Hospital Costs and Inpatient Mortality among Children Undergoing Surgery for Congenital Heart Disease

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Objective. To determine the association between hospital costs and risk-adjusted inpatient mortality among children undergoing surgery for congenital heart disease (CHD) in U.S. acute-care hospitals.

Data Sources/Study Settings. Retrospective cohort study of 35,446 children in 2003, 2006, and 2009 Kids' Inpatient Database (KID).

Study Design. Cross-sectional logistic regression of risk-adjusted inpatient mortality and hospital costs, adjusting for a variety of patient-, hospital-, and community-level confounders.

Data Collection/Extraction Methods. We identified relevant discharges in the KID using the AHRQ Pediatric Quality Indicator for pediatric heart surgery mortality, and linked these records to hospital characteristics from American Hospital Association Surveys and community characteristics from the Census.

Principal Findings. Children undergoing CHD surgery in higher cost hospitals had lower risk-adjusted inpatient mortality ($p = .002$). An increase from the 25th percentile of treatment costs to the 75th percentile was associated with a 13.6 percent reduction in risk-adjusted mortality.

Conclusions. Greater hospital costs are associated with lower risk-adjusted inpatient mortality for children undergoing CHD surgery. The specific mechanisms by which greater costs improve mortality merit further exploration.

Key Words. Health care costs, health policy, quality of care, pediatrics, geographic variation, acute inpatient care

There is substantial evidence that higher medical spending in regions within the United States does not necessarily equate with improved quality of care or health outcomes among adults (Fisher et al. 2003a,b; Wennberg 2010). Less is known about this relationship in pediatric patients. Pediatric diseases are rare and often more complex than adult-acquired diseases. This is particularly true in the case of congenital heart disease (CHD) (Garson et al. 1994; Ungerleider et al. 1997; Connor, Gauvreau, and Jenkins 2005; Burstein et al. 2010, 2011;

Jacobs et al. 2011; Pasquali et al. 2011). In view of the high cost of treating children with CHD and the long-term impact on health outcomes, it is critical to examine the relationship between costs and outcomes in this population.

A series of studies in adults have shown that higher spending on hospital care may entail health benefits in some circumstances (Ong et al. 2009; Kaestner and Silber 2010; Silber et al. 2010; Romley, Jena, and Goldman 2011; Stukel et al. 2012), although the evidence is not conclusive (Jha et al. 2009; Chen et al. 2010). A study of six California teaching hospitals found that adult patients with congestive heart failure had lower mortality rates when length of stay and costs were higher (Ong et al. 2009). Another analysis demonstrated an association between lower 30-day mortality and greater inpatient spending among patients undergoing surgery (Silber et al. 2010). A study of patients treated for a variety of acute medical conditions in California hospitals showed lower risk-adjusted inpatient mortality in higher spending hospitals (Romley, Jena, and Goldman 2011). In Ontario, Canada, greater hospital spending was associated with lower mortality and readmission rates (Stukel et al. 2012). In other relevant research, Barnato et al. (2010) find higher rates of risk-adjusted survival at hospitals with higher “end-of-life” treatment intensity, as measured by a weighted amalgam of six standardized intensive care unit and life-sustaining treatment metrics.

This evidence is limited to the adult (and in some cases elderly) population, often near the end of life (Barnato 2010). This study analyzed the association between hospital costs and risk-adjusted inpatient mortality among children undergoing surgery for CHD. While CHD is rare, its burden is acute and frequently enduring, and is manifested not only in health but in myriad other ways, including workplace productivity and general well-being, for both patients and their families. The treatment of CHD is complex and costly (Garson et al. 1994; Ungerleider et al. 1997; Connor, Gauvreau, and Jenkins 2005; Burstein et al. 2010, 2011; Jacobs et al. 2011; Pasquali et al. 2011), and surgical outcomes are strongly associated with factors such as case volume (Hannan et al. 1998; Spiegelhalter 2002; Allen et al. 2003; Dagan et al. 2003;

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Checchia et al. 2005; Berry et al. 2006; Bazzani and Marcin 2007; Hirsch et al. 2008; Welke et al. 2008, 2009).

To analyze hospital costs and mortality among children undergoing surgery for CHD, we used national samples of hospital admissions in 2003, 2006, and 2009. A validated risk adjustment model accounted for underlying differences in inpatient mortality risk across hospitals (Agency for Healthcare Research