Cardiology in the Young

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Variation in hospital costs and resource utilisation after congenital heart surgery

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Abstract

Background: Children undergoing cardiac surgery have overall improving survival, though they consume substantial resources. Nationwide inpatient cost estimates and costs at longitudinal follow-up are lacking. *Methods:* Retrospective cohort study of children <19 years of age admitted to Pediatric Health Information System administrative database with an International Classification of Diseases diagnosis code undergoing cardiac surgery. Patients were grouped into neonates (≤30 days of age), infants (31–365 days of age), and children (>1 year) at index procedure. Primary and secondary outcomes included hospital stay and hospital costs at index surgical admission and 1- and 5-year follow-up. *Results:* Of the 99,670 cohort patients, neonates comprised 27% and had the highest total hospital costs, though daily hospital costs were lower. Mortality declined (5.6% in 2004 versus 2.5% in 2015, $p < 0.0001$) while inpatient costs rose (5% increase/year, $p < 0.0001$). Neonates had greater index diagnosis complexity, greater inpatient costs, required the greatest ICU resources, pharmacotherapy, and respiratory therapy. We found no relationship between hospital surgical volume, mortality, and hospital costs. Neonates had higher cumulative hospital costs at 1- and 5-year follow-up compared to infants and children. *Conclusions:* Inpatient hospital costs rose during the study period, driven primarily by longer stay. Neonates had greater complexity index diagnosis, required greater hospital resources, and have higher hospital costs at 1 and 5 years compared to older children. Surgical volume and in-hospital mortality were not associated with costs. Further analyses comprising merged clinical and administrative data are necessary to identify longer stay and cost drivers after paediatric cardiac surgery.

Children with CHD may require cardiac surgery and resource-intensive perioperative care. Prolonged hospital length of stays following cardiac surgery are due to patient-related and patient-care related factors.[1–9] While survival has improved over time, many children require life-long care, including multiple hospitalisations, catheter, and surgical interventions into adulthood.[10–12] Resource utilisation among this growing survivor population is substantial[10,13,14] and may be increasing.[15]

Existing studies examining CHD resource utilisation are limited to patient subsets (e.g., neonates),[10,11,16] focused on specific operations,[11,17–19] or phases of care.[20] Cost-influencers were identified, but most were single centre[10,21] or did not consider inpatient care across age groups.[15,18,22–26] Except in rare cases, nationwide post-surgical CHD hospital healthcare cost estimates are lacking.[15,27] To address this knowledge gap, we performed a retrospective cohort study to compare surgical resource utilisation, outcomes as well as readmission and long-term hospital costs associated with CHD surgery.

We hypothesise that children receiving congenital heart surgery consume substantial and increasing healthcare resources and that costs are unevenly distributed across patient age strata and variation exists between hospitals of different surgical volume. We anticipate that most inpatient costs are associated with the first surgery admission (index admission); younger children require more frequent subsequent interventions and have higher long-term hospital costs.

Materials and methods

Data source

The Pediatric Health Information System, managed by the Children's Hospital Association (Lenexa, KS), contains inpatient, emergency department, and observation unit information submitted by over 50 United States not-for-profit, tertiary care paediatric hospitals. Pediatric Health

Information System data includes demographics, diagnoses, procedures, discharge disposition, and daily billings for medications, laboratory tests, imaging procedures, clinical services/procedures, supplies, and room and board. Each patient has a unique identifier for longitudinal follow-up. Data quality is assured through a joint effort between the Children's Hospital Association and participating hospitals. This study merited exemption by the Institutional Review Board.

Study cohort and follow-up

The retrospective cohort study identified children <19 years old hospitalised in a Pediatric Health Information System centre between January 2004 and September 2015 and with any cardiac diagnosis (International Classification of Diseases-9 codes: 394.XX–397.XX, 410.XX–417.XX, 420.XX–429.XX, 745.XX–746.XX, 747.0–747.4, V15.87. Only patients receiving cardiac planned surgeries (see Supplemental Table S1) during the index admission were included, and each patient's records from index operation were followed longitudinally for up to 5 years, from index admission to death or the last Pediatric Health Information System hospitalisation discharge.

Covariates

Patients were grouped into three categories based on age at index cardiac surgery: neonates (≤30 days at cardiac surgery date), infant (31–365 days), and children (>1 year). Patient characteristics included sex, insurance type (private, public, self, other, or unknown). Genetic syndromes (trisomy 21, trisomy 18, trisomy 13, DiGeorge, Turner, and Williams syndrome) were determined by International Classification of Diseases-9 diagnosis codes at index admission. Chronic complex conditions include congenital and/or genetic anomalies, gastrointestinal, hematologic/immunologic, malignancy, metabolic, neuromuscular, renal, and respiratory defined by Feudtner et al.[28] Since all study patients had cardiovascular chronic complex conditions, it was not included as a covariate.

As Pediatric Health Information System only reports discharge diagnoses (not surgical diagnoses), and RACHS-1 score and case ascertainment based on administrative data may be inaccurate, [17] diagnostic classification from the index surgical admission was assessed based on discharge diagnoses and grouped hierarchically into four diagnostic complexity groups: Simple two ventricle, complex two ventricle, single ventricle, and unclassified.[29]

Pre-operative length of stays include days from the index surgical admission date to the day before surgery. ICU-level care was determined by pre-operative ICU-level resources and defined *a priori* by specific International Classification of Diseases-9-CM procedure codes or clinical resource utilisation.[30] Daily pre-operative resource utilisation was identified from Pediatric Health Information System billing data.

