Published in final edited form as:
Ann Thorac Surg. 2014 November ; 98(5): 1660–1666. doi:10.1016/j.athoracsur.2014.06.032.

Excess Costs Associated with Complications and Prolonged Length Of Stay Following Congenital Heart Surgery

Sara K. Pasquali, MD MHS[1], **Xia He, MS**[1], **Marshall L. Jacobs, MD**[1], **Samir S. Shah, MD MSCE**[4], **Eric D. Peterson, MD MPH**[2], **Michael G. Gaies, MD MPH**[1], **Matthew Hall, PhD**[5], **J. William Gaynor, MD**[6], **Kevin D. Hill, MD MS**[2], **John E. Mayer, MD**[7], **Jennifer S. Li, MD MHS**[2], and **Jeffrey P. Jacobs, MD**[3]

[1]Department of Pediatrics, University of Michigan C. S. Mott Children's Hospital, Ann Arbor, MI

[2]Duke Clinical Research Institute, Duke University Medical Center, Durham, NC

[3]Department of Surgery, Johns Hopkins University School of Medicine, Baltimore, MD

[4]Department of Pediatrics, Cincinnati Children's Hospital Medical Center, Cincinnati, OH

[5]Children's Hospital Association, Overland Park, KS

[6]Department of Surgery, Children's Hospital of Philadelphia, Philadelphia, PA

[7]Department of Cardiac Surgery, Children's Hospital Boston, Boston, MA

Abstract

Background—While there is an increasing emphasis on both optimizing quality of care and reducing healthcare costs, there are limited data regarding how to best achieve these goals for common and resource-intense conditions such as congenital heart disease. We evaluated excess costs associated with complications and prolonged length of stay (LOS) following congenital heart surgery in a large multicenter cohort.

Methods—Clinical data from The Society of Thoracic Surgeons Database were linked to estimated costs from the Pediatric Health Information Systems Database (2006–10). Excess cost/case association with complications and prolonged LOS was modeled for 9 operations of varying complexity adjusting for patient baseline characteristics.

Results—Of 12,718 included operations (27 centers), average excess cost/case in those with any complication (vs. none) was $56,584 (+$132,483 for major complications). The 5 highest cost complications were tracheostomy, mechanical circulatory support, respiratory complications, renal failure, and unplanned reoperation/reintervention (ranging from $57,137–$179,350). Patients with an additional day of LOS above the median had an average excess cost/case of $19,273 (+$40,688 for LOS 4–7 days above median). Potential cost savings in the study cohort achievable through

Corresponding author: Sara Pasquali MD MHS, C.S. Mott Children's Hospital, 1540 E. Hospital Drive, Ann Arbor, MI 48105, Phone: 734-232-8594, Fax: 734-936-9470, pasquali@med.umich.edu.

reducing major complications (by 10%) and LOS (by 1–3 days) were greatest for the Norwood operation ($7,944,128 and $3,929,351 respectively) and several other commonly performed operations of more moderate complexity.

Conclusions—Complications and prolonged LOS following congenital heart surgery are associated with significant costs. Initiatives able to achieve even modest reductions in these morbidities may lead to both improved outcomes and cost savings across both moderate and high complexity operations.

Keywords

congenital heart disease; health economics

Introduction

In this era of rising healthcare expenditures, hospitals face increasing pressure to provide high quality care at low cost (1). Congenital heart disease is known to be a commonly treated and resource-intense condition across US children's hospitals, compared with other birth defects and pediatric diseases (2,3). In addition, it has recently been demonstrated that there is significant variation in the cost of surgical care for these patients across hospitals, related in part to differences in post-operative complication rates and length of stay (LOS) (4).

However, the specific costs associated with common post-operative morbidities remain undefined across the spectrum of congenital heart surgery. Identifying targets that may lead to both improved outcomes, and the greatest potential cost savings, is crucial in informing initiatives focused on delivering high value care to these patients. In addition, this information could also provide insight into whether children's hospitals, pediatric heart programs, and other stakeholders participating in quality improvement collaboratives and other initiatives could expect to offset participation costs through potential savings related to reduction in postoperative morbidities (5).

Therefore, the purpose of this study was to describe excess costs associated with prolonged LOS and post-operative complications across a wide spectrum of congenital heart operations. We utilized a unique multi-center dataset consisting of linked clinical information from the Society of Thoracic Surgeons Congenital Heart Surgery (STS-CHS) Database and resource utilization data from the Pediatric Health Information Systems (PHIS) Database.

