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Variability in noncardiac surgical procedures in children with congenital heart disease

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ABSTRACT

Background: The purpose of this study was to examine the volume and variability of noncardiac surgeries performed in children with congenital heart disease (CHD) requiring cardiac surgery in the first year of life.
Methods: Patients who underwent cardiac surgery by 1 year of age and had a minimum 5-year follow-up at 22 of the hospitals contributing to the Pediatric Health Information System database between 2004 and 2012 were included. Frequencies of noncardiac surgical procedures by age 5 years were determined and categorized by subspecialty. Patients were stratified according to their maximum RACHS-1 (Risk Adjustment in Congenital Heart Surgery) category. The proportions of patients across hospitals who had a noncardiac surgical procedure for each subspecialty were compared using logistic mixed effects models.
Results: 8857 patients underwent congenital heart surgery during the first year of life, 3621 (41%) of whom had 13,894 noncardiac surgical procedures by 5 years. Over half of all procedures were in general surgery (4432; 31.9%) or otolaryngology (4002; 28.8%). There was significant variation among hospitals in the proportion of CHD patients having noncardiac surgical procedures. Compared to children in the low risk group (RACHS-1 categories 1–3), children in the high-risk group (categories 4–6) were more likely to have general, dental, orthopedic, and thoracic procedures.
Conclusions: Children with CHD requiring cardiac surgery frequently also undergo noncardiac surgical procedures; however, considerable variability in the frequency of these procedures exists across hospitals. This suggests a lack of uniformity in indications used for surgical intervention. Further research should aim to better standardize care for this complex patient population.

Congenital heart disease (CHD) is the most common type of congenital anomaly, occurring in up to 1% of all live births. CHD is characterized by a wide range of clinical presentations, anatomic variations, and expected outcomes [1]. Within this population, some anatomic anomalies are more severe than others, and children who require intervention by one year of age have been defined as having critical CHD [2,3]. These patients frequently also undergo noncardiac surgical procedures for the management of both comorbid conditions and additional noncardiac congenital anomalies [4]. The need for multiple major operative procedures in this population is of particular concern owing to the more complicated anesthetic management and increased risk for perioperative complications [5–12].

There is little information regarding the types and frequencies of noncardiac procedures that are commonly performed in patients with CHD. Most studies present a single institutional experience, which limits generalizability and is inadequate to assess variability in practice across institutions. Obtaining a better understanding of the noncardiac surgical procedures performed in patients with CHD at tertiary children's hospitals can be informative for family counseling and setting expectations. In addition, examining procedure types and frequencies across institutions can allow us to identify variation in practice and to determine factors that may account for such variation [13].

The objectives of this study were (1) to characterize the types and frequencies of noncardiac procedures performed in patients with CHD undergoing cardiac surgery within the first year of life across a multi-institutional cohort of freestanding children's hospitals, and (2) to examine variability in practice across institutions.

1. Methods

1.1. Data source and cohort development

A multi-institutional cohort of patients with critical CHD undergoing cardiac surgery by one year of age was developed using the

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Pediatric Health Information System (PHIS), an administrative database that contains inpatient, observation, emergency department, and ambulatory surgery discharge/encounter data from 44 freestanding children's hospitals that are part of the Children's Hospital Association. The PHIS contains International Classification of Diseases 9th Revision, Clinical Modification (ICD-9-CM) diagnostic and procedure codes, date-stamped billing data, and other administrative data from 44 free-standing children's hospitals [13–15].

Patients born between January 2004 and June 2007 who had an ICD-9-CM diagnosis code for CHD (745.0–747.49, except 746.86 "congenital heart block") and a cardiac surgical procedure code by one year of age were included (Fig. 1) [16]. Pediatric cardiac surgical procedures were defined by adapting the algorithm utilized by The Agency for Healthcare Research and Quality pediatric heart surgery quality indicators [17]. Catheter-based interventions for CHD are not included in this algorithm. Patients who were premature or under the age of 30 days and underwent patent ductus arteriosus (PDA) ligation only, and patients who underwent cardiac transplantation as their only cardiac procedure were excluded. In order to capture noncardiac surgical procedures performed in a variety of settings, only hospitals that submitted data from all encounter types during the entire time period of study were included.