Outcomes

Pediatric Health Information System-adjusted inpatient costs

Pediatric Health Information System provided wage index adjusted charges for each billing item. These charges and the cost-to-charge ratios were multiplied to derive each patient's daily inpatient treatment costs and adjusted to 2017-dollar value with Medical Services component of the Consumer Price Index for overall comparison. Daily adjusted costs were summarised within six billing departments: room and board, pharmacy, laboratory, clinical, supply, and imaging. At follow-up, adjusted overall cost and billing department costs were derived by summing the daily costs reported. All billings were *a priori* grouped into 21 categories (Supplemental Table S2) to describe resource utilisation; the top ten were reported as cost drivers. Cost per inpatient day was calculated by dividing total inpatient cost by inpatient day number during the selected follow-up period.

Mortality, in-hospital length of stays, readmissions, and resource utilisation

Inpatient mortality was evaluated at index surgical admission and at 1- and 5-year follow-up. Pediatric Health Information System discharge status identified inpatient deaths. Index total hospital length of stays were calculated. At each follow-up, total readmission in-hospital days were determined for patients requiring post-surgery discharge hospitalisation.

Post-operative and follow-up ICU resource utilisation and medication use were determined from billing data. Binary indicators for resource exposure on each inpatient day were created and summed to obtain number of exposed days at follow-up.

Statistical analyses

Patient characteristics were summarised using frequencies and percentages for categorical variables and median and interquartile range for continuous variables. Characteristics were compared across age groups using chi-square test for categorical variables and Wilcoxon test for continuous variables. Mortality, resource utilisation, and readmissions during follow-up were compared using the chi-square test; length of stays, resource utilisation days, and cost by the Wilcoxon test.

Time-trend was evaluated using logistic regression (for mortality) and linear regression with gamma distribution (for cost), including year, age group, geographic region, diagnostic complexity, and hospital annual surgical volume. Odds ratio and cost ratio for the current year versus previous year were reported, with 95% confidence intervals.

Hospital volume variation, mortality, and median costs were plotted. Pearson's correlations between hospital mortality and hospital median cost (or hospital annual surgical volume) were estimated to explore the associations between these hospital-level summaries. All analyses were performed in SAS 9.3; two-sided p value of <0.05 was considered significant.

Results

Cohort characteristics

The cohort comprised 99,670 patients from 46 Pediatric Health Information System-contributing institutions during the study period. Neonates represented 27% of the cohort, while 38% were infants and the remaining were older children (Table 1). Females represented 46% (n = 45,656) and 47% (n = 46,371) had public insurance. Sixty-four percent (n = 63,792) were white, 12% were black (n = 12,318), and 15% (n = 14,893) were unclassified. Genetic syndromes were prevalent with trisomy 21 (n = 10,347, 10%) most common. Index diagnostic complexity was highest among neonates with 28% having single ventricle heart disease and 67% having complex two ventricle heart disease (Table 1). Over one-third had chronic complex conditions at index hospitalisation with non-cardiac congenital or genetic anomaly being most common (Table 1).

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Table 1. Patient characteristics at index surgery

	All patients		Age at index surgery			
			Neonate (≤30 days)	Infant (31 day-1 yr)	Older child (>1 year)	
	N = 99,670		*N* = 27,209	*N* = 37,720	*N* = 34,741	
	n	%	%	%	%	*P* value
Diagnosis group						<0.0001
Single ventricle	12,314	12.4	27.9	5.9	7.3	
Complex two ventricle	56,049	56.2	67.1	54.7	49.4	
Simple two ventricle	28,560	28.7	4.6	38.1	37.3	
Unclassified	2,747	2.8	0.5	1.4	6.1	
Sex						<0.0001
Female	45,656	45.8	40.8	48.7	46.6	
Race						<0.0001
White	63,792	64.0	63.5	63.5	64.9	
Black	12,318	12.4	10.8	13.3	12.6	
Asian	3,953	4.0	3.2	4	4.5	
Other	14,893	14.9	16.9	14.6	13.8	
Unknown	4,714	4.7	5.7	4.6	4.2	
Insurance status						<0.0001
Public	46,371	46.5	49.9	48.6	41.6	
Private	41,806	41.9	40	39.8	45.8	
Self	1,815	1.8	1.7	1.8	1.9	
Other	8,554	8.6	7.3	8.5	9.7	
Unknown	1,124	1.1	1.1	1.3	1	
Syndromes						
Trisomy 21	10,347	10.4	2.9	21.5	4.2	<0.0001
DiGeorge Syndrome	2,723	2.7	4.5	2.4	1.7	<0.0001
Trisomy 18	145	0.2	0.2	0.2	0.1	<0.0001
Trisomy 13	62	0.1	0.1	0.1	0.0	0.001
Turner	363	0.4	0.8	0.1	0.3	<0.0001
Williams	364	0.4	0.6	0.3	0.2	<0.0001
Chronic Complex Condition						
Number of CCC						
0	63,594	63.8	55.4	57.8	76.9	<0.0001
1	23,526	23.6	24.8	29.0	16.7	
2	8,152	8.2	11.7	9.1	4.4	
3	3,060	3.1	5.3	3.0	1.4	
4+	1,338	1.3	2.8	1.1	0.6	
CCC specific type						
Congenital/genetic defect	18,995	19.1	15.3	29.1	11.1	<0.0001
Gastrointestinal	10,102	10.1	17.5	10.5	4.0	<0.0001
Renal	6,515	6.5	14.8	3.9	2.9	<0.0001
Respiratory	6,001	6.0	10.4	6.2	2.3	<0.0001
Neuromuscular	4,483	4.5	6.7	3.7	3.6	<0.0001