Material and Methods

Data Source

STS-CHS and PHIS data were linked at the patient-level using the method of indirect identifiers as previously described and verified (6,7). The STS-CHS Database is the largest existing pediatric heart surgery registry, and collects peri-operative data on all children undergoing heart surgery at >100 North American centers. Data quality is evaluated through intrinsic data verification (e.g. identification and correction of missing/out of range values and inconsistencies across fields), and random site audits at 10% of participating institutions annually. The PHIS Database is a large administrative database that collects hospital billing information from >40 US children's hospitals. Systematic monitoring in the PHIS Database includes coding consensus meetings, consistency reviews, and quarterly data quality reports. Linking these datasets enabled us to capitalize on the strengths of both datasets, including the detailed clinical information and data on post-operative morbidities in the STS-CHS Database and resource utilization information in the PHIS Database (6). This study was not considered human subjects research by the Duke Institutional Review Board in accordance with the Common Rule (45 CFR 46.102(f)).

Study Population

As described previously, hospitals participating in both the STS-CHS and PHIS Databases from 2006–2010 were eligible for inclusion (n=33 hospitals) (4). Hospitals that did not report resource utilization data (n=1 hospital) and those with >15% missing data for any preoperative variables or outcomes/cost data described below (n=5 hospitals) were excluded. From the remaining 27 hospitals, patients undergoing nine operations of varying complexity were included. These included the STS benchmark operations: ventricular septal defect (VSD) repair, tetralogy of Fallot (TOF) repair (excluding pulmonary atresia or absent pulmonary valve, or atrioventricular canal repair), complete atrioventricular canal (CAVC) repair, arterial switch operation (ASO) +/− VSD repair, Fontan operation (including lateral tunnel and extracardiac conduit +/− fenestration; excluding Fontan revision), truncus arteriosus repair (excluding concomitant truncal valve repair/replacement or interrupted aortic arch repair), and the Norwood operation (including either systemic-to-pulmonary artery shunt or right ventricle-to-pulmonary artery conduit) (8). In addition to these benchmark operations we also included atrial septal defect (ASD) repair and bidirectional Glenn (BDG)/hemi-Fontan. Of the 13,013 eligible patients, those with missing data for any of the outcomes described below were excluded (n=295 patients). For the purposes of this study, we included all patients regardless of survival status, as our previous work has demonstrated that complications can be associated with higher costs both on a patient and hospital level regardless of survival to discharge (4).

Data Collection

Data collected from the STS-CHS Database included demographics, standard STS-defined pre-operative risk factors, non-cardiac/genetic abnormalities, presence of prematurity, history of previous cardiothoracic surgery, diagnosis and procedure data as described above, post-operative complications, and LOS (9). Both the occurrence of any post-operative complication collected and defined in the STS-CHS Database, and major complications were evaluated. Major complications included renal failure requiring dialysis, neurologic deficit persisting at discharge, arrhythmia requiring permanent pacemaker, mechanical circulatory support, phrenic nerve injury/paralyzed diaphragm, and unplanned re-operation/re-intervention (8).

Resource utilization information collected from the PHIS Database included payer type (government, private, and other) and total hospital charges. As described previously, costs were estimated using hospital and department specific cost-to-charge ratios, adjusted for regional differences using the Centers for Medicare and Medicaid Services price and wage index, and indexed to 2010 dollars (4). Of note, professional fees are not included in most administrative datasets, including the PHIS database, and thus were not included in this analysis.

