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ORIGINAL RESEARCH

Patients With Congenital Heart Disease Undergoing Noncardiac Procedures at Hospitals With and Without a Cardiac Surgical Program

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BACKGROUND: The type and location of hospitals where patients with congenital heart disease (CHD) undergo noncardiac procedures have not been investigated. This study aimed to describe (1) the characteristics of these patients, (2) the distribution of procedures among hospitals with and without a cardiac surgical program and travel distances, (3) the characteristics determining the distribution, and (4) mortality rates.

METHODS AND RESULTS: This is a retrospective cohort analysis of inpatient data from the Center for Healthcare Information and Analysis of the Commonwealth of Massachusetts, Texas Healthcare Information Collection, and Health Care Cost and Utilization Project State Inpatient Database. Children <18 years old with CHD who underwent noncardiac procedures were included. Distances were calculated using the Haversine formula. Logistic regression was performed to evaluate the odds of a procedure at a hospital with a cardiac program. There were 7435 encounters at 235 hospitals analyzed. Most procedures (87.8%) occurred at hospitals with a cardiac program. Patients at a hospital without a cardiac program had simple CHD (72.4%) with <1% with single ventricle disease. At hospitals with a cardiac program, 56.8% had simple CHD, 35.4% complex CHD, and 7.8% single ventricle disease. The median distance traveled was 25.2 miles (interquartile range, 10.3–73.8 miles) to a hospital with a cardiac program and 14.6 miles (interquartile range, 6.2–37.4 miles) to a hospital without a cardiac program (P<0.001). Single ventricle disease (adjusted odds ratio [aOR], 16.25 [95% CI, 7.22–36.61]) and ≥6 chronic conditions (aOR, 1.81 [95% CI, 1.57–2.09]) were associated with performance at a hospital with a cardiac program. Mortality rate was 3.8%.

CONCLUSIONS: Patients with CHD are more likely to travel to a hospital with a cardiac program for noncardiac procedures than to a hospital without; especially patients with single ventricle disease, other complex CHD, and with ≥6 chronic conditions.

Key Words: congenital heart disease ■ hospitals ■ noncardiac procedures ■ travel distance

The incidence of congenital heart disease (CHD) in the United States is estimated to be 6 per 1000 live-born full-term infants.[1] Recent advances in pediatric cardiology, surgery, and critical care have significantly improved the survival rates of patients with CHD, leading to an increase in prevalence in both children and adults.[2,3] Children with significant CHD who require cardiac surgery frequently undergo noncardiac diagnostic, interventional, or surgical procedures under sedation or general anesthesia. The Pediatric Health Information System is an administrative database that contains inpatient, observation, and outpatient surgical data from 52 freestanding children's hospitals. A study using the Pediatric Health Information System database between 2004 and 2012 demonstrated that 41% of children who had undergone surgery to correct

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CLINICAL PERSPECTIVE

What Is New?

- Noncardiac surgical encounters among patients with congenital heart disease continue to increase.
- However, the type and location of hospitals where patients with congenital heart disease undergo noncardiac procedures have not been investigated.

What Are the Clinical Implications?

- Patients with congenital heart disease are more likely to travel to a hospital with a cardiac program for their noncardiac procedures; this is particularly true for patients with single ventricle disease, other complex congenital heart disease, and with ≥6 chronic conditions.

Nonstandard Abbreviations and Acronyms

CCI	Chronic Condition Indicator
SID	State Inpatient Database

CHD in the first year of life also underwent at least 1 noncardiac surgical procedure by the age of 5 years.[4] In addition, analysis of the Pediatric Health Information System database between 2015 and 2019 demonstrated that the total number of noncardiac surgical encounters among patients with a diagnosis of CHD significantly increased each year, from 38 272 in 2015 to 45 993 in 2019.[5]

The type and location of hospitals where patients with CHD undergo their cardiac surgical procedure have been evaluated.[6] In 1 study, 53% of patients traveled to high-volume hospitals (those within the highest-volume quartile for cardiac surgeries), bypassing the nearest congenital heart surgery hospital.[6] However, the type and location of hospitals where patients with CHD undergo noncardiac procedures have not been investigated.

The purpose of this study, using all-encounter data sets from state and federal sources, is to describe (1) the characteristics of patients with CHD undergoing noncardiac diagnostic and therapeutic procedures requiring inpatient admission, (2) the distribution of these procedures between hospitals with and without a dedicated cardiac surgical program and the travel distances to these hospitals, (3) the factors that determine the distribution of patients in each type of hospital, and (4) the mortality rates following these noncardiac procedures.

METHODS

The study was approved by the institutional review board at Boston Children's Hospital and no informed consent was required. The data that support the findings of this study are available from the corresponding author on request and following approval by the Center for Healthcare Information and Analysis of the Commonwealth of Massachusetts, Texas Healthcare Information Collection, and the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project.

Data Source

This is a retrospective cohort analysis of hospital inpatient data obtained directly from the Center for Healthcare Information and Analysis of the Commonwealth of Massachusetts, Texas Healthcare Information Collection, and of State Inpatient Database (SID) obtained from the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project.[7–9] These are administrative, all-payer, inpatient-care databases comprising encounter-level information reported by all hospitals to their respective states. Each data set contains clinical and resource-use information that is included in a typical discharge abstract, and over 100 clinical and nonclinical variables included in a hospital discharge summary. These include primary and secondary diagnoses and procedures (using *International Classification of Diseases*, *Tenth Revision* [*ICD-10*]), admission and discharge status, patient demographic characteristics (eg, sex, age, and race), expected payment source, total charges, and length of hospital stay. Data for 2017 or 2018 from 27 states (Arkansas, Arizona, Colorado, District of Columbia, Delaware, Florida, Georgia, Iowa, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, New Jersey, New Mexico, New York, North Carolina, Nevada, Oregon, Rhode Island, Texas, Utah, Vermont, Washington, and Wisconsin) were gathered. Because not all data elements are included in every SID, the states of Arkansas, Colorado, District of Columbia, Georgia, Maryland, Maine, Michigan, New Mexico, and Nevada were excluded from the distance analysis for the absence of either the zip code or hospital location data.