(*Continued*)

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Table 1. (*Continued*)

	All patients		Age at index surgery			
			Neonate (≤30 days)	Infant (31 day-1 yr)	Older child (>1 year)	
	N = 99,670		N = 27,209	N = 37,720	N = 34,741	
	n	%	%	%	%	*P* value
Hematologic/immunologic	4,334	4.4	6.4	3.6	3.5	<0.0001
Metabolic	3,422	3.4	4.2	3.2	3.1	<0.0001
Malignancy	834	0.8	0.5	0.7	1.3	<0.0001
Pre-operative ICU-level care						
Respiratory	22,809	22.9	61.7	11.8	4.6	<0.0001
Cardiac	25,688	25.8	62.1	15.3	8.7	<0.0001
Renal	445	0.5	0.8	0.2	0.4	<0.0001
Leukopheresis	82	0.1	0.08	0.1	0.1	0.0414
Neurological	4	0.0	0.0	0.0	0.0	0.0238
Pre-operative LOS* (median, IQR)		0, 0-4	5, 3-9	0, 0-1	0, 0-0	<0.0001
Pre-operative life support						
ECMO	851	0.9	1.5	0.5	0.7	<0.0001
Alprostadil	19,024	19.1	68.5	1.0	0.0r	<0.0001
IV Inotropes	21,762	21.8	50.6	13.7	8.2	<0.0001
Dialysis	276	0.3	0.4	0.1	0.4	<0.0001
Mechanical Ventilator	20,586	20.7	55.9	10.5	4.2	<0.0001
Inhaled NO	2,561	2.6	6.3	1.6	0.8	<0.0001

*LOS: In-hospital length of stay, in days

Index surgical admission resource utilisation

Pre-operative hospitalisation (median 5 days, interquartile [3,9]) and ICU-level therapies were more common among neonates (Table 1), including mechanical ventilation (56%) and intravenous inotropic support (51%), ($p < 0.001$ for all). Post-operative ICU care was common with 91% of patients receiving inotropic support, 78% receiving mechanical ventilation, 14% receiving nitric oxide; neonatal utilisation was highest for all post-operative life support categories while post-operative pharmaceutical utilisation varied across age groups (Table 2, $p < 0.001$ for all).

Index surgical hospitalisation costs are summarised in Table 3. Overall median patient-level hospital cost was ~$60,000 in 2017 value. While total neonatal costs were highest (median $151,587 for neonates, $51,032 for infants, and $40,848 for older children, $p < 0.0001$), neonates had the lowest daily inpatient costs among the three age groups (median $5650, versus $6284 for infants, and $7336 for older children, $p < 0.0001$), suggesting that longer length of stays were the driver for higher total neonatal hospital costs. Compared across six billing departments, room and board represented the largest cost driver for all age groups (Table 3, $p < 0.0001$ for all).

In sub-group stratified cost analyses (Table 4a–e), neonates with simple two ventricle diagnosis at index hospitalisation had highest overall hospital costs and lowest daily hospital costs, suggesting that prolonged hospitalisation informed the higher overall hospital costs these children incur (Table 4e) Except for neonates, patients with single ventricle diagnosis had the highest overall hospital costs. After adjusting for hospital length of stay, patients in each age group showed no difference in daily hospitalisation costs across diagnostic groups (Table 4a–b). In contrast to index hospitalisation costs, at 1- and 5-year follow-up, overall hospital costs were highest among the single ventricle diagnosis population (Table 4c–d). Hospital length of stay was longest among infants undergoing simple two ventricle repairs, as compared to more complex two ventricle and single ventricle surgery (Table 4e).

Index surgical hospitalisation costs were further evaluated across 21 resource utilisation sub-categories, the 10 highest of which are reported in Table 3. Room and board accounted for >50% of total and daily hospital costs, whereas imaging, pharmacy supply, and laboratory accounted for <10%. Age-related variation in hospital costs was observed across billing departments (Table 3), with the difference between age groups in the ICU, acute care unit , pharmacotherapy and respiratory therapy categories, and the smallest differences in the anaesthesia category. Non-neonatal infants and older children had higher costs in the "inpatient" (non-ICU or acute care unit) category (Table 3). Greater hospital costs occurred post-operatively for all age groups; neonates had overall higher pre-operative costs (Supplemental Table S3), indicating that ICU care variation occurred across all age groups.