Analysis

Study population characteristics were described using standard summary statistics. Unadjusted rates of complications, median LOS, and total hospital costs were also described for the nine operations. In our evaluation of adjusted excess costs associated with complications and prolonged LOS, we fitted procedure-specific negative binomial models (with log-link functions to account for the skewed cost distribution). We evaluated both those with any complication and those with major complications (vs. no complications), and the LOS data were divided into 5 groups for the purposes of analysis: ≤procedure-specific median LOS, and +1, +2–3, +4–7, +8 or more days above the median LOS. The method of generalized estimating equations with robust standard error estimates was used, in order to account for within-center clustering. All models were adjusted for important patient characteristics, including age, weight, gender, race, prematurity, the presence of any non-cardiac/genetic abnormality or STS-defined pre-operative risk factor, previous cardiothoracic surgery, payer type, and year of surgery. VSD repair was also included in the ASO models and the presence of concurrent atrioventricular valvuloplasty was included in the models for Fontan and BDG/hemi-Fontan. Adjusted ratios of cost in those with and without complications and in those in the various LOS groups vs. those with ≤ median LOS were calculated as the exponentials of the estimated regression coefficients. Adjusted procedure-specific excess cost associated with prolonged LOS or complications was then defined as: Adjusted Excess Cost = Median Procedure-Specific Cost * (Adjusted Ratio of Cost – 1). For the purposes of this analysis, the LOS and complication variables were added in to separate models and evaluated individually. In addition, we also evaluated costs associated with specific complications of interest. These models were adjusted for the same variables described above, and the estimates represent cost in those patients with a particular complication vs. those without (regardless of other complications which may have occurred). This approach was taken as we felt it was difficult clinically to justify “adjusting away” the impact of other likely inter-related complications. For the LOS data, we also performed a sensitivity analysis, including adjustment for complications within these models, in an attempt to better assess the impact of prolonged LOS alone on costs.

Finally, we estimated the potential cost savings over the study period that might be achieved with in the study cohort through reducing complications or LOS, taking into account the prevalence of the operation, the prevalence of complication or prolonged LOS, and the point estimates for excess cost from our models described above. For complications we estimated the potential cost savings for each operation if major complications were reduced by 10%. For LOS we estimated the potential cost savings if those with a LOS +1–3 days above the median were reduced to the average LOS in those with ≤ the median LOS, as we hypothesized that these cases may be more amenable to intervention rather than those with substantially prolonged LOS which may be more related to comorbidities that are less modifiable (10). All analyses were performed using SAS version 9.3 (SAS Institute Inc, Cary, NC). A p-value <0.05 was considered statistically significant.

Results

Study Population Characteristics

A total of 12,718 patients from 27 centers were included. Study population characteristics are displayed in Table 1. Compared with the overall national cohort of hospitals participating in the STS-CHS Database during the study period (n=108), the 27 included hospitals had a higher average annual surgical volume (360 vs. 175 cases/year) and included more centers in the Midwest (37% vs. 22%).

Complication rates, median post-operative LOS, and median cost/case for each of the 9 operations are displayed in Table 2. As expected, each of these increased with operation complexity, from a major complication rate of 0.6%, median LOS of 3 days, and median total hospital cost/case of $25,499 for ASD repair to 32.2%, 29 days, and $165,168 respectively, for the Norwood operation. The overall rate of complications was 43%, and overall rate of major complications was 9%.

Excess Cost Associated with Complications

The excess cost/case associated with post-operative complications for each operation is displayed in Table 3. Across operations the average excess cost/case in patients with any postoperative complication compared with those without a complication was $56,584 and ranged from $16,097 (ASD repair) to $146,571 (truncus arteriosus repair). The average excess cost/case associated with major complications was higher ($132,483), ranging from $52,127 (VSD repair) to $261,188 (truncus arteriosus repair).

Costs associated with specific types of complications are displayed in Table 4. Complications associated with the highest excess cost/case were tracheostomy, mechanical circulatory support, respiratory complications, renal failure, and unplanned reoperation/intervention.

Excess Cost Associated with Prolonged Post-operative LOS

The excess cost/case associated with prolonged LOS for each operation is displayed in Table 5. Across operations, the average excess cost/case in those with an additional day of LOS above the median vs. those with a LOS ≤ the median was $19,273, ranging from $1,912 (ASD repair) to $51,597 (truncus arteriosus repair). The average excess cost associated with a LOS 4–7 additional days above the median was $40,688, and $181,043 on average for >7 days above the median. In a sensitivity analysis where the LOS models were adjusted for complications (in order to better assess the impact of LOS alone), values for cost associated with prolonged LOS were slightly lower across operations. For example, the average excess cost/case in those with an additional day of LOS above the median was $17,836 (compared to $19,23 in the original models as noted above), ranging from $1,959 (ASD repair) to $50,573 (truncus arteriosus repair).