Study Population

The study population included all neonates, infants, and children <18 years old with a diagnosis of CHD who underwent noncardiac diagnostic or therapeutic procedures in an operating room that required an inpatient admission. CHD was determined using *International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM)* codes and classified as simple CHD, single ventricle

disease, or other complex CHD[10] (Data S1). Chronic conditions were identified according to the Chronic Condition Indicator (CCI). The CCI is an 18-category tool developed by the Agency for Healthcare Research and Quality to classify diagnostic *ICD-10-CM* codes as chronic within the Healthcare Cost and Utilization Project databases.[11,12]

Designation as a noncardiac surgical procedure was identified using the Medicare Severity-Diagnosis Related Group system, which indicates that a major diagnostic or therapeutic procedure was performed in the operating room.[13] Cardiac procedures and procedures related to obstetric care (eg, cesarean section) were excluded. Encounters that include both a cardiac surgical procedure and a noncardiac procedure were excluded.

Study Hospitals

All hospitals participating in the databases as previously described were included. The hospitals were classified as cardiac and noncardiac hospitals based on the presence of a cardiac surgical program. Hospitals performing only ligation of isolated patent ductus arteriosus or <10 cardiac surgeries per year were not considered hospitals with a cardiac program. In addition, 2 authors (V.G.N., M.N.) reviewed the hospitals and identified 4 hospitals that performed <40 procedures and did not include a cardiac program. These centers were included in the centers without a cardiac program for the purpose of analysis.

Statistical Analysis

All analyses were performed within Jupyter notebooks using Python 3.7 and open-source data science tools. We report descriptive statistics for the encounters' demographics and characteristics. Patient demographics with nonnormally distributed data are summarized by their median and interquartile range (IQR). The centroids of the 5-digit zip codes associated with the encounters were used for mapping and analysis of the distance between patient and hospital when both zip code and hospital geolocation were available. Distances were calculated using the Haversine formula.[14–16] Comparisons among hospitals with and without a cardiac program were assessed using the Mann-Whitney *U* test for continuous variables and the χ^2 test for categorical variables. Univariable logistic regression analyses were performed to evaluate the effects of age, cardiac disease, chronic conditions category, payer, and type of procedure on the odds of admission to a cardiac hospital. Multivariable logistic regression analysis without interactions was performed using significant variables from the univariable analysis to estimate the independent association between age, cardiac disease, chronic conditions, and payer with location of care at a hospital with a cardiac program. Odds ratio (OR), adjusted odds ratio (aOR), and 95% CI were calculated. *P* values were 2-tailed and statistical significance set at $P<0.05$.

RESULTS

A total of 7435 encounters of patients younger than 18 years were included in the analysis. These encounters occurred at 235 hospitals, of which 68 (29.0%) were classified as hospitals with a cardiac program and 167 (71.0%) as hospitals without a cardiac program. The total number of procedures was 17 228, with patients undergoing an average of 2.3 procedures per encounter. Most encounters (87.2%) and procedures (87.8%) occurred at hospitals with a cardiac program (Figure S1). Table 1 summarizes the characteristics of the patients and the procedures performed. Patients <12 months old constituted most encounters (62.8%), at both hospitals with (62.9%) and without (61.7%) a cardiac program, accounting for 64% of procedures (11 112/17 228). Table 2 summarizes the characteristics of patients undergoing noncardiac procedures at both hospitals with and without a cardiac program. Fifty-one percent of patients (3789) had 6 or more chronic conditions in the overall cohort. Although 52.9% of patients admitted to a hospital with a cardiac program had 6 or more chronic conditions, only 37.3% of such patients were admitted to hospitals without a cardiac program ($P<0.001$). In hospitals with a cardiac program, the median number of chronic conditions per patient was 6.0 (IQR, 4.0–8.0), and in hospitals without a cardiac program the median number of chronic conditions per patient was 4.0 (IQR, 3.0–7.0).

The classification of cardiac disease in the overall cohort was as follows: simple disease 4370 (58.8%), complex disease 2554 (34.3%), and single ventricle disease 511 (6.9%). Most patients admitted to a hospital without a cardiac program had simple CHD (687 [72.4%]) with <1% of patients classified as single ventricle disease. At hospitals with a cardiac program, the distribution of patients was simple CHD 3683 (56.8%), other complex CHD 2298 (35.4%), and single ventricle disease 505 (7.8%) (Figure 1). Atrial and ventricular septal defects were the most common CHD diagnoses at both types of hospitals. Patients with the complex lesion, hypoplastic left heart syndrome received care exclusively at hospitals with a cardiac program. (Table 3). Public insurance was the most common form of payment overall at both hospitals with and without a cardiac program (Table 2). Therapeutic procedures were more common than diagnostic procedures at both hospitals with 14 913 (98.6%) and without 2086 (98.9%) a cardiac program. The most common procedures were gastrointestinal (gastrotomy tubes, repair