Post-operative outcome and mortality and cost trends

Median post-operative length of stays were 8 days (interquartile 5–16), with neonates having longer post-operative length of stays (Table 2). Index hospitalisation mortality was 4% overall and

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Table 2. Post-operative outcomes, index surgical admission

	All patients		Age at index surgery			
			Neonate	Infant	Older child	
			(≤30 days)	(31 day–1 yr)	(> 1 year)	
	N = 99,670		*N* = 27,209	*N* = 37,720	*N* = 34,741	
	n	%	%	%	%	*P* value
Mortality	3,976	4.0	10.4	1.8	1.4	<0.0001
Post-operative life support						
ECMO	3,992	4	8.6	2.4	2.1	<0.0001
Alprostadil	7,970	8	28.1	0.6	0.3	<0.0001
Dialysis	3,183	3.2	7.1	1.7	1.3	<0.0001
Inhaled NO	13,595	13.6	26	11.6	6.2	<0.0001
Ventilator						
yes	78,067	78.3	96.2	82.9	59.4	<0.0001
# of days (median, IQR)		2, 1–5	1, 0–4	0	0	
IV Inotropes						
yes	91,064	91.4	96.3	93.9	84.7	<0.0001
# of days (median, IQR)		2, 1–4	5, 2–9	2, 1–4	1, 1–2	<0.0001
Other resource utilisation						
Opioids						
yes	91,261	91.6	88.4	94.3	91.0	<0.0001
number of days (median, IQR)		4, 2–6	2, 0–5	4, 3–6	3, 2–5	
Non-opioid sedatives						
yes	87,083	87.4	83.9	88.7	88.6	<0.0001
number of days (median, IQR)		4, 2–7	6, 2–15	4, 2–7	3, 2–5	
Benzodiazepines						
yes	87,384	87.7	85.6	88.0	89.0	<0.0001
number of days (median, IQR)		2, 1–4	4, 1–9	2, 1–4	1, 1–2	
Diuretics						
yes	93,590	93.9	97.8	98.9	86.5	<0.0001
number of days (median, IQR)		6, 4–13	14, 8–29	6, 4–10	4, 2–6	
Antibiotics						
yes	98,095	98.4	98.6	98.5	98.2	0.0009
number of days (median, IQR)		3, 2–8	7, 3–16	3, 2–6	3, 2–4	<0.0001
Post-operative LOS (median, IQR)	8	5–16	19, 11–37	7, 5–12	5, 4–8	<0.0001

differed across age groups (10.4% for neonates vs. 1.8% for infant and 1.4% >1 year, $p < 0.0001$).

Figure 1 showed each hospital's mortality and its relationship to median hospital cost and annual hospital surgical volume. While there was substantial cost ($p < 0.001$) and mortality ($p < 0.001$) variation between hospitals, no relationship between hospital mortality and hospital costs (correlation = −0.03, $p = 0.831$) or surgical volume (correlation = −0.11, $p = 0.469$) was identified.

Mortality declined during the study period, while overall hospital costs increased (Fig 2a) with a year-over-year adjusted odds ratio 0.90 for mortality (95% confidence intervals 0.89–0.91) and a year-over-year adjusted cost ratio 1.05 for total cost (95% confidence intervals 1.04–1.05). In comparison, daily hospital costs decreased only slightly (Fig 2b): year-over-year adjusted cost ratio 95) 0.993% confidence intervals 0.992–0.994, $p < 0.0001$), indicating annual 1% decline in daily hospital cost.

One- and five-year outcomes and hospital readmission costs

When stratified by diagnosis complexity group (Fig 3), single ventricle patients had the highest hospital costs at 1- and 5-year follow-up, while simple two ventricle neonates had higher costs at 1- and 5-year follow-up than neonates with complex two ventricle disease. Among subjects >30 days of age at index operation, those subjects with simple two ventricle operations had the lowest hospital costs at 1- and 5-year follow-up.

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Table 3. Total costs, index cardiac surgery admission

	All patients		Age at index surgery			
			Neonate (<=30 days)	Infant (31 day-1 yr)	Older Child (>1 year)	
	N = 99,670		N = 27,209	N = 37,720	N = 34,741	
	Median	IQR	Median	Median	Median	*P* value
Total Costs						
All departments	$59,832	$36,977–$132,448	$151,587	$51,032	$40,848	<0.0001
Clinical	$5,739	$2,064–$16,961	$16,636	$4,723	$3,029	<0.0001
Imaging	$2,810	$1,590–$5,636	$6,224	$2,458	$1,970	<0.0001
Lab	$5,725	$3,182–$133,399	$16,270	$5,196	$3,340	<0.0001
Room and Board	$30,121	$18,043–$65,647	$78,513	$26,782	$19,387	<0.0001
Pharmacy	$4,085	$2,042–$10,144	$10,909	$3,359	$2,754	<0.0001
Supply	$7,009	$3,164–$14,101	$11,100	$5,641	$6,585	<0.0001
Daily (per inpatient day) Costs						
All departments	$6,403	$5,092–$8,117	$5,650	$6,284	$7,336	<0.0001
Clinical	$546	$258–$1,081	$598	$532	$497	<0.0001
Imaging	$273	$175–$413	$224	$269	$329	<0.0001
Lab	$602	$407–$866	$610	$620	$577	<0.0001
Room and Board	$3,207	$2,597–$3,882	$3,054	$3,234	$3,341	<0.0001
Pharmacy	$432	$270–$679	$415	$403	$487	<0.0001
Supply	$623	$248–$1,333	$387	$596	$1,052	<0.0001
Top 10 cost categories among 21 categories*						
Operating Room	$10,470	$6,903–$15,872	$12,969	$10,024	$9,574	<0.0001
Supplies	$7,009	$3,164–$14,101	$11,100	$5,641	$6,585	<0.0001
Lab	$5,534	$3,092–$12,976	$15,723	$4,996	$3,279	<0.0001
Pharmacotherapy	$4,085	$2,042–$19,144	$10,909	$3,359	$2,754	<0.0001
ICU	$3,717	$0–$14,058	$23,025	$3,446	$1,946	<0.0001
CCU	$2,880	$0–$14,067	$10,149	$3,741	$2,225	<0.0001
Radiology	$2,787	$1,584–$5,516	$6,080	$2,447	$1,960	<0.0001
Inpatient	$2,529	$0–$7,511	$1,511	$2,917	$2,361	<0.0001
Respiratory Therapy	$1,689	$650–$6,025	$7,122	$1,581	$717	<0.0001
Anaesthesia	$725	$312–$1,544	$964	$697	$645	<0.0001