Estimates of Cost Savings

Finally, we estimated the potential cost savings over the study period (in the cohort of included hospitals) that might be achieved through reducing complications or post-operative LOS, based on both the prevalence of the operation, the prevalence of complications and prolonged LOS, and the cost estimates derived from our models described above. The estimated cost savings in the study cohort that might be achieved through reducing major complications by 10% was greatest for the Norwood operation ($7,944,128) (Table 6). However, potential cost savings were also substantial for some of the more moderate complexity but frequently performed operations. In our evaluation of LOS, we assessed the potential cost savings achieved through reducing LOS in those with a LOS 1–3 days above the median to ≤ the median LOS. Similar potential cost savings were seen for the Norwood operation and many commonly performed moderate and lower complexity operations. Potential savings for truncus arteriosus repair were relatively low compared with other operations given the relative infrequency with which this operation is performed.

Comment

This large multi-center analysis describes costs associated with complications and prolonged LOS across the spectrum of congenital heart surgery. Although it is known that the surgical treatment of congenital heart disease is costly, there has been limited information available to policy makers, hospitals, and providers regarding which areas may be targeted to achieve the greatest improvement in both the domains of quality and cost in order to optimize "value" (1–3). We previously demonstrated that the wide variation in costs across hospitals performing congenital heart surgery is driven to a large extent by differences in the rate of post-operative complications, and average LOS (4). For example, high cost (vs. low cost) hospitals had a major complication rate following the Norwood operation of 50% vs. 25% and an average post-operative LOS of 50.8 days vs. 31.8 days (4). Benavidez and colleagues utilized a large administrative dataset to evaluate hospital charges associated with complications among 10,602 children undergoing heart surgery, and reported that complications were associated with higher charges (11).

The present analysis leverages a unique linked dataset consisting of merged clinical registry and administrative data in order to perform a detailed evaluation of costs associated with specific post-operative morbidities across the spectrum congenital heart surgery. This approach helps to overcome limitations associated with the use of administrative data alone, which include issues related to accurate case ascertainment, appropriate adjustment for case mix and patient characteristics, and accurate assessment of post-operative complications (12–14). In our merged dataset, the detailed information available in the clinical registry data allow a precise evaluation of specific congenital heart operations and post-operative complications, as well as more detailed adjustment for patient risk factors, while the administrative data provide valuable resource utilization data.

The results of our study suggest that quality improvement efforts aimed at reducing postoperative complications and LOS may have the potential to reduce costs. Even modest reductions in major complication rates (~10%) and LOS (1–3 days) were estimated to be associated with substantial savings. Finally, our findings also indicate that while potential cost savings are highest for the Norwood operation, initiatives focused on lower complexity, but commonly performed, operations may also result in significant savings.

Although these data may provide useful information regarding where to best focus efforts aimed at improving both quality and cost, further investigation is needed to understand practical strategies to achieve these goals. A previous single-center study evaluating children undergoing ASD and VSD repair demonstrated that LOS (and associated hospital costs) could be reduced by standardization of care involving practices aimed at early extubation and mobilization (15). Thus, it appears that LOS can be reduced through other mechanisms aside from indirect improvements through reducing complications. In adult surgical subspecialties, multicenter quality improvement collaboratives have proven to be successful models for sharing best practices across hospitals, and reducing variation in outcomes and cost (16,17). For example, a state-wide collaborative in Michigan is estimated to reduce complications following general and vascular surgery in ~2,500 patients each year, resulting in an annual savings of approximately $20 million (16). New initiatives in the field of pediatric cardiology and cardiac surgery such as those sponsored by the Pediatric Heart Network and the Pediatric Cardiac Critical Care Consortium (PC^4) aim to employ similar approaches, involving implementation of data-driven best practices across centers, and subsequent evaluation of outcomes and resource utilization (18). It should be noted that participating in these initiatives can also often involve a cost to the institution, most often including an annual fee on the order of $5–10,000, and salary associated with data entry personnel. The present study and data from the adult collaboratives suggest that these costs may be offset if participation leads to successful reduction in complications or LOS in even a handful of patients each year (16,17).

Limitations

Our analysis was limited to centers participating in both the STS-CHS and PHIS Databases during the study period, and thus may not be generalizable to all US pediatric heart programs. Ongoing expansion of linkages between clinical registry and administrative data will facilitate the inclusion of additional centers in the future. While our estimates suggest that reductions in complication rates and LOS may result in decreased resource utilization, prospective studies are necessary to confirm whether this is the case, and whether standardization of peri-operative care and sharing of best practices across hospitals can achieve these goals. In addition, it is difficult to separate the intertwined effects of LOS and complications as the two are most certainly related and impacting one will also likely impact the other. This study focused on in-hospital outcomes and costs. Further study of longer-term costs in those with multiple hospitalizations/operations, and of outpatient resource utilization will also be necessary. Finally, further development of methods which standardize line item costs may allow better delineation of true resource use through further removing inter-institutional variability in item costs, and future study of payments/reimbursements from large payer datasets may allow further analysis from the insurer or consumer’s perspective (2,5).