Table 1. Characteristics of Patients and Noncardiac Procedures

Variables	N (%) or median (IQR)
No. of hospitals	235
No. of encounters	7435
Sex	
Male	4201 (56.5)
Female	3232 (43.5)
Unknown	2 (0.0)
Age*	
<12 mo	4666 (62.8)
1–4 y	1446 (19.4)
5–9 y	566 (7.6)
10–14 y	457 (6.1)
15–17 y	276 (3.7)
Race and ethnicity	
White	3088 (41.5)
Black	1037 (13.9)
Hispanic	1424 (19.1)
Asian or Pacific Islander	208 (2.8)
Native American	58 (0.8)
Not specified	460 (6.2)
Missing	922 (12.4)
No. of patients with CCI	
CCI ≥6	3789 (51.0)
CCI <6	3646 (49.0)
Cardiac disease	
Simple CHD	4370 (58.8)
Single ventricle disease	511 (6.9)
Other complex CHD	2554 (34.3)
Encounter based on procedure type	
Therapeutic encounters	7255
Diagnostic encounters	180
No. of procedures	17 228
Procedures per encounter, median (IQR)	2.0 (1.0–3.0)
Therapeutic procedures (therapeutic only, therapeutic and diagnostic)	16 999 (98.7)
Diagnostic procedures	229 (1.3)
Primary payer	
Private	2909 (39.1)
Public	4147 (55.8)
Other	379 (5.1)
Mortality	281/7435 (3.8%)

CCI indicates Chronic Condition Indicator; CHD, congenital heart disease; and IQR, interquartile range.

*One of the states reports 0 to 4 years as 1 category and includes 24 patients (0.3).

of abdominal wall, excision of the ileum) and otolaryngologic (tracheostomy, restriction of esophagogastric junction). The most common encounters were emergent with 3813 (58.8%) at hospitals with a cardiac program and 580 (61.1%) at hospitals without a cardiac program. The most common procedures at hospitals with and without a cardiac program are summarized in Table 3.

The median distance traveled by a patient undergoing a noncardiac procedure was 23.7 (IQR, 9.5–68.2) miles. Figure S2 illustrates the travel pattern of patients with CHD undergoing noncardiac procedures in the overall study population. Figure 2 compares the travel distances to hospitals with and without a cardiac program. The median distance traveled to a hospital with a cardiac program was 25.2 miles (IQR, 10.3–73.8 miles), whereas that to a hospital without a cardiac program was 14.6 miles (IQR, 6.2–37.4 miles) (P<0.001). When the entire cohort was stratified by cardiac disease, patients with single ventricle disease traveling to a hospital with a cardiac program were seen to have the longest median travel distance, 29.1 miles (IQR, 11.0–85.7 miles) (Table S1). When stratified by CCI, patients with ≥6 having their procedure at a hospital with a cardiac program had the longest travel distance (26.9 miles [IQR, 10.5–82.2 miles]).

The findings of univariable and multivariable analyses are presented in Table 4. Single ventricle disease (adjusted odds ratio [aOR], 16.25 [95% CI, 7.22–36.61]) and having 6 or more chronic conditions (aOR, 1.81 [95% CI, 1.57–2.09]) were associated with performance of noncardiac procedures at hospitals with a cardiac program.

The mortality rate for the entire study population was 3.8%. The distribution of total mortality was highest for patients <1 year old (62.8%), followed by 1 to 4 years old (19.4%), 5 to 9 years old (7.6%), 10 to 14 years old (6.1%), and 15 to 17 years old (3.7%). When stratified by age, the mortality rate in patients <1 year old was 5.1% (238/4666), followed by 1.9% (27/1446) in 1 to 4 years old, 1.6% in 5 to 9 years old, 0.7% in 10 to 14 years old, and 1.4% in 15 to 17 years old. Based on CHD diagnosis, the highest mortality rate was among patients with single ventricle disease such as hypoplastic left heart syndrome (9.5%) and other complex CHD such as double outlet right ventricle (6.7%).

DISCUSSION

Patients with CHD are more likely to travel to a hospital with a cardiac program for their noncardiac procedures. More specifically, patients with single ventricle disease and other complex CHD and those with 6 or more chronic conditions are more likely to travel to a cardiac hospital for their noncardiac procedures. Patients presenting to a hospital without a cardiac program are more likely to have simple cardiac disease and a lower CCI number. The mortality rate is highest in patients with single ventricle disease, ≥6 CCI, and <1 year old.

Table 2. Comparison of Characteristics of Patients Undergoing Noncardiac Procedures at Hospitals With and Without a Cardiac Program

