2010.03.085.
21. Jacobs JP, Mayer JE Jr, Pasquali SK, Hill KD, Overman DM, St Louis JD, Kumar SR, Backer CL, Tweddell JS, Dearani JA, et al. The society of thoracic surgeons congenital heart surgery database: 2019 update on outcomes and quality. *Ann Thorac Surg*. 2019;107:691–704.
22. Schilling C, Dalziel K, Nunn R, Du Plessis K, Shi WY, Celermajer D, Winlaw D, Weintraub RG, Grigg LE, Radford DJ, et al. The Fontan epidemic: Population projections from the Australia and New Zealand Fontan Registry. *Int J Cardiol*. 2016;219:14–19. DOI: 10.1016/j.ijcard.2016.05.035.
23. d'Udekem Y, Iyengar AJ, Galati JC, Forsdick V, Weintraub RG, Wheaton GR, Bullock A, Justo RN, Grigg LE, Sholler GF, et al. Redefining expectations of long-term survival after the Fontan procedure twenty-five years of follow-up from the entire population of Australia and New Zealand. *Circulation*. 2014;130:S32–S38. DOI: 10.1161/CIRCULATIONAHA.113.007764.
24. Petit CJ, Fraser CD, Mattamal R, Slesnick TC, Cephus CE, Ocampo EC. The impact of a dedicated single-ventricle home-monitoring program on interstage somatic growth, interstage attrition, and 1-year survival. *J Thorac Cardiovasc Surg*. 2011;142:1358–1366. DOI: 10.1016/j.jtcvs.2011.04.043.
25. Rudd NA, Frommelt MA, Tweddell JS, Hehir DA, Mussatto KA, Frontier KD, Slicker JA, Bartz PJ, Ghanayem NS. Improving interstage survival after Norwood operation: outcomes from 10 years of home monitoring. *J Thorac Cardiovasc Surg*. 2014;148:1540–1547. DOI: 10.1016/j.jtcvs.2014.02.038.
26. Clauss SB, Anderson JB, Lannon C, Lihn S, Beekman RH, Kugler JD, Martin GR. Quality improvement through collaboration: the national pediatric quality improvement collaborative initiative. *Curr Opin Pediatr*. 2015;27:555–562. DOI: 10.1097/MOP.0000000000000263.
27. Bingler M, Erickson LA, Reid KJ, Lee B, O'Brien J, Apperson J, Goggin K, Shirali G. Interstage outcomes in infants with single ventricle heart disease comparing home monitoring technology to three-ring binder documentation: a randomized crossover study. *World J Pediatr Congenit Hear Surg*. 2018;9:305–314. DOI: 10.1177/2150135118762401.
28. Dean PN, Hillman DG, McHugh KE, Gutgesell HP. Inpatient costs and charges for surgical treatment of hypoplastic left heart syndrome. *Pediatr*. 2011;128:e1181. DOI: 10.1542/peds.2010-3742.
29. Feudtner C, Hays RM, Haynes G, Geyer JR, Neff JM, Koepsell TD. Deaths attributed to pediatric complex chronic conditions: national trends and implications for supportive care services. *Pediatr*. 2001;107:e99. DOI: 10.1542/peds.107.6.e99.
30. Stoll BJ, Hansen NI, Bell EF, Walsh MC, Carlo WA, Shankaran S, Laptook AR, Sánchez PJ, Van Meurs KP, Wyckoff M, et al. Trends in care practices, morbidity, and mortality of extremely preterm Neonates, 1993–2012. *JAMA - J Am Med Assoc*. 2015;314:1039–1051. DOI: 10.1001/jama.2015.10244.
31. Parikh K, Hall M, Teach SJ. Bronchiolitis management before and after the AAP guidelines. *Pediatr*. 2014;133:e1–e7. DOI: 10.1542/peds.2013-2005.
32. Kaiser SV, Rodean J, Bekmezian A, Hall M, Shah SS, Mahant S, Parikh K, Auerbach AD, Morse R, Puls HT, et al. Effectiveness of pediatric asthma pathways for hospitalized children: a multicenter, national analysis. *J Pediatr*. 2018;197:165–171. DOI: 10.1016/j.jpeds.2018.01.084.
33. Berry JG, Poduri A, Bonkowsky JL, Zhou J, Graham DA, Welch C, Putney H, Srivastava R. Trends in resource utilization by children with neurological impairment in the United States inpatient health care system: a repeat cross-sectional study. *PLoS Medicine*. 2012;9:e1001158. DOI: 10.1371/journal.pmed.1001158.