* Billing-based resource utilisation categories, see Supplemental Table S2 for complete listing

Tables 5 and Supplemental Table S4 summarise mortality, hospital readmission, and hospital costs at 1- and 5-year follow-up, respectively. While most patients (73%) required no hospital readmission at 1-year follow-up, 48% of neonates were readmitted and 54% of the readmitted patients had additional cardiac surgery. Among readmitted, median length of stays were 10 days, with neonates staying twice as long as older children (14 days for neonates, 8 days for infants, and 7 days for older children, $p < 0.001$). Given the infrequency of hospital readmission, 1-year post-surgery total hospital costs were similar to costs observed during the index operation with neonates (median $196,362) having the highest hospital costs. Cumulative hospital costs for the nine stratified sub-groups also identified highest hospital costs among neonates (Fig 3).

Discussion

In our large, multi-centre cardiac surgery cohort, we identified variations in pre- and post-operative resource utilisation among and across age strata, with neonates contributing the longest index hospitalisation and greatest index hospital costs, 1-year and 5-year hospitalisation costs compared to infants and older children. The findings that neonates had lower daily hospital costs indicated longer length of stays were the primary driver of hospital costs. There were substantial age-related differences in resource utilisation categories; in most categories, neonates required higher costs across these categories. In long-term, post-operative follow-up, only neonates showed significant inpatient resource utilisation. Mortality declined among patients receiving surgery more recently, while

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Table 4. Median costs by diagnosis complexity and age category

	Neonate (<=30 days)	Infant (31 day-1 yr)	Older Child (>1 year)
a. Total costs during index surgical admission (median)			
Diagnosis Group			
Single Ventricle	$189,027	$63,306	$65,791
Complex Two Ventricle	$134,533	$54,497	$42,703
Simple Two Ventricle	$212,245	$44,514	$32,667
b. Daily costs during index surgical admission (median)			
Diagnosis Group			
Single Ventricle	$5,754	$6,109	$6,208
Complex Two Ventricle	$5,665	$6,309	$7,501
Simple Two Ventricle	$4,539	$6,259	$7,258
c. Total costs at one-year follow-up after index surgical admission (median)			
Diagnosis Group			
Single Ventricle	$286,197	$80,852	$74,020
Complex Two Ventricle	$160,842	$58,496	$43,985
Simple Two Ventricle	$253,474	$46,653	$33,287
d. Total costs at five-year follow-up after index surgical admission (median)			
Diagnosis Group			
Single Ventricle	$335,507	$130,493	$81,336
Complex Two Ventricle	$172,252	$62,899	$45,404
Simple Two Ventricle	$271,789	$48,156	$33,702
e. Index admission hospital length of stay after index operation (days median)			
Diagnosis Group			
Single Ventricle (d)	32	10	11
Complex Two Ventricle (d)	33	8	5
Simple Two Ventricle (d)	46	7	4

surgical-related healthcare costs increased by year, mostly due to longer length of stays.

Interestingly, while daily hospital costs were higher among neonates with single ventricle diagnosis, we observed that those with simple two ventricle diagnosis had greater median overall hospital costs and longest post-surgery hospital stay than those with more complex two ventricle or single ventricle surgery. We postulate that many neonates with simple two ventricle diagnoses (e.g., ventricular septal defect) had important unmeasured (e.g., gestational age, low birth weight) comorbidities which prolonged the hospitalisation contributed to higher post-operative and overall index hospitalisation costs.

While Pasquali identified that children undergoing Society of Thoracic Surgeons' benchmark operations had wide hospital cost variation,[19] we identified no relationship between mortality, surgical volume, and median hospital costs from our long-term cohort follow-up.

Not surprisingly, pre-operative care represented relatively little overall resource burden as few patients were hospitalised pre-operatively. While neonates often required pre-operative ICU care, non-neonatal patients generally did not. In addition, the overall pre-operative length of stays for patients *requiring* pre-operative admission were much shorter compared to the post-operative hospitalisation. While neonates required overall higher pre-operative ICU-level care and had higher pre-operative costs, this was relatively low, suggesting that most were relatively "well" prior to surgical intervention. Our data confirmed findings from previous reports that neonates had more organ system dysfunction compared to non-neonatal subjects, which may increase overall care costs.[31]

We noted decreasing mortality over time coupled with slightly declining daily costs. This trend was observed with recent practice changes after single ventricle palliation with at least some post-surgical convalescent care occurring in the inpatient setting versus at home[32]. In addition, as overall post-surgery mortality declined, patients are spending longer time in-hospital due to recovery from post-operative morbidities, narcotic weaning, and feeding difficulties. We identified that longer hospital length of stays may not always reflect long ICU-level care.