Conclusions

This multi-center analysis suggests that initiatives able to achieve even modest reductions in complication rates and post-operative LOS may lead to reductions in costs for both high complexity operations such as the Norwood operation, as well as lower complexity, but more commonly performed surgeries. Further investigation is needed to evaluate whether standardization of care, adoption of data-driven best practices across institutions, and other strategies commonly employed by quality improvement initiatives to reduce post-operative morbidities and costs in other fields are also effective in the congenital heart surgery population, and can offset the cost of participating in these initiatives.

Acknowledgments

Funding sources: National Heart, Lung, and Blood Institute (K08HL103631, PI: Pasquali; RC1HL099941, co-PI's: J Jacobs, Li).

References

1. Porter ME. What is value in health care? N Engl J Med. 2010; 363:2477–2481. [PubMed: 21142528]
2. Keren R, Luan X, Localio R, et al. Prioritization of comparative effectiveness research topics in hospital pediatrics. Arch Pediatr Adolesc Med. 2012; 166:1155–1164. [PubMed: 23027409]
3. Robbins JM, Bird TM, Tilford JM, et al. Hospital stays, hospital charges, and in-hospital deaths among infants with selected birth defects-United States, 2003. MMWR. 2007; 56:25–29. [PubMed: 17230142]
4. Pasquali SK, Jacobs ML, He X, et al. Variation in congenital heart surgery costs across hospitals. Pediatrics. 2014; 133:e553–e560. [PubMed: 24567024]
5. Dimick JB, Weeks WB, Karia RJ, et al. Who pays for poor surgical quality? Building a business case for quality improvement. J Am Coll Surg. 2006; 202:933–937. [PubMed: 16735208]
6. Pasquali SK, Jacobs JP, Shook GJ, et al. Linking clinical registry data with administrative data using indirect identifiers: Implementation and validation in the congenital heart surgery population. Am Heart J. 2010; 160:1099–1104. [PubMed: 21146664]
7. Pasquali SK, Li JS, He X, et al. Perioperative methylprednisolone and outcome in neonates undergoing heart surgery. Pediatrics. 2012; 129:e385–e391. [PubMed: 22271697]
8. Jacobs JP, Jacobs ML, Austin EH, et al. Quality Measures for Congenital and Pediatric Cardiac Surgery. World J Pediatr Congenit Heart Surg. 2012; 3:32–47. [PubMed: 23804682]
9. STS Database Full Specifications. Available at: http://www.sts.org/sites/default/files/documents/pdf/CongenitalDataSpecificationsV3_0_200 90904.pdf.
10. Kiefe CI, Weissman NW, Allison JJ, et al. Identifying achievable benchmarks of care: concepts and methodology. Int J Qual Health Care. 1998; 10(5):443–447. [PubMed: 9828034]
11. Benavidez OJ, Connor JA, Gauvreau K, Jenkins KJ. The contribution of complications to high resource utilization during congenital heart surgery admissions. Congenit Heart Dis. 2007; 2:319–326. [PubMed: 18377447]
12. Pasquali SK, Peterson ED, Jacobs JP, et al. Differential case ascertainment in clinical registry vs. administrative data and impact on outcomes assessment in pediatric heart surgery. Ann Thorac Surg. 2013; 95:197–203. [PubMed: 23141907]
13. Lawson EH, Louie R, Zingmond DS, Brook RH, Hall BL, Han L, Rapp M, Co CY. A comparison of clinical registry versus administrative claims data for reporting of 30-day surgical complications. Ann Surg. 2012; 256:973–981. [PubMed: 23095667]
14. Parnell AS, Shults J, Gaynor JW, et al. Accuracy of the all patient refined diagnosis related groups classification system in congenital heart surgery. Ann Thorac Surg. 2014; 97:641–650. [PubMed: 24200398]