The frequencies of all procedures other than cardiac surgeries performed prior to age 5 were examined. A noncardiac procedure was defined as a procedure performed in an operating room that was not part of palliating the cardiac lesion. These procedures were manually reviewed to exclude therapeutic interventions that have ICD-9-CM procedure codes, but do not represent surgical procedures (e.g. 38.93 venous catheter not elsewhere classifiable, 99.04 packed cell transfusion). In addition, thoracotomy and thymus resection/excision procedure codes were excluded if they occurred on the same day as any cardiac procedure, as these were likely part of the cardiac operation. The remaining procedures were classified into one of nine subspecialty divisions by the authors: general surgery, otolaryngology, dental or oral and maxillofacial surgery (OMFS), urology, noncardiac thoracic surgery, plastic surgery, ophthalmology, orthopedic surgery, and neurosurgery. A table of the included procedures can be viewed at https://sharedoc.nchri.org/CSOR/Pages/ProcedureTable.aspx.

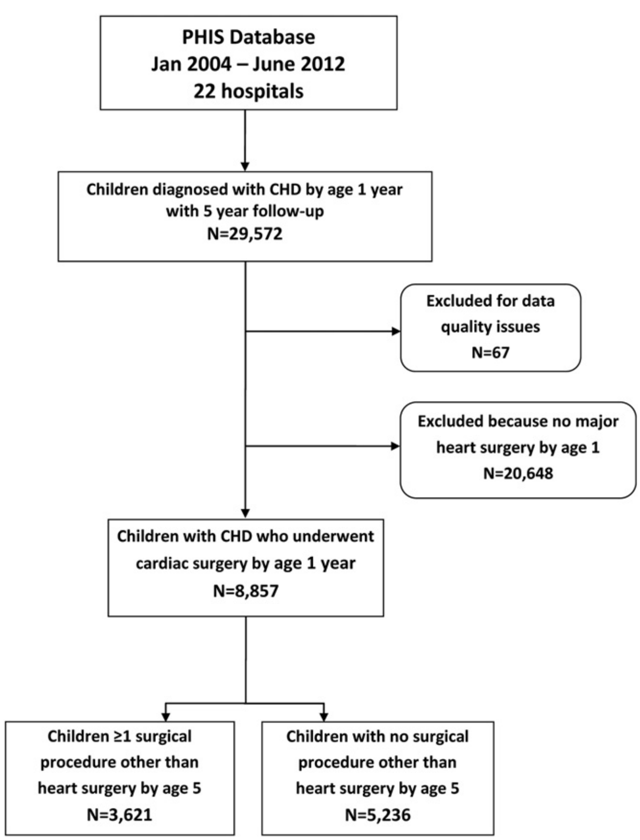

Fig. 1. Strategy used to identify the cohort of patients with critical CHD undergoing non-cardiac surgical procedures by 5 years of age within the PHIS database.

1.2. Risk stratification

CHD patients were stratified by the Risk Adjustment in Congenital Heart Surgery, version 1 (RACHS-1) method, which is a consensus-based system used widely in administrative data that stratifies congenital heart operations based on associated inhospital mortality risk [18]. For the purposes of this analysis, these categories were then combined into low risk (RACHS-1 categories 1–3) and high risk (categories 4–6) groups. Patients with no assigned RACHS-1 category werce not included in these stratified analyses. For patients who underwent multiple different cardiac surgical procedures, their highest RACHS-1 category was used for classification purposes in order to capture the maximum severity of their CHD.