Characteristics	With a cardiac program, n (%) unless otherwise indicated	Without a cardiac program, n (%) unless otherwise indicated	*P* value
No. of hospitals, n=235	68	167	
No. of encounters, n=7435	6486 (87.2)	949 (12.8)	
No. of procedures, n=17 228	15 119 (87.8)	2109 (12.2)	
Age*			<0.001
<12 mo	4080 (62.9)	586 (61.7)	
1–4 y	1276 (19.7)	170 (17.9)	
5–9 y	504 (7.8)	62 (6.5)	
10–14 y	397 (6.1)	60 (6.3)	
15–17 y	208 (3.2)	68 (7.2)	
Race and ethnicity			<0.001
White	2683 (41.4)	405 (42.7)	
Black	861 (13.3)	176 (18.5)	
Hispanic	1205 (18.6)	218 (23.0)	
Asian or Pacific Islander	185 (2.9)	23 (2.4)	
Native American	45 (0.7)	13 (1.4)	
Other	396 (6.1)	64 (6.7)	
Missing	880 (13.6)	42 (4.4)	
No. of chronic conditions indicators, median (IQR)	6.0 (4.0–8.0)	4.0 (3.0–7.0); minimum 1, maximum 15	<0.001
No. of encounters with CCI ≥6	3435 (52.9)	354 (37.3)	<0.001
No. of encounters with CCI<6	3051 (47.1)	595 (62.7)	
Procedures			*P* =0.35
Therapeutic	14 913 (98.6)	2086 (98.9)	
Diagnostic	206 (1.4)	23 (1.1)	
Encounter type			<0.001
Elective	2530 (39.0)	322 (33.9)	
Emergent	3813 (58.8)	580 (61.1)	
Other	143 (2.2)	47 (5)	
Primary payer			<0.001
Private	2600 (40.1)	309 (32.6)	
Public	3567 (55.0)	580 (61.1)	
Other	319 (4.9)	60 (6.3)	
Cardiac disease			<0.001
Simple CHD	3683 (56.8)	687 (72.4)	
Single ventricle disease	505 (7.8)	<10 (<1)	
Other complex CHD	2298 (35.4)	256 (26.6)	
Disposition			<0.001
Routine	5113 (78.8)	697 (73.4)	
Home health care	724 (11.2)	142 (15.0)	
Transfer to short-term hospital	500 (3.3)	59 (6.2)	
Transfer other: SNF, ICF	170 (2.6)	29 (3.1)	
Alive, destination unknown	25 (0.4)	…	
Death	259 (3.9)	22 (2.3)	
Mortality			<0.001
Simple CHD	106/3683 (2.9%)	<20/687 (2.9%)	0.71
Single ventricle disease	43/505 (8.5%)	…	
Other complex CHD	110/2298 (4.8%)	<11/256 (4.2%)	0.02

CCI indicates Chronic Condition Indicator; CHD, congenital heart disease; ICF, intermediate care facility; IQR, interquartile range; and SNF, skilled nursing facility.
*One of the states reports 0–4 years as 1 category. It includes 21 patients (0.3%) in cardiac centers and <10 patients in noncardiac centers.

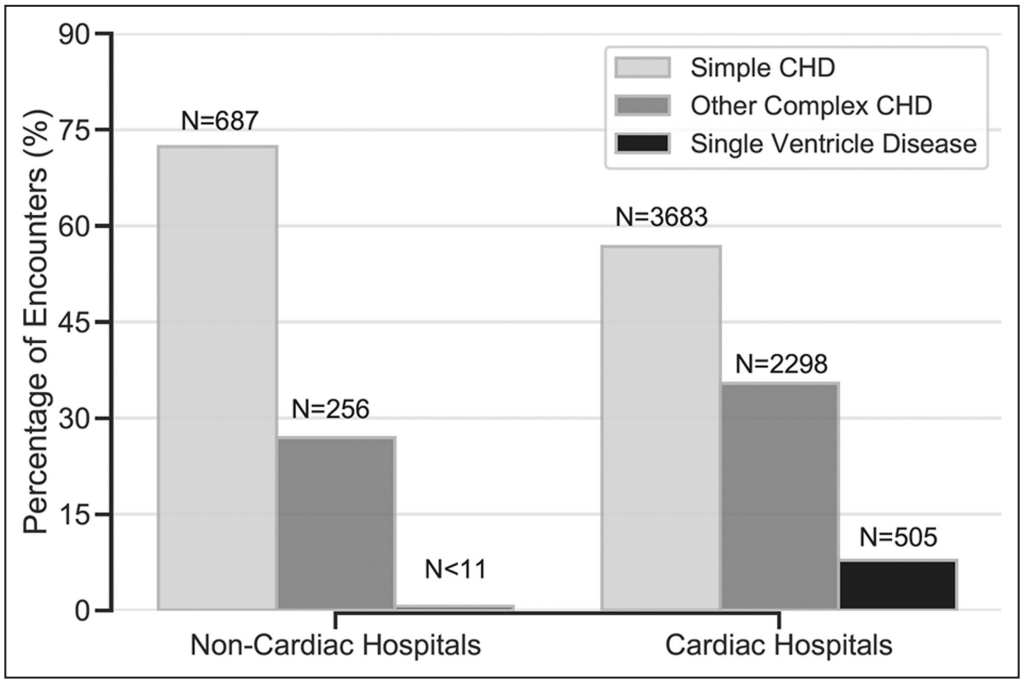

Figure 1. Percentage of encounters based on cardiac disease at hospitals with and without a cardiac surgical program.
CHD indicates congenital heart disease.

These results are similar to previous studies using a large statewide database of outpatient surgery in the United States. Analysis of the California Ambulatory Surgery Database between 2005 and 2011 determined the proportion of children and adults with CHD undergoing noncardiac surgery both outside and within hospitals with a cardiac program.[17] The authors determined that children are more likely than adults (57% of children compared with only 26% of adults) to undergo noncardiac surgery at a hospital with a cardiac program. Both children and adults undergoing a procedure at a hospital without a cardiac program lived a greater distance from a hospital with a cardiac program. However, among pediatric patients, the more common location of care is at a hospital with a cardiac program. Even in cases of emergency procedures, in this study, patients traveled to a hospital with a cardiac program incurring an additional 10 miles. This contrasts with prior surveys demonstrating that in hypothetical scenarios involving the choice between surgery at a local center and a referral hospital, greater proportions of families chose the local center as the distance to the referral hospital increased, even if presented with the tradeoff that there was a higher mortality rate for surgery at the local center.[18]