15. Lawrence EJ, Nguyen K, Morris SA, et al. Economic and safety implications of introducing fast tracking in congenital heart surgery. Circ Cardiovasc Qual Outcomes. 2013; 6:201–207. [PubMed: 23443672]
16. Share DA, Campbell DA, Birkmeyer N, et al. How a regional collaborative of hospitals and physicians in Michigan cut costs and improved quality of care. Health Aff (Millwood). 2011; 30:636–635. [PubMed: 21471484]
17. Prager RL, Armenti FR, Bassett JS, et al. Cardiac Surgeons and the Quality Movement: the Michigan Experience. Semin Thorac Cardiovasc Surg. 2009; 21:20–27. [PubMed: 19632559]
18. Gaies MG, Pasquali SK, Scheurer MA. Follow the Leaders. World J Pediatr Congenit Heart Surg. 2014; 5:135–137. [PubMed: 24403375]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 1

Study Population Characteristics

Variable	N = 12,718 (27 centers)
Age	4.4 months (77 days – 2.1 years)
Weight (kg)	6.1 (4.1 – 11.0)
Sex, Female	5,777 (45.4%)
Race/Ethnicity	
Non-Hispanic white	6,636 (52.2%)
Other	6,082 (47.8%)
Prematurity	863 (6.8%)
Any STS preoperative factor	2,595 (20.4%)
Any non-CV/genetic abnormality	3,720 (29.2%)
Previous Cardiothoracic Surgery	3,457 (27.2%)
Payer type	
Government	5,620 (44.2%)
Private	4,526 (35.6%)
Other	2,572 (20.2%)
Operation type	
ASD repair	1,581 (12.4%)
VSD repair	2,669 (21.0%)
TOF repair	1,560 (12.3%)
Fontan	1,542 (12.1%)
BDG/Hemi-Fontan	1,692 (13.3%)
CAVC repair	1,150 (9.0%)
ASO	1,128 (8.9%)
Truncus repair	226 (1.8%)
Norwood	1,170 (9.2%)

Data are presented as median (interquartile range), or n (%)

Table 2

Overall Complication rates, LOS, and Cost by Operation

Operation	Any Complications	Major Complications	Post-operative LOS (days)	Cost/case
ASD repair	211 (13.3%)	10 (0.6%)	3 (3–4)	$25,499 (20,645 – 30,962)
VSD repair	757 (28.4%)	68 (2.5%)	5 (4–8)	$33,679 (26,915 – 47,381)
TOF repair	660 (42.3%)	88 (5.6%)	7 (5–10)	$44,318 (34,743 – 63,808)
Fontan	869 (56.4%)	144 (9.3%)	9 (7–14)	$51,464 (39,976 – 74,640)
BDG/Hemi-Fontan	673 (39.8%)	121 (7.2%)	7 (5–12)	$44,893 (33,695 – 69,400)
CAVC repair	603 (52.4%)	89 (7.7%)	8 (6–16)	$49,445 (36,293 – 80,545)
ASO	597 (52.9%)	145 (12.9%)	17 (13–24)	$94,902 (70,357 – 129,984)
Truncus repair	150 (66.4%)	53 (23.5%)	25 (14–47)	$133,006 (90,189 – 204,006)
Norwood	887 (75.8%)	377 (32.2%)	29 (19–49)	$165,168 (110,446 – 257,980)

Data are presented as median (interquartile range), or n (%)

Table 3

Adjusted Excess Cost/Case Associated with Complications

Operation	Any Complication	Lower 95% CI	Upper 95% CI	Major Complication	Lower 95% CI	Upper 95% CI
ASD repair	$16,097	$7,029	$27,691	$76,319	$21,354	$195,764
VSD repair	$19,902	$14,784	$25,559	$52,127	$34,284	$74,654
TOF repair	$26,886	$20,006	$34,503	$75,161	$42,516	$120,080
Fontan	$33,065	$24,156	$43,023	$104,485	$73,768	$142,737
BDG/Hemi-Fontan	$46,844	$30,009	$67,463	$134,202	$85,041	$201,962
CAVC repair	$46,795	$36,592	$58,207	$135,263	$99,314	$179,900
ASO	$53,790	$35,335	$74,860	$142,736	$109,643	$181,183
Truncus repair	$146,571	$103,521	$197,455	$261,188	$184,575	$356,282
Norwood	$119,303	$81,948	$162,306	$210,865	$154,452	$277,234

Data represent excess cost/case in those with any or major complications vs. no complications