34. Bucholz EM, Toomey SL, Schuster MA. Trends in pediatric hospitalizations and readmissions: 2010–2016. *Pediatr*. 2019;143:2010–2016. DOI: 10.1542/peds.2018-1958.
35. Berry JG, Agrawal R, Kuo DZ, Cohen E, Risko W, Hall M, Casey P, Gordon J, Srivastava R. Characteristics of hospitalizations for patients who use a structured clinical care program for children with medical complexity. *J Pediatr*. 2011;159:284–290. DOI: 10.1016/j.jpeds.2011.02.002.
36. Nasr VG, Faraoni D, Valente AM, DiNardo JA. Outcomes and costs of cardiac surgery in adults with congenital heart disease. *Pediatr Cardiol*. 2017;38:1359–1364. DOI: 10.1007/s00246-017-1669-7.
37. Khairy P, Fernandes SM, Mayer JE Jr, Triedman JK, Walsh EP, Lock JE, Landzberg MJ. Long-term survival, modes of death, and predictors of mortality in patients with Fontan surgery. *Circulation*. 2008;117:85–92. DOI: 10.1161/CIRCULATIONAHA.107.738559.
38. Opotowsky AR, Siddiqi OK, Webb GD. Trends in hospitalizations for adults with congenital heart disease in the U.S. *J Am Coll Cardiol*. 2009;5:460–467. DOI: 10.1016/j.jacc.2009.04.037.
39. Seckeler MD, Moe TG, Thomas ID, Meziab O, Andrews J, Heller E, Klewer SE. Hospital resource utilization for common noncardiac diagnoses in adult survivors of single cardiac ventricle. *Am J Cardiol*. 2015;116:1756–1761. DOI: 10.1016/j.amjcard.2015.09.008.
40. Seckeler MD, Moe TG, Thomas ID, Meziab O, Andrews J, Heller E, Klewer SE. Higher cost of hospitalizations for non-cardiac diagnoses in adults with congenital heart disease. *Pediatr Cardiol*. 2018;39:437–444. DOI: 10.1007/s00246-017-1770-y.
41. Singh S, Desai R, Fong HK, Sadolikar A, Samani S, Goyal H. Extracardiac comorbidities or complications in adults with congenital heart disease: a nationwide inpatient experience in the United States. *Cardiovasc Diagn Ther*. 2018;8:825–826. DOI: 10.21037/cdt.2018.09.12.
42. DeMone JA, Gonzalez PC, Gauvreau K, Piercey GE, Jenkins KJ. Risk of death for medicaid recipients undergoing congenital heart surgery. *Pediatr Cardiol*. 2003;24:97–102. DOI: 10.1007/s00246-002-0243-z.
43. Schechter MS, Shelton BJ, Margolis PA, FitzSimmons SC. The association of socioeconomic status with outcomes in cystic fibrosis patients in the United States. *Am J Respir Crit Care Med*. 2001;163:1331–1337. DOI: 10.1164/ajrccm.163.6.9912100.
44. Rossano JW, Kim JJ, Decker JA, Price JF, Zafar F, Graves DE, Morales DLS, Heinle JS, Bozkurt B, Towbin JA, et al. Prevalence, morbidity, and mortality of heart failure-related hospitalizations in children in the United States: a population-based study. *J Card Fail*. 2012;18:459–470. DOI: 10.1016/j.cardfail.2012.03.001.
45. Burstein DS, Shamszad P, Dai D, Almond CS, Price JF, Lin KY, O'Connor MJ, Shaddy RE, Mascio CE, Rossano JW. Significant mortality, morbidity and resource utilization associated with advanced heart failure in congenital heart disease in children and young adults. *Am Heart J*. 2019;209:9–19. DOI: 10.1016/j.ahj.2018.11.010.
46. McCracken C, Spector LG, Menk JS, Knight JH, Vinocur JM, Thomas AS, Oster ME, St Louis JD, Moller JH, Kochilas L. Mortality following pediatric congenital heart surgery: an analysis of the causes of death derived from the national death index. *J Am Heart Assoc*. 2018;7:e010624. DOI: 10.1161/JAHA.118.010624.