Using the 2012 SID from 39 states, Welke et al demonstrated that 25% of patients with CHD were traveling >100 miles for their cardiac procedures, with most traveling to hospitals within the highest-volume quartile.[6] Unlike noncardiac procedures where travel distance was associated with cardiac disease severity and number of chronic conditions, travel distance for cardiac surgery

Table 3. Most Common Cardiac Diagnosis for Patients Undergoing Noncardiac Procedures and Most Common Procedures at Hospitals With and Without a Cardiac Program

Variables	Hospital with a cardiac program	Hospital without a cardiac program
Cardiac diagnosis	• Atrial septal defect • Ventricular septal defect • Hypoplastic left heart syndrome • Stenosis of pulmonary artery • Tetralogy of Fallot	• Atrial septal defect • Ventricular septal defect • Stenosis of pulmonary artery • Congenital insufficiency of aortic valve • Other congenital malformations of tricuspid valve
Noncardiac procedure	• Tracheostomy • Gastrostomy tube • Restriction of esophagogastric junction • Repair abdominal wall • Excision of ileum	• Excision of ileum, • Gastrostomy tube • Tracheostomy • Repair abdominal wall • Repair bilateral inguinal region

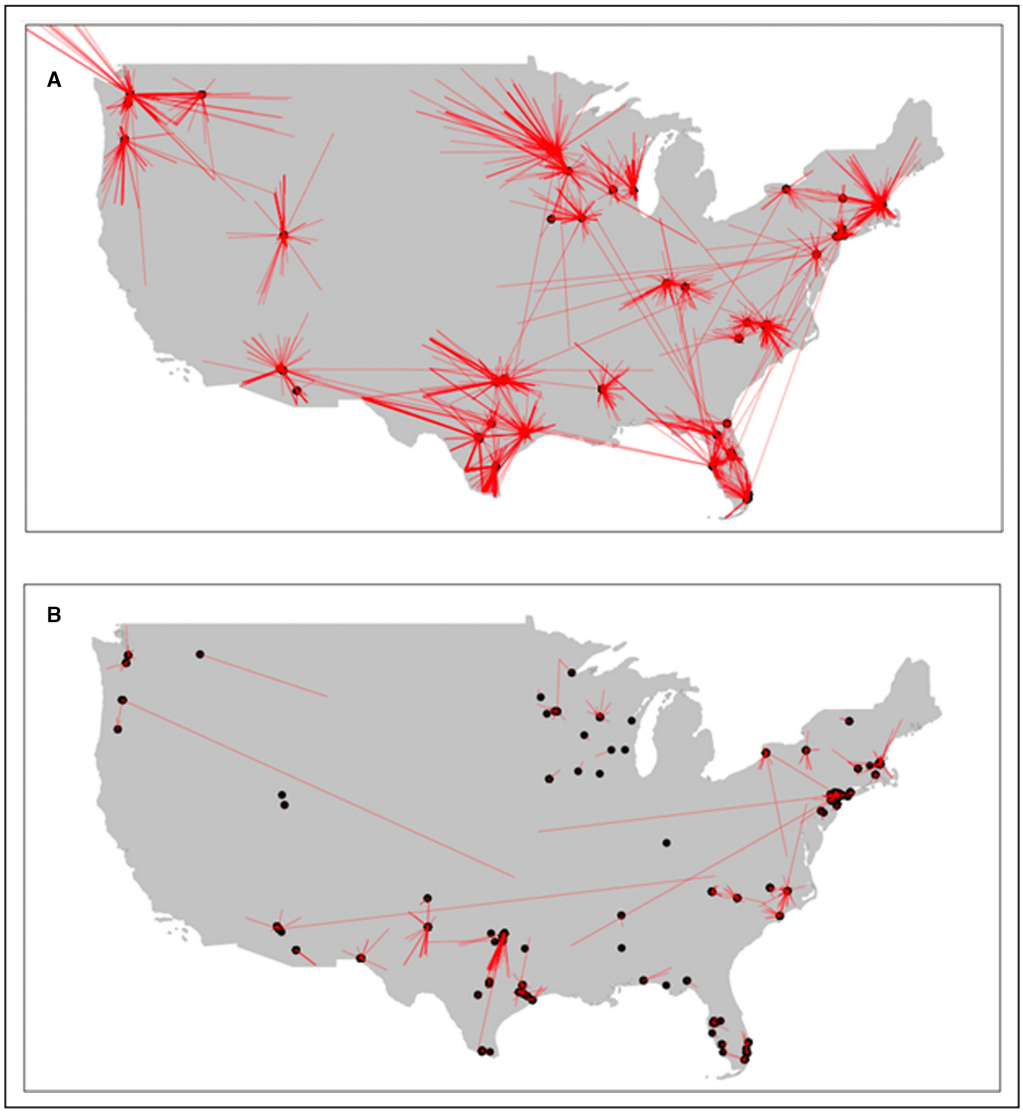

Figure 2. Distance traveled by patients with congenital heart disease to hospitals with and without a cardiac program.
A, The median distance traveled to a cardiac hospital is 25.2 miles (IQR, 10.3–73.8 miles). **B**, The median distance traveled to a noncardiac hospital is 14.6 miles (IQR, 6.2–37.4 miles). Red lines indicate the travel lines between the zip code of residency and the hospital; black dots indicate hospital locations. IQR indicates interquartile range.

was not associated with Risk Adjustment for Congenital Heart Surgery-1 category but was associated with age (with neonates traveling the shortest distance) and insurance status. Self-paying patients were more likely to have surgery close to home.