1.3. Statistical analysis

Patient demographic and clinical characteristics were reported as frequencies and percentages and were compared between groups with and without a noncardiac procedure using Pearson chi square tests. A logistic mixed effects model for each subspecialty was used to compare the proportion of CHD patients at each hospital who had a noncardiac surgical procedure in that specialty. The models included a random intercept for each hospital, and the significance of the between-hospital variability was tested with a likelihood ratio test for the variance of the random effect. Interhospital variability was examined before and after adjustment for RACHS-1 category, hospital volume of all noncardiac procedures in patients less than 5 years of age included for the particular specialty being evaluated, and additional patient-level characteristics that differed significantly between patients with and without a noncardiac procedure. All patients were included in the above analyses; those patients who could not be assigned a RACHS-1 category were included as another category of the RACHS-1 variable in these analyses. Analyses based on RACHS-1 category grouping into low or high groups were also performed; these stratified analyses excluded patients who could not be assigned a RACHS-1 category. To display interhospital variability, empirical Bayes estimates and confidence intervals of the random hospital-specific intercepts from the logistic mixed effects models were plotted after inverse logit transformation. Outlier hospitals were defined as those whose 95% confidence interval after adjustment did not include the overall average proportion. Finally, as a sensitivity analysis, because we expected there to be differences between patients who did and did not die inhospital by 5 years of age, and because those patients who died had no procedures afterwards, we repeated all analyses in only those patients who did not die at a PHIS hospital by age 5. All statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC). Statistical significance was defined as $p < 0.05$. The conduct of this study was approved by Nationwide Children's Hospital Institutional Review Board.

2. Results

2.1. Cohort of patients with critical CHD

Twenty-two of the 44 participating PHIS hospitals submitted inpatient, observation, and ambulatory surgery data for the entirety of 2004–2012. Of the 29,505 patients with ICD-9-CM diagnosis codes for CHD treated at these hospitals, 8857 underwent a cardiac surgical procedure within the first year of life and were included in the present analysis (Fig. 1). By 5 years of age, 3621 (40.9%) of these children underwent a total of 13,894 noncardiac surgical procedures.

Table 1
Characteristics of the study cohort of patients with CHD.

Characteristic	Overall cohort (N = 8857) N (%) or median (IQR)	Patients with noncardiac procedures (N = 3621)	Patients without noncardiac procedures (N = 5236)	P
Male gender	4934 (55.7)	2123 (58.6)	2811 (53.7)	<**.0001**
Race				
White	5892 (66.5)	2490 (68.8)	3402 (65.0)	**0.0005**
Black	1207 (13.6)	475 (13.1)	732 (14.0)	
Other/unknown	1758 (19.9)	656 (18.1)	1102 (21.1)	
Age at first heart surgery				
<30 days	3831 (43.3)	1794 (49.5)	2037 (38.9)	<**.0001**
≥30 days and <1 year	5026 (56.7)	1827 (50.5)	3199 (61.1)	
Premature birth	953 (10.8)	566 (15.6)	387 (7.4)	<**.0001**
Major noncardiac structural anomaly	1382 (15.6)	1080 (29.8)	302 (5.8)	<**.0001**
Down syndrome	1221 (13.8)	583 (16.1)	638 (12.2)	<**.0001**
Other major chromosomal anomaly	374 (4.2)	244 (6.7)	130 (2.5)	<**.0001**
Multiple cardiac surgery admissions	2142 (24.2)	1212 (33.5)	930 (17.8)	<**.0001**
Inhospital death by age 5				
At first cardiac surgery admission	546 (6.2)	254 (7.0)	292 (5.6)	**0.006**
At a subsequent admission	235 (2.7)	164 (4.5)	71 (1.4)	<**.0001**
Maximum RACHS-1 category				
1	725 (8.2)	255 (7.0)	470 (9.0)	<**.0001**
2	3036 (34.3)	997 (27.5)	2039 (38.9)	
3	2868 (32.4)	1278 (35.3)	1590 (30.4)	
4	1342 (15.2)	589 (16.3)	753 (14.4)	
5/6	660 (7.5)	399 (11.0)	261 (5.0)	
None assigned*	226 (2.6)	103 (2.8)	123 (2.4)	

* This group includes patients with procedure codes that are not classified by the RACHS-1 algorithm.