SUPPLEMENTAL MATERIAL

Table S1. Trend of CHD Related Admission (Restricted to ages 0-17 years).

Year	All Pediatric Admissions		Pediatric Admissions with CHD							
			All CHD related Admissions		CHD Group					
					Single ventricle disease		Other complex CHD		Simple CHD	
	Weighted Number	% Change*	Weighted Number (%)†	% Change*	Weighted Number (%)†1	% Change*	Weighted Number (%)†2	% Change*	Weighted Number (%)†3	% Change*
2003	6,468,925	0.00	141,604 (0.46)	0.00	7,508 (0.89)	0.00	58,261 (6.90)	0.00	75,836 (8.98)	0.00
2006	6,578,068	1.68	165,564 (0.53)	16.92	8,450 (1.00)	12.55	65,160 (7.72)	11.84	91,954 (10.89)	21.23
2009	6,393,989	-1.16	181,600 (0.58)	28.24	8,618 (1.02)	14.78	65,778 (7.79)	12.90	107,204 (12.69)	41.36
2012	5,850,184	-9.56	169,209 (0.55)	19.49	8,462 (1.00)	12.71	49,956 (5.91)	-14.25	110,791 (13.12)	46.09
2016	5,604,984	-13.36	186,600 (0.60)	31.78	10,468 (1.24)	39.42	62,261 (7.36)	6.87	113,871 (13.47)	50.15

*Percentage change based on 2003 as reference year. †Trend tests for the proportion of admissions among children with CHD over time (p <0.0001). †1Trend tests for the proportion of admissions among children with single ventricle disease over time (p<0.0001). †2Trend tests for the proportion of admissions among children with other complex CHD over time (p < 0.0001). †3Trend tests for the proportion of admissions among children with simple CHD over time (p <0.0001).

Table S2. Mortality in IP for All CHD related Admissions and by CHD group (Restricted to ages 0-17 years).

Year	All Pediatric Mortalities		Pediatric Mortalities with CHD							
			All CHD related Mortalities		CHD Group					
					Single ventricle disease		Other complex CHD		Simple CHD	
	Weighted Number	% Change*	Weighted Number (%)†	% Change*	Weighted Number (%)†1	% Change*	Weighted Number (%)†2	% Change*	Weighted Number (%)†3	% Change*
2003	25,418	0.00	4,573 (17.99)	0.00	644 (14.09)	0.00	1,897(41.47)	0.00	2,032 (44.43)	0.00
2006	25,682	1.04	4,807 (18.72)	5.12	652 (13.57)	1.24	1,852 (38.52)	-2.37	2.303 (47.91)	13.34
2009	24,079	-5.27	5,761 (23.93)	25.98	589 (10.23)	-8.54	1,917 (33.28)	1.05	3,254 (56.49)	60.14
2012	20,842	-18.00	4,824 (23.14)	5.49	533 (11.05)	-17.24	1,650 (34.20)	-13.02	2,641 (54.75)	29.97
2016	20,822	-18.08	5,096 (24.47)	11.44	632 (12.40)	-1.86	1,769 (34.71)	-6.75	2,695 (52.89)	32.63

*Percentage change based on 2003 as reference year. †Trend tests for the proportion of admissions among children with CHD over time (p <0.0001). †1Trend tests for the proportion of admissions among children with single ventricle disease over time (p<0.0001). †2Trend tests for the proportion of admissions among children with other complex CHD over time (p < 0.0001). †3Trend tests for the proportion of admissions among children with simple CHD over time (p <0.0001).

Table S3. Trend Tests across years (Restricted to ages 0-17 years).

