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. 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. 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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CHD in the first year of life also underwent at least 1 noncardiac surgical procedure by the age of 5 years. 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 (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 χ² 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
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.

| Variables | N (%) or median (IQR) |
|-----------|-----------------------|
| No. of hospitals | 235 |
| No. of encounters | 7435 |
| Sex | Male 4201 (66.5) 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 | 17228 |
| Procedures per encounter, median (IQR) | 2.0 (1.0–3.0) |
| Therapeutic procedures (therapeutic only, therapeutic and diagnostic) | 16999 (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).
### 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 (8.7)                                                  |         |
| 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%)                                          | <20/887 (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.
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. 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.

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. 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               | • Atrial septal defect                  |
|                                                          | • Ventricular septal defect          | • Ventricular septal defect             |
|                                                          | • Hypoplastic left heart syndrome    | • Stenosis of pulmonary artery          |
|                                                          | • Stenosis of pulmonary artery       | • Congenital insufficiency of aortic valve |
|                                                          | • Tetralogy of Fallot                | • Other congenital malformations of tricuspid valve |
| Noncardiac procedure                                       | • Tracheostomy                       | • Excision of ileum,                   |
|                                                          | • Gastrostomy tube                   | • Gastrostomy tube                     |
|                                                          | • Restriction of esophagogastric junction | • Tracheostomy                        |
|                                                          | • Repair abdominal wall              | • Repair abdominal wall                |
|                                                          | • Excision of ileum                  | • Repair bilateral inguinal region     |
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. 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. 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. 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. The findings of this study are consistent with our study, because our study demonstrated a higher mortality in

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.
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

### 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                 | 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 (/).
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.

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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 ventercle                                       | 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                 |
| Code   | Description                                                                 | Category               |
|--------|-----------------------------------------------------------------------------|------------------------|
| 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                                                      | Other Complex CHD      |
| 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)* | p-values |
|----------------------|---------------------------------------------|-----------------------------------------------|----------|
| **Distance**         | Median (IQR)                                | Median (IQR)                                  | P<0.001 |
| 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.

Encounters of Patients ≤18 years old with CHD having a non-cardiac procedure
N=7435

Encounters at Cardiac Hospitals
N=6486 (87.2%)

Number of Procedures
N=15119 (87.8%)

Encounters at Non-Cardiac Hospitals
N=949 (12.8%)

Number of Procedures
N=2109 (12.2%)
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.