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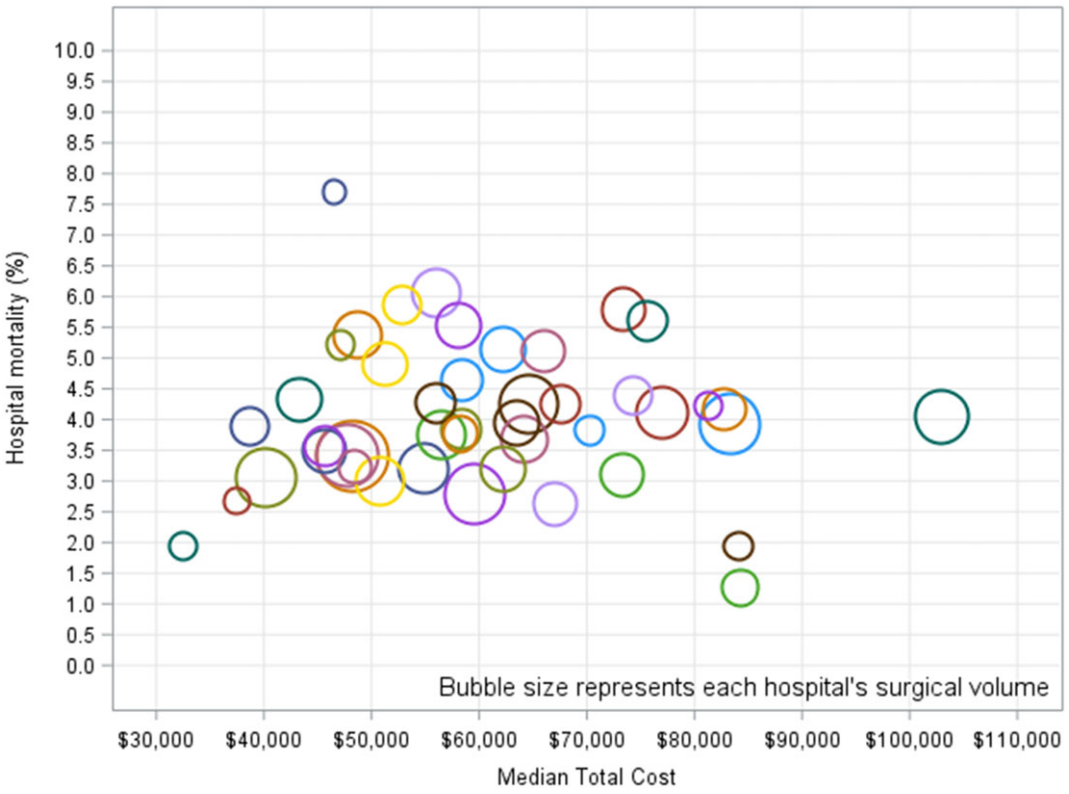

Figure 1. While we found variation in surgical volume, mortality and median hospital costs, no relationship between surgical volume, mortality, and median hospital costs was identified.

Our observation is that higher neonatal resource utilisation is consistent with previous reports. Neonates require more complex surgery with higher mortality rates.[33] As a result, neonates require more ICU care, including extracorporeal membrane oxygenation, mechanical ventilation, and intravenous therapies compared to older children.[5,34] Our data are consistent with previous reports identifying that room and board was the principal CHD cost driver.[12,19,27,35,36] Prolonged hospitalisation would increase utilisation of these expenditures. Neonates required more frequent rehospitalisation translating to 48 and 58% increase in cumulative costs at 1- and 5-year follow-up, compared to relatively insubstantial cost increases observed from infants (0%, 2%) and older children (0%, 0%) (data not reported). As neonates may require readmission following the index operation for surgical or catheter-based reintervention, as well as medical admissions for non-surgical needs, this finding is consistent with clinical practices. Healthcare costs incurred from these subsequent readmissions represent a substantial cost burden for both patient families and society.

Previous reports have suggested a relationship between hospital cardiac surgical volume and post-surgery mortality, that may in part be explainable by local surgical experience and post-operative standardised care practices.[37–42] While we found substantial variation in hospital costs and mortality, we identified no discernible relationship between hospital volume, mortality and hospital costs. This may at least be partially explained by hospital variations in case-mix which we could not account for in this administrative database analysis.

Our analysis includes several important limitations. First, the Pediatric Health Information System database lacks detailed clinical information, limiting our ability to make important conclusions about the relationship between case-mix and outcomes, though we have used a limited classification scheme to identify anatomic complexity.[12] While we can surmise parts of the clinical state based on resource utilisation (e.g., need for inotropes, mechanical ventilation or renal replacement therapies), we are unable to identify what role hemodynamic residua have in driving variations in hospital costs, resource utilisation and mortality. We lack important patient-level covariates, including prematurity, gestational age, and birth weight, which may influence clinical outcome, but are frequently missing from Pediatric Health Information System administrative data. Important hospital-level covariates influencing variations in costs, resource utilisation, and outcome may not have been captured. Deaths outside the hospital as well as deaths and hospitalisations at other hospitals could not be captured. Most patients with CHD die in-hospital and were exposed to significant medical technology in the ICU.[43,44] We lack data regarding resources consumed in the outpatient environment, which may make up a substantial fraction of overall healthcare resources consumed. Recent data found that higher inpatient costs were associated with greater outpatient resource utilisation in a large cohort after tetralogy of Fallot, though the outpatient costs were approximately 30%–40% of inpatient costs.[45] Due to our large cohort size, result interpretation should focus on the magnitude of estimated effect size (difference) rather than statistical significance (p value). Finally, we