Table 4

Adjusted Excess Cost/Case Associated with Specific Complications

Complication	N (%)	Excess cost/case	Lower 95% CI	Upper 95% CI
Tracheostomy	29 (0.2%)	$179,350	$132,958	$237,769
Mechanical circulatory support	263 (2.1%)	$68,964	$53,020	$87,475
Respiratory	953 (7.5%)	$67,149	$53,720	$82,386
Renal failure	138 (1.15)	$65,042	$45,232	$89,152
Re-operation/re-intervention	662 (5.2%)	$57,137	$47,419	$67,866
Neurologic	209 (1.6%)	$50,649	$29,498	$77,724
Infectious	511 (4.0%)	$49,968	$41,464	$59,298
Cardiac arrest	246 (1.9%)	$42,366	$29,271	$57,739
Phrenic/recurrent laryngeal nerve injury	241 (1.9%)	$37,271	$23,370	$53,958
Pleural effusion/chylothorax	959 (7.5%)	$30,356	$24,132	$37,132

Top 10 high cost complications listed

Certain individual complications were grouped for the purposes of analysis: respiratory complications (respiratory insufficiency requiring mechanical ventilator support >7 days and/or or re-intubation), renal failure (requiring temporary and/or permanent dialysis), reoperation/re-intervention (reoperation due to bleeding and/or unplanned cardiac re-operation or interventional cardiac catheterization), neurologic (transient or persistent neurologic deficit, seizure, or stroke), infectious (mediastinitis, wound infection, pneumonia, sepsis, or endocarditis).

Table 5

Adjusted Excess Cost/Case Associated with Prolonged LOS

Operation	Additional days > median	Excess cost/case	Lower 95% CI	Upper 95% CI
ASD Repair	+1	$1,912	$−2,007	$6,484
	+2–3	$5,723	$1,014	$11,268
	+4–7	$17,203	$9,212	$27,034
	>7	$123,896	$79,100	$187,877
VSD Repair	+1	$5,476	$2,092	$9,180
	+2–3	$10,661	$6,010	$15,857
	+4–7	$22,783	$18,553	$27,355
	>7	$101,246	$86,279	$118,081
TOF Repair	+1	$12,130	$6,045	$18,951
	+2–3	$16,469	$10,629	$22,930
	+4–7	$33,004	$26,832	$39,711
	>7	$134,040	$105,467	$168,062
Fontan	+1	$11,096	$6,904	$15,588
	+2–3	$16,062	$11,152	$21,357
	+4–7	$26,845	$18,788	$35,827
	>7	$112,903	$93,718	$134,623
BDG/Hemi-Fontan	+1	$11,543	$7,524	$15,870
	+2–3	$17,919	$13,378	$22,813
	+4–7	$32,759	$27,922	$37,917
	>7	$160,597	$127,862	$199,534
CAVC Repair	+1	$16,904	$10,474	$24,023
	+2–3	$25,534	$20,709	$30,691
	+4–7	$35,073	$28,809	$41,839
	>7	$178,721	$152,682	$208,114
ASO	+1	$19,007	$9,905	$28,899
	+2–3	$39,090	$31,162	$47,515
	+4–7	$57,517	$46,172	$69,775
	>7	$189,085	$153,923	$229,216
Truncus Repair	+1	$51,597	$8,245	$108,255
	+2–3	$54,637	$22,981	$92,717
	+4–7	$61,825	$30,748	$98,800
	>7	$340,298	$268,188	$425,369
Norwood	+1	$43,789	$9,783	$84,405
	+2–3	$77,795	$38,108	$125,230
	+4–7	$79,185	$46,383	$117,072

Operation	Additional days > median	Excess cost/case	Lower 95% CI	Upper 95% CI
	>7	$288,601	$235,308	$348,987

Table 6

Estimated cost savings

	Estimated cost savings during the study period*	
Operation	**If major complications reduced by 10%**	**If those with LOS +1–3 days reduced to ≤ median**
ASD repair	$72,396	$1,550,529
VSD repair	$347,817	$3,862,510
TOF repair	$656,606	$3,753,565
Fontan	$1,498,377	$3,638,318
BDG/Hemi-Fontan	$1,634,902	$3,628,331
CAVC repair	$1,197,753	$3,185,342
ASO	$2,076,980	$4,198,048
Truncus repair	$1,387,169	$795,235
Norwood	$7,944,128	$3,929,351

*in the hospitals included in the study cohort