Demographic and clinical characteristics of the study cohort are shown in Table 1. In our cohort, patients who underwent noncardiac procedures were more likely to be premature (15.6% vs. 7.4%), have noncardiac congenital anomalies (29.8% vs. 5.8%), and have Down syndrome (16.1% vs. 12.2%) or another chromosomal anomaly (6.7% vs. 2.5%) ($p < 0.001$ for all). They were also more likely to have multiple admissions for additional cardiac procedures (33.5% vs. 17.8%, $p < 0.0001$) and had higher inhospital mortality rates by 5 years of age (11.5% vs. 7%, $p < 0.01$). General surgical procedures (N = 4,432; 31.9%) and otolaryngology procedures (N = 4002; 28.8%) accounted for the majority of noncardiac operations (Table 2).

2.2. Distribution of noncardiac procedures across RACHS-1 categories

The distribution of CHD patients undergoing noncardiac surgical procedures by maximum RACHS-1 category is shown in Table 1. Approximately 38.2% of patients in the low RACHS-1 group underwent a noncardiac procedure compared to 50.6% in the high RACHS-1 group. The numbers of procedures performed by each surgical subspecialty stratified by RACHS-1 group are shown in Table 2; most of the procedures (72.8%) were performed in patients in the low RACHS-1 group. The most common types of noncardiac procedures performed were otolaryngology procedures in patients in the low RACHS-1 group (81.7%) and noncardiac thoracic surgical procedures in patients in the high RACHS-1 group (38.8%) (Table 2). Among patients who had any noncardiac operations, patients in the low RACHS-1 group underwent significantly more noncardiac operations by age 5 than patients in the high RACHS-1 group (median (IQR): 3 (1, 5) vs. 2 (1, 4), $p < 0.0001$); this statistically significant difference remained after adjustment for inhospital mortality by age 5.

After adjustment for differences in demographic and clinical characteristics, patients in the high RACHS-1 group were more likely than those in the low RACHS-1 group to have at least one general surgical, dental/OMFS, orthopedic, or thoracic procedure by age 5 (Table 3). In contrast, patients in the High RACHS-1 group were significantly less likely to undergo an ophthalmologic procedure. These findings were similar when the trend across increasing individual RACHS-1 score categories was examined rather than between the low and high groups.

2.3. Sensitivity analysis based on inhospital mortality

When the patients who died inhospital by age 5 were examined, they were found on average to be younger at their first heart surgery and more likely to have government insurance, high RACHS-1 score, a major non-cardiac structural anomaly, a major chromosomal anomaly or syndrome other than Down syndrome, and to have been born prematurely. They were less likely to have Down syndrome or to have

Table 2
Frequency of noncardiac surgical procedures performed in CHD patients by surgical subspecialty.

Subspecialty division	Total no. procedures (column %)	Low RACHS-1 group (row %)	High RACHS-1 group (row %)
General surgery	4432 (31.9)	3148 (71.0)	1133 (25.6)
Otolaryngology	4002 (28.8)	3271 (81.7)	614 (15.3)
Dental/OMFS	1494 (10.8)	962 (64.4)	507 (33.9)
Urology	1199 (8.6)	856 (71.4)	312 (26.0)
Noncardiac thoracic	850 (6.1)	499 (58.7)	330 (38.8)
Soft tissue/plastics	635 (4.6)	426 (67.1)	197 (31.0)
Ophthalmology	581 (4.2)	464 (79.9)	76 (13.1)
Orthopedics	432 (3.1)	284 (65.7)	127 (29.4)
Neurosurgery	269 (1.9)	209 (77.7)	52 (19.3)
Total	**13894**	**10119 (72.8)**	**3348 (24.1)**

Data are shown as frequencies and column percentages for the total procedures and row percentages for the low and high RACHS-1 group columns.

Table 3
Number of CHD patients undergoing noncardiac surgical procedures by surgical subspecialty and by RACHS-1 groups.