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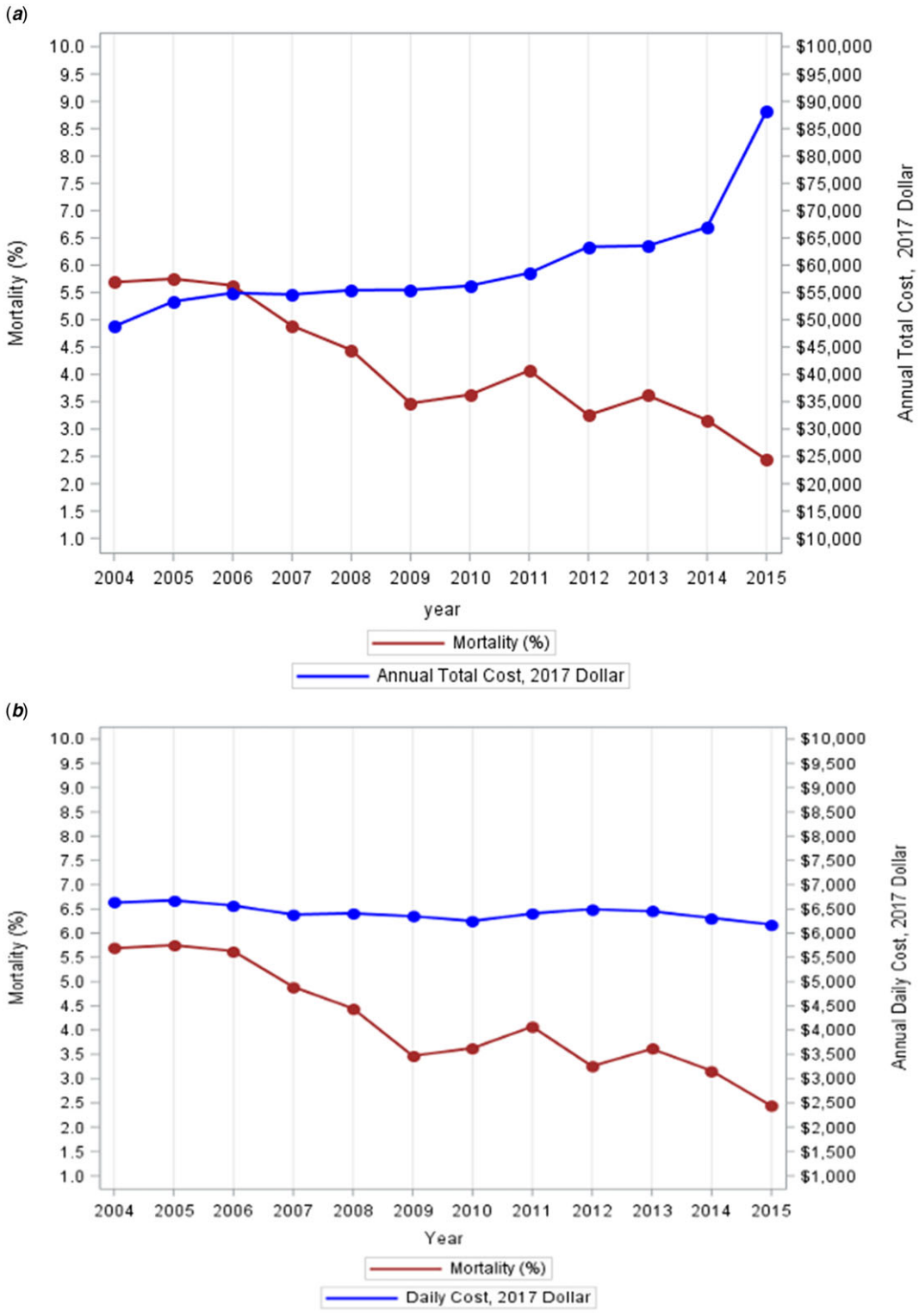

Figure 2 A: While mortality declined, median cumulative hospital costs increased. Adjusted for surgical complexity. B: While mortality declined, median daily hospital costs were relatively constant over time. Adjusted for surgical complexity.