Patients with chronic conditions have higher rate of morbidity and mortality.[13,19–21] A recent study using the Healthcare Cost and Utilization Project Kids' Inpatient Database demonstrated that patients with CHD and chronic conditions had a higher mortality rate, with an aOR of 1.34 (95% CI, 1.27–1.42). It was found that neonates, infants, and children with circulatory system disorders (eg, secondary pulmonary hypertension) unrelated to CHD, perinatal conditions, and hematologic diseases were at high risk for mortality following noncardiac surgery.[20] In addition, the presence of CCI ≥3 increased the risk of perioperative morbidity (OR, 1.77 [95% CI, 1.46–2.15]) in a large single-center study.[19] In a study using the American College of Surgeons National Surgical Quality Improvement Program pediatric database, patient comorbidities and severity of the cardiac lesion at the time of noncardiac surgical procedures appeared to be the overwhelming predominant determinants of 30-day mortality.[22] The findings of this study are consistent with our study, because our study demonstrated a higher mortality in

Table 4. Univariable and Multivariable Analysis of Location of Care for Patients With CHD Undergoing Noncardiac Procedures

Variable	OR (95% CI)	aOR (95% CI)	*P* value*
Age			
<12 mo	2.28 (1.71–3.03)	3.09 (2.28–4.18)	<0.001/<0.001
1–4 y	2.45 (1.79–3.37)	2.75 (1.97–3.82)	<0.001/<0.001
5–9 y	2.66 (1.82–3.89)	2.85 (1.92–4.20)	<0.001/<0.001
10–14 y	2.16 (1.47–3.18)	2.01 (1.35–2.98)	0.001/0.001
15–17 y	1	1	…
Cardiac disease			
Simple CHD	1	1	-/-
Other complex CHD	1.68 (1.44–1.96)	1.77 (1.51–2.08)	<0.001/-
Single ventricle disease	15.72 (7.00–35.31)	16.25 (7.22–36.61)	<0.001/-
No. of chronic conditions			
CCI <6	1	1	…
CCI ≥6	1.89 (1.64–2.18)	1.81 (1.57–2.09)	<0.001/<0.001
Primary payer			
Public	1	1	…
Private	1.37 (1.18–1.58)	1.41 (1.22–1.64)	<0.001/<0.001
Other	0.86 (0.65–1.15)	0.85 (0.63–1.15)	0.32/0.30
Type of procedure			
Diagnostic	1	…	…
Therapeutic	0.67 (0.40–1.12)	…	0.12

aOR indicates adjusted odds ratio; CCI, Chronic Condition Indicator; CHD, congenital heart disease; and OR, odds ratio.
**P* values for the univariable and multivariable are separated by a slash (/).

patients with single ventricle disease and 6 or more chronic conditions. Because these patients travel to hospitals with a cardiac program for their care, the finding of higher mortality rate (3.9 versus 2.3) at hospitals with a cardiac program is expected. It is important to note that a previous study demonstrated that integration of intrinsic surgical risk into a risk stratification score does not improve prediction of mortality in children with CHD undergoing noncardiac surgery.[22] In children with CHD, patient comorbidities and functional severity of the cardiac lesion are the predominant predictors of 30-day mortality. Hence, the difference in mortality between a hospital with a cardiac program and without a cardiac program in patients with the same CHD diagnosis could be different because of the functional severity of cardiac disease and/or the number of comorbidities, which is found to be higher at hospitals with a cardiac program.

The most common types of noncardiac procedures performed in patients with CHD in this study are consistent with previous studies that have demonstrated that general surgical and otolaryngologic procedures are the most common procedures performed in the first 5 years of life following infant cardiac surgery.[4,5]

An important limitation of our study is the lack of granular stratification of the severity of CHD in the SID database. The CHD subtype based on complexity, whether the defect was repaired or unrepaired, and the associated residual lesion burden are all known to impact a child's perioperative risk, but are not available in the SID database.[22,23] Because of the limited number of patients with single ventricle disease presenting to hospitals without a cardiac program, evaluation of the potential effect modification between single ventricle disease and chronic conditions in determining the location of the noncardiac procedure was not possible. However, we were able to perform multivariable analysis adjusting for the different significant factors in determining the location of the noncardiac procedure. Additional limitations inherent to registry studies include selection bias, the potential for inaccurate coding, and the fact that individual patients may have presented for multiple encounters. In addition, reporting included in the SID is program based rather than hospital based, and several small satellite hospitals may report under a larger institutional umbrella. This may prevent identification of satellite hospitals and result in consolidation of their data with that of the major parent hospital. Finally, although analyses of inpatient pediatric surgery using the SID and the Kid's Inpatient Database (the largest pediatric care sample database in the United States comprising 47 US states) show similar results and practice patterns, the generalizability of our findings using 27 US states should be taken with caution, because the patterns of care in the states not included might differ.[24,25]

In conclusion, patients with single ventricle disease and other complex CHD and patients with ≥6 chronic conditions are more likely to travel to a hospital with a cardiac program. Understanding the distribution of noncardiac procedures based on a patient's complexity may guide allocation of hospital resources and determination of the required staffing expertise, especially in hospitals with a cardiac program, aiming to improve outcomes of patients with CHD.

ARTICLE INFORMATION

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Disclosures

None.

Supplemental Material

Data S1
Table S1
Figures S1–S2

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SUPPLEMENTAL MATERIAL

Data S1.