Subspecialty division	Total patients	Low RACHS-1 group, N (%)	High RACHS-1 group, N (%)	Adjusted odds ratio (95% CI)	P value
General surgery	1850	1265 (68.4)	526 (28.4)	1.25 (1.06, 1.48)	**0.01**
Otolaryngology	1256	986 (78.5)	229 (18.2)	0.83 (0.67, 1.03)	0.08
Dental/OMFS	413	271 (65.6)	134 (32.5)	1.54 (1.15, 2.06)	**0.004**
Urology	846	594 (70.2)	230 (27.2)	1.19 (0.94, 1.51)	0.14
Noncardiac thoracic	536	308 (57.5)	213 (39.7)	1.93 (1.46, 2.54)	<**0.0001**
Soft tissue/plastics	462	312 (67.5)	141 (30.5)	1.20 (0.91, 1.58)	0.20
Ophthalmology	237	190 (80.2)	35 (14.8)	0.51 (0.30, 0.90)	**0.02**
Orthopedics	241	151 (62.7)	83 (34.4)	1.52 (1.03, 2.23)	**0.03**
Neurosurgery	131	99 (75.6)	29 (22.1)	0.63 (0.37, 1.07)	0.09

Overall patients in each group are as follows: Total, N = 8857; Low RACHS-1 group, N = 6629; High RACHS-1 group, N = 2002. Data are shown as frequencies and row percentages are given for the low and high RACHS-1 group columns. Odds ratios indicate the odds of having at least one noncardiac procedure in that surgical specialty by age 5 years for high (categories 4–6) vs. low (categories 1–3) RACHS-1 groups after adjustment for hospital volume of the included procedures in that specialty in all patients under 5 years of age, prematurity, presence of a major noncardiac anomaly, presence of Down syndrome, presence of another major chromosomal anomaly, gender, age at first heart surgery, race, having had multiple cardiac surgery admissions by age 5, and inhospital death by age 5.

multiple cardiac surgery admissions ($p < 0.01$ for all, data not shown). However, when all analyses were reexamined in only those patients who did not die inhospital by age 5, the findings were similar to those in the total cohort (Table 4).

2.4. Variability in noncardiac surgical procedures across hospitals

Following the exclusion of one hospital that had only 8 patients in the study cohort, 21 hospitals (median number of patients in study cohort per hospital n = 407, range: 83, 1163) were included in analyses of interhospital variability. The proportion of cardiac surgery patients who had noncardiac surgery showed significant variation among the 21 hospitals for all specialties ($p < 0.0001$ for all except neurosurgery, $p < 0.01$) (Fig. 2). Prior to adjustment for patient and hospital-level factors, these proportions showed the following ranges: general surgery 15–32%, otolaryngology 5–28%, dental surgery 1–10%, and urology 4–22%. Significant interhospital variability remained for all subspecialties except neurosurgery ($p = 0.09$ after adjustment) after adjusting for age at first cardiac surgery, gender, race, multiple heart surgery admissions, inhospital death before age 5, prematurity, major noncardiac structural anomalies, Down syndrome, other chromosomal anomalies, RACHS-1 severity category, and overall hospital volume of procedures in each subspecialty in patients up to age 5 years. At least one hospital was identified as being a high or low outlier in all of the subspecialties except neurosurgery. Of note, in the subspecialties of otolaryngology, thoracic surgery, and urology, there were five or more hospitals identified as outliers, with a significantly lower or higher than expected percentage of their patients undergoing noncardiac surgical procedures.

3. Discussion

Forty-one percent of CHD patients who had cardiac surgery by one year of age also underwent at least one noncardiac procedure prior to five years of age. General surgical and otolaryngology procedures were the most commonly performed noncardiac procedures. Across all of the surgical subspecialties, most noncardiac procedures were performed in patients with lower RACHS-1 scores. However, for general surgical, dental/OMFS, orthopedic, or thoracic procedures, the odds of undergoing a noncardiac surgical procedure were higher in patients with higher RACHS-1 scores even after adjustment for other patient and hospital-level characteristics that were predictive of having these procedures. In addition, there was significant variability in the proportion of patients with critical CHD who underwent noncardiac surgical procedures among the included children's hospitals.

With more than 90% of patients with CHD now surviving into adulthood, a large proportion of these of patients are undergoing noncardiac surgical procedures [19]. In a National Inpatient Sample study of children with hypoplastic left heart syndrome, over 50% of patients underwent a noncardiac procedure, with half of these procedures involving the gastrointestinal system [20]. Another study found that almost two-thirds of CHD patients in the highest RACHS-1 category underwent a noncardiac procedure, with gastrostomy and fundoplication being the two most common [12]. These studies demonstrate that patients with CHD frequently undergo noncardiac surgical interventions. The current study confirms these rates of noncardiac surgical procedures in patients with CHD, with many undergoing less complex procedures such as circumcision, gastrostomy tube placement, and hernia repair. In addition, our current study builds upon the previous studies by identifying several

Table 4
Number of CHD patients undergoing noncardiac surgical procedures by surgical subspecialty (including only patients who did not die in the PHIS hospital by age 5).

Subspecialty division	Total patients	Low RACHS-1 group, N (%)	High RACHS-1 group, N (%)	Adjusted odds ratio (95% CI)	P value
General surgery	1541	1114 (72.3)	386 (25.1)	1.28 (1.06, 1.55)	**0.01**
Otolaryngology	1160	928 (80.0)	195 (16.8)	0.81 (0.64, 1.02)	0.08
Dental/OMFS	408	267 (65.4)	133 (32.6)	1.60 (1.2, 2.15)	**0.002**
Urology	829	586 (70.7)	221 (26.7)	1.18 (0.92, 1.49)	0.19
Noncardiac thoracic	405	243 (60.0)	155 (28.3)	2.26 (1.65, 3.09)	<**0.0001**
Soft tissue/plastics	411	286 (69.6)	118 (28.7)	1.25 (0.92, 1.69)	0.15
Ophthalmology	230	185 (80.4)	33 (14.4)	0.46 (0.25, 0.84)	**0.01**
Orthopedics	204	135 (66.2)	65 (31.9)	1.67 (1.09, 2.57)	**0.02**
Neurosurgery	107	83 (77.6)	22 (20.6)	0.69 (0.37, 1.28)	0.24

Overall patients in each group are as follows: Total, N = 8076; Low RACHS-1 group, N = 6262; High RACHS-1 group, N = 1636. Data are shown as frequencies and row percentages are given for the low and high RACHS-1 group columns. Odds ratios compare high (categories 4–6) vs. low (categories 1–3) RACHS-1 groups after adjustment for hospital volume, prematurity, presence of a noncardiac anomaly, presence of Down syndrome, gender, age at first heart surgery, race, and having had multiple cardiac surgery admissions by age 5.