	Year							
	2003	**2006**	**2009**	**2012**	**2016**	**Test Statistic**	**DF**	**P-value**
All Admissions, N	6468925	6578068	6393989	5850184	5604984	117663.7	4	<.0001
All Deaths	25418	25682	24079	20842	20822	9.9	4	<.0001
All CHD Admissions, %	2.2	2.5	2.8	2.9	3.3	-126.7	4	<.0001
Single Ventricle Admissions, %	0.9	1.0	1.0	1.0	1.2	-3.9	4	<.0001
CHD Admissions Death, %	18.0	18.7	23.9	23.1	24.5	7.9	4	<.0001
CHD Mortalities by year, %	3.2	2.9	3.2	2.9	2.7	7.9	4	<.0001
Median Inflated Adjusted Charges for CHD Admissions,(IQR)	35,577 (9,303 – 110,439)	41,043 (10,424 – 132,087)	51,332 (11,914 – 170,856)	55,146 (12,961 – 190,534)	61,696 (15,212 – 210,237))	2850.84	4	<.0001

Figure S1. ICD-9/10 Coding Designations.

ICD-9 codes			ICD-10 codes		
				Category	
745.0	7450	Common truncus	Q200	2	1= Single Ventricle Disease
	7451	complete transposition of great vessels	Q20.3	2	2= Other Complex CHD
745.10	74510	complete transposition of great vessels	Q20.3	2	3= Simple CHD (ASD, VSD, PDA)
745.11	74511	DORV	Q20.1	2	
745.12	74512	l-TGA	Q20.5	2	
745.19	74519	Other transposition	Q20.3	2	
745.2	7452	ToF	Q21.3	2	
745.3	7453	Common ventricle	Q20.4	1	
745.4	7454	VSD	Q21.0	3	
745.5	7455	Ostium secundum ASD	Q21.1	3	
	7456	Endocardial cushion defect, unspecified type	Q21.2	3	
745.60	74560	Endocardial cushion defect, unspecified type	Q21.2	3	
745.61	74561	Ostium primum ASD	Q21.2	3	
745.69	74569	other endocardial cushion defect	Q21.2	3	
745.70	7457	cor biloculare	Q20.8	2	
745.80	7458	other bulbus cordis anomaly of septal defect	Q20.8 Q21.8	3	
745.90	7459	unspecified defect of septal closure	Q21.9	3	
746.00	74600	pulmonary valve anomaly, unspecified	Q22.3	2	
746.01	74601	Pulmonary atresia	Q22.0	2	
746.02	74602	congenital pulmonary stenosis	Q22.1	2	
746.09	74609	other anomalies of pulmonary valve	Q22.2	2	
746.1	7461	tricuspid atresia and stenosis, congenital	Q22.4 Q22.9	1	
746.2	7462	ebstein's anomaly	Q22.5	2	
746.3	7463	congenital stenosis of aortic valve	Q23.0	2	
746.4	7464	congenital insufficiency of aortic valve	Q23.1	2	
746.5	7465	congenital mitral stenosis	Q23.2	2	
746.6	7466	congenital mitral insufficiency	Q23.3	2	
746.70	7467	Hypoplastic left heart syndrome	Q23.4	1	
746.81	74681	subaortic stenosis	Q24.4	2	
746.82	74682	Cor triatriatum	Q24.2	2	
746.83	74683	Infundibular pulmonic stenosis congenital	Q24.3	2	
746.84	74684	Obstructive anomalies of heart not elsewhere classified	Q24.8	2	
746.85	74685	Coronary artery anomaly congenital	Q24.5	2	

746.87	74687	Malposition of heart and cardiac apex	Q24.0	2	
746.89	74689	other congenital anomalies of heart	Q24.8	2	
746.90	7469	unspecified anomaly of heart	Q20.9 Q24.9	2	
747.0	7470	Patent ductus arteriosus	Q25.0	3	
747.10	74710	Coarctation of the aorta	Q25.1	2	
747.11	74711	Interruption of aortic arch	Q25.2	2	
747.20	74720	Other congenital anomalies of aorta	Q25.4	2	
747.21	74721	anomalies of aortic arch	Q25.4	2	
747.22	74722	atresia and stenosis of aorta	Q25.2 Q25.3	1	
747.29	74729	other anomalies of aorta	Q25.4	2	
	7473	Congenital anomalies of pulmonary artery		2	
747.40	74740	Congenital anomalies of great veins, unspecified	Q26.9	2	
747.41	74741	Total anomalous pulmonary venous return	Q26.2	2	
747.42	74742	Partial anomalous pulmonary venous connection	Q26.3	2	
	74749	Other anomalies of great veins (Scimitar or LSVC)	Q26.8	2	