ICD 10 coding designation. (Edelson JB, Rossano JW, Griffis H, Quarshie WO, Ravishankar C, O'Connor MJ, Mascio CE, Mercer-Rosa L, Glatz AC, Lin KY. Resource Use and Outcomes of Pediatric Congenital Heart Disease Admissions: 2003 to 2016. J Am Heart Assoc. 2021 Feb 16;10(4):e018286. doi: 10.1161/JAHA.120.018286. Epub 2021 Feb 6. PMID: 33554612; PMCID: PMC7955343.)

ICD 10 Codes	ICD 10 Description	CHD classification
Q20.0	Common arterial trunk	Other Complex CHD
Q20.1	Double Outlet Right Ventricle	Other Complex CHD
Q20.3	Discordant ventriculoarterial connection	Other Complex CHD
Q20.4	Double inlet ventricle	Single Ventricle Disease
Q20.5	Discordant atrioventricular connection	Other Complex CHD
Q20.6	Isomerism of atrial appendages	Other Complex CHD
Q20.8	Other congenital malformations of cardiac chambers and connections	Other Complex CHD
Q20.9	Congenital malformation of cardiac chambers and connections, unspecified	Other Complex CHD
Q21.0	Ventricular septal defect	Simple CHD
Q21.1	Atrial septal defect	Simple CHD
Q21.2	Atrioventricular septal defect	Simple CHD
Q21.3	Tetralogy of Fallot	Other Complex CHD
Q21.4	Aortopulmonary septal defect	Simple CHD
Q21.8	Other congenital malformation of cardiac septa	Simple CHD
Q21.9	Congenital malformation of cardiac septum, unspecified	Simple CHD
Q22.0	Pulmonary atresia	Other Complex CHD
Q22.1	Congenital pulmonary valve stenosis	Other Complex CHD
Q22.2	Congenital pulmonary valve insufficiency	Other Complex CHD
Q22.3	Other congenital malformations of pulmonary valve	Other Complex CHD
Q22.4	Congenital tricuspid stenosis	Single Ventricle Disease
Q22.5	Ebstein's anomaly	Other Complex CHD
Q22.6	Hypoplastic right heart syndrome	Single Ventricle Disease
Q22.8	Other congenital malformations of tricuspid valve	Other Complex CHD
Q22.9	Congenital malformation of tricuspid valve, unspecified	Single Ventricle Disease
Q23.0	Congenital stenosis of aortic valve	Other Complex CHD
Q23.1	Congenital insufficiency of aortic valve	Other Complex CHD
Q23.2	Congenital mitral stenosis	Other Complex CHD
Q23.3	Congenital mitral insufficiency	Other Complex CHD
Q23.4	Hypoplastic left heart syndrome	Single Ventricle Disease
Q23.8	Other congenital malformations of aortic and mitral valves	Other Complex CHD

Q23.9	Congenital malformation of aortic and mitral valves, unspecified	Other Complex CHD
Q24.0	Dextrocardia	Other Complex CHD
Q24.2	Cor Triatriatum	Other Complex CHD
Q24.3	Pulmonary infundibular stenosis	Other Complex CHD
Q24.4	Congenital subaortic stenosis	Other Complex CHD
Q24.5	Malformation of coronary vessels	Other Complex CHD
Q24.8	Other specified congenital malformations of the heart	Other Complex CHD
Q24.9	Congenital malformation of heart, unspecified	Other Complex CHD
Q25.0	Patent ductus arteriosus	Simple CHD
Q25.1	Coarctation of aorta	Other Complex CHD
Q25.2	Atresia of aorta	Other Complex CHD
Q25.21	Interruption of aortic arch	Other Complex CHD
Q25.29	Other atresia of aorta	Single Ventricle Disease
Q25.3	Supravalvar aortic stenosis	Simple CHD
Q25.4	Congenital malformation of aorta unspecified	Other Complex CHD
Q25.42	Hypoplasia of aorta	Other Complex CHD
Q25.43	Congenital aneurysm of aorta	Other Complex CHD
Q25.44	Congenital dilation of aorta	Other Complex CHD
Q25.45	Double aortic arch	Other Complex CHD
Q25.46	Tortuous aortic arch	Other Complex CHD
Q25.47	Right aortic arch	Other Complex CHD
Q25.48	Anomalous origin of subclavian artery	Other Complex CHD
Q25.49	Other congenital malformations of aorta	Other Complex CHD
Q25.5	Atresia of pulmonary artery	Other Complex CHD
Q25.6	Stenosis of pulmonary artery	Other Complex CHD
Q25.7	Other congenital malformations of pulmonary artery	Other Complex CHD
Q25.71	Coarctation of pulmonary artery	Other Complex CHD
Q25.72	Congenital pulmonary arteriovenous malformation	Other Complex CHD
Q25.79	Other congenital malformations of pulmonary artery	Other Complex CHD
Q25.8	Other congenital malformations of other great arteries	Other Complex CHD
Q25.9	Congenital malformation of great arteries, unspecified	Other Complex CHD
Q26.1	Persistent left superior vena cava	Other Complex CHD
Q26.2	Total anomalous pulmonary venous connection	Other Complex CHD
Q26.3	Partial anomalous pulmonary venous connection	Other Complex CHD
Q26.4	Anomalous pulmonary venous connection, unspecified	Other Complex CHD
Q26.8	Other congenital malformations of great veins	Other Complex CHD
Q26.9	Congenital malformation of great vein, unspecified	Other Complex CHD

Table S1. Travel Distances to Hospitals With And Without A Cardiac Program Based On Patient and Encounter Characteristics.