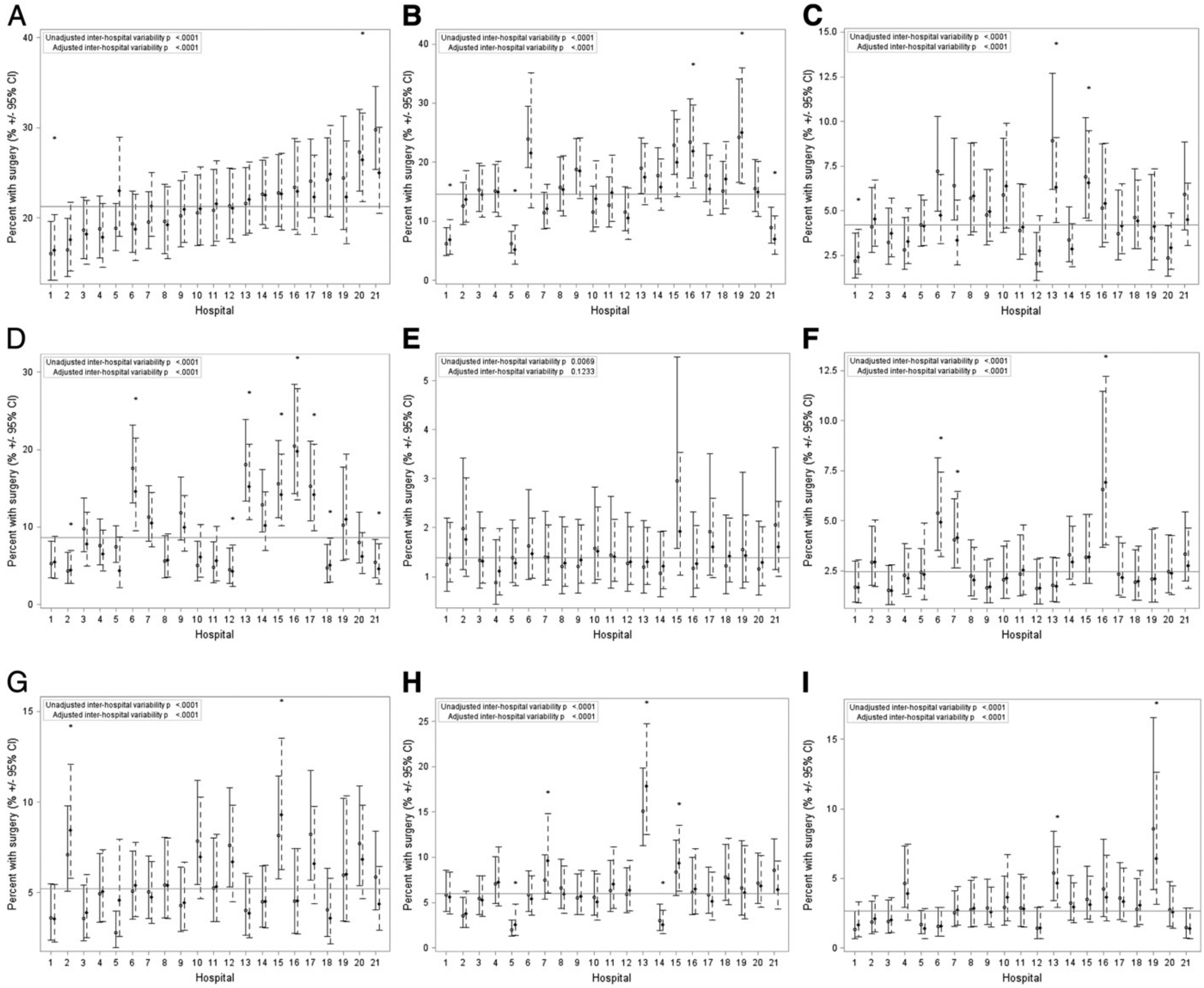

Fig. 2. Variability between PHIS hospitals in the proportion of patients with critical CHD who undergo procedures by surgical subspecialty with the highest overall frequencies. A) General surgery, B) otolaryngology, C) dental surgery, D) urology, E) neurologic surgery, F) orthopedic surgery, G) plastic surgery, H) thoracic surgery, I) ophthalmology. Unadjusted estimates and 95% CI from logistic mixed models are represented by the open circles and solid error bars; adjusted estimates and 95% CI from logistic mixed models are represented by the solid circles and dashed error bars. The asterisks denote hospitals with adjusted estimates that were significantly higher or lower than average (as shown by the reference line). The variables adjusted for were RACHS-1 group, hospital volume of the included procedures in that specialty in all patients under 5 years of age, prematurity, presence of a major noncardiac structural anomaly, presence of Down syndrome, presence of another major chromosomal anomaly, gender, age at first heart surgery, race, having had multiple cardiac surgery admissions by age 5, and inhospital death by age 5. One hospital was excluded because it only contributed 8 patients.

clinical characteristics associated with a higher likelihood of undergoing a noncardiac procedure, determining the rates of noncardiac surgical procedures performed by each surgical subspecialty, and exploring variability in the frequency each of these subspecialties perform procedures across hospitals.

Obtaining a better understanding of the noncardiac surgical procedures performed in patients with CHD at tertiary children's hospitals is important for several reasons. First, improvements in medical care have led to a growing population of children with CHD that may undergo additional surgical procedures by noncardiac surgical specialists for indications both related and unrelated to their heart disease. Estimates of the types and rates of noncardiac procedures that these patients undergo and the differences in these rates across levels of CHD severity may assist care providers in counseling and setting expectations for these families. Data from this study suggest that patients who are born premature, have noncardiac congenital anomalies, Down syndrome or other chromosomal anomalies, and who have more severe CHD have a greater probability of needing noncardiac surgical procedures.