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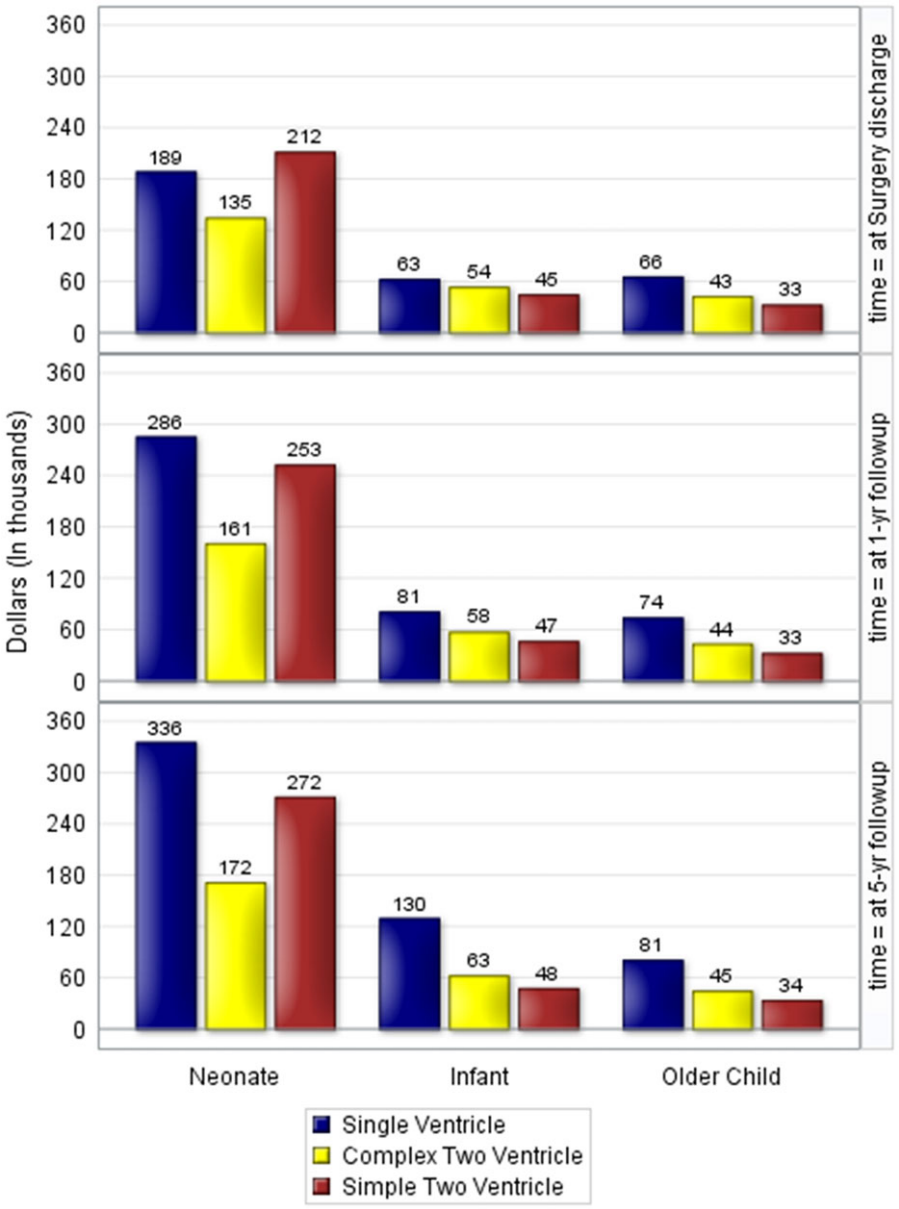

Figure 3. Cumulative median costs at index surgery discharge, 1- and 5-year follow-up.

only have data from centres contributing to the Pediatric Health Information System database; while these tertiary hospitals encompass a substantial fraction of institutions in the United States where cardiac surgery occurs, the findings may not be generalised to other CHD centres.

Conclusions

By establishing one of the largest paediatric CHD surgical cohorts and following each patient's hospital care for 5 years, we observed two important trends: an annual mortality rate reduction over the study period with a concomitant annual increase in CHD surgery costs. We identified several drivers associated with variations in hospital costs, including the role longer hospital length of stays may play in the observed hospital total cost increases. Neonates utilise the largest portion of inpatient hospital resources and consume substantial additional hospital resources after index hospital discharge due to subsequent hospital readmission. While there was hospital mortality and cost variation between institutions, we identified no discernable pattern among surgical volume, mortality, and hospital costs. Further analysis with more detailed clinical data merged with administrative data is necessary to understand factors driving variations in outcome, resource utilisation, and hospital costs among children undergoing cardiac surgery.

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Table 5. Hospital readmissions and costs, one-year post-index surgical admission

	All patients		Age at index surgery			
			Neonate	Infant	Older Child	
			(<=30 days)	(31 day-1 yr)	(>1-year)	
	N = 99,670		*N* = 27,209	*N* = 37,720	*N* = 34,741	
	n	%	%	%	%	*P* value
No. of readmissions						
0	72,861	73.1	52.1	76.9	85.5	<0.0001
1	14,399	14.4	21.8	13.4	9.8	
2	6,171	6.2	12.4	5	2.7	
3+	6,239	6.3	13.7	4.7	2	
No. of readmissions requiring surgery						
0	85,321	85.6	63.8	91.4	96.4	<0.0001
1	11,392	11.4	27.9	7.1	3.2	
2	2,365	2.4	6.7	1.1	0.3	
3+	592	0.6	1.6	0.4	0.1	
Mortality	5,019	5.0	12.7	2.6	1.7	<0.0001
		Median	IQR	Median, IQR	Median, IQR	Median, IQR
Length of follow-up, in days (max 365 days)	11	5–69	79, 21–201	9, 6–35	5, 4–11	<0.0001
Total in-hospital LOS	10	5–28	34, 19–68	9, 6–19	5, 4–9	<0.0001
Total readmission LOS, among readmitted	10	5–23	14, 7–30	8, 4–19	7, 4–14	<0.0001
Total Costs within 1-year						
All departments	65,825	$38,169–$166,386	$196,362	$54,670	$42,257	<0.0001
Clinical	6,626	$2,244–$21,168	$22,434	$5,202	$3,192	<0.0001
Imaging	3,119	$1,676–$7,042	$8,199	$2,634	$2,089	<0.0001
Lab	6,158	$3,285–$16,063	$20,093	$5,473	$3,424	<0.0001
Room and Board	33,233	$18,711–$82,267	$100,525	$28,893	$20,118	<0.0001
Pharmacy	4,492	$2,142–$12,506	$14,003	$3,626	$2,858	<0.0001
Supply	7,754	$3,413–$16,636	$14,595	$6,044	$6,815	<0.0001

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S1047951122001019

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Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines with the use of protected health information and with the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the Children's Hospital of Philadelphia Institutional Review Board.

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