Location (n=5,628) *	**Hospital with a Cardiac Program (n=4,585)**	**Hospital without a cardiac program (n=719)**	
Distance	Median (IQR)	Median (IQR)	**p-values**
Distance traveled	25.2 (10.3-73.8)	14.6 (6.2-37.4)	P<0.001
Number of Chronic Condition Indicators			
CCI>=6	26.9 (10.5-82.2)	15.4 (5.6-36.4)	P<0.001
CCI<6	24.4 (10.0-65.3)	14.5 (6.6-39.6)	P<0.001
Pay Group			
Private	25.1 (11.5-69.1)	14.8 (7.4-31.9)	P<0.001
Public	24.7 (8.7-73.8)	14.7 (5.4-39.6)	P<0.001
Other	38.0 (13.0-95.5)	12.0 (6.9-75.7)	P<0.001
Cardiac Disease			
Simple CHD	23.6 (9.6-67.2)	14.5 (6.2-40.5)	P<0.001
Single Ventricle Disease	29.1 (11.0-85.7)	27.3 (20.7-39.0) †	P=0.48
Other complex CHD	27.2 (11.2-83.7)	14.9 (6.3-31.9)	P<0.001
Type of Encounter			
Elective	26.2 (10.8-76.6)	14.1 (6.2-39.6)	P<0.001
Emergency	24.7 (10.0-73.3)	14.7 (6.2-36.9)	P<0.001
Other	22.1 (7.4-58.8)	15.8 (9.5-38.2)	P=0.18

*subset of encounters where travel distance estimation was viable; †encounter count less than 10.

CCI, Chronic Condition Indicator; CHD, congenital heart disease; IQR, interquartile range.

Figure S1. Flow Diagram.

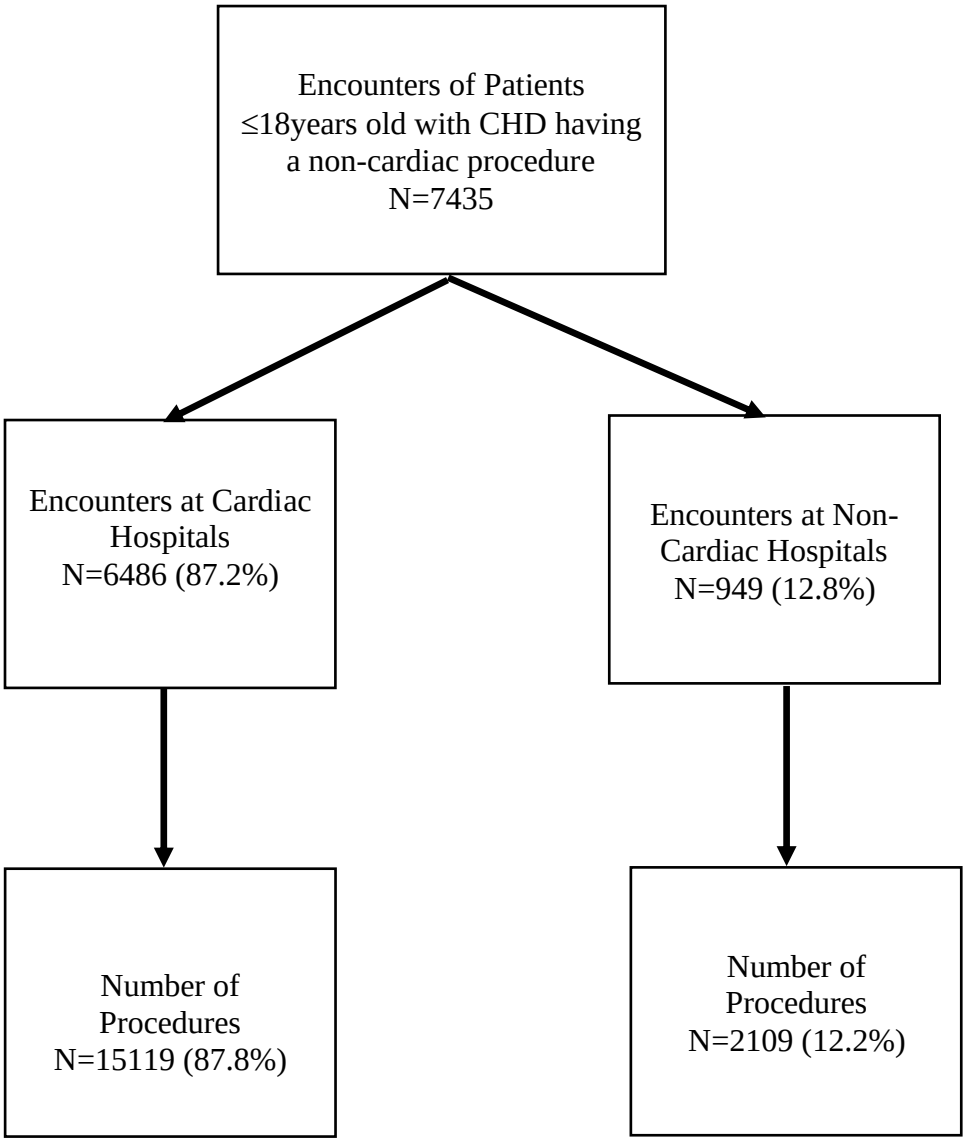

Figure S2. This figure is a representation of the Distance Traveled by Patients with Congenital Heart Disease in the United States. The median traveled distance is 23.7 (Interquartile Range: 9.9-68.2) miles.