Second, identifying variation in practice and the potential causes of such variation are important for improving care across all institutions [21]. The substantial variation observed across children's hospitals in the proportion of patients with critical CHD who underwent noncardiac surgical procedures is notable. Even after adjusting for known confounders such as procedure volume, case mix, clinically important comorbid conditions, and RACHS-1 score, we detected significant variability in the rates of noncardiac procedures performed by each subspecialty (with the exception of neurosurgery) at the 21 free-standing children's hospitals included in this analysis. Unfortunately, our current study is not able to identify the cause of this interhospital variability. However, one possibility may be inconsistent indications for noncardiac procedures across institutions. For example, a patient at one hospital who receives a gastrostomy tube might be sent home at another with a nasogastric tube. On the other hand, neurosurgical problems such as hydrocephalus might have less ambiguous surgical indications from one institution to another, potentially explaining the decreased variability within that subspecialty. Another, though less likely, explanation is that there are unmeasured differences in the populations of CHD children treated at each institution that are associated with the likelihood of having noncardiac surgery, such as the proportion of patients with specific syndromes or specific forms of CHD. Further investigation into possible causes of this practice variability is warranted.

This study has several limitations. First, although the PHIS database has a rigorous quality control system in place to ensure the accuracy of its data, as with any administrative database, its use may be associated with misclassification bias [22–26]. Specific to this study, it is known that there can be miscoding and misclassification of congenital heart disease diagnoses and procedures in administrative data [23–26]. However, these errors may be lessened when examining larger categories of operations rather than specific individual procedures. Therefore, we chose to evaluate the RACHS-1 categories rather than individual cardiac operations. With regard to risk stratification, the RACHS-1 system is the only system that has been developed for use in administrative data, although other risk stratification systems have been developed [27,28]. It stratifies operations based on risk of associated inhospital mortality, and this may not necessarily translate directly to risk for other morbidities such as subsequent noncardiac operations. Nonetheless, it does provide us with the ability to generally stratify operations and adjust for differences in case mix across hospitals. Furthermore, in patients that underwent multiple cardiac procedures, we chose to assign the highest RACHS-1 category in order to capture the maximum severity of their CHD diagnosis. Second, although this complex patient population will often receive lifelong care at a single hospital, the PHIS database represents only a select group of children's hospitals. This study cannot detect any surgical procedures that were performed outside of the original PHIS hospital where the initial cardiac procedure was performed, thereby potentially underestimating the rate of noncardiac procedures performed. However, the majority of hospital admissions for CHD patients are concentrated in high volume centers. In addition, CHD patients continue having procedures at pediatric hospitals into adulthood and are less likely to be lost to follow-up when they have more severe CHD requiring CHD-related hospitalizations early in life [29–31]. Furthermore, this cohort only includes data from roughly half the institutions currently included in PHIS, which may limit the generalizability of the results. In order to capture all of the procedures for each patient in the cohort, we included only hospitals that submitted both inpatient and ambulatory surgery data during our study period. This resulted in the exclusion of several children's hospitals with high cardiac surgery volume. However, given that significant interhospital variability was detected among the 21 included hospitals, significant variability would certainly be detected if additional hospitals were included in the analysis.

In conclusion, this study used the PHIS database to identify a cohort of patients with critical CHD who underwent cardiac surgery by 1 year of age. Approximately 40% of these patients underwent at least one noncardiac surgical procedure by 5 years of age. Significant variability between children's hospitals in the proportion of patients with critical CHD who underwent noncardiac surgical procedures was identified for all surgical subspecialties except neurosurgery. Future investigations into the potential causes of this variability may lead to improvements in the care of patients with CHD. Studies investigating specific subspecialties and procedures may be useful to more precisely understand the causes of practice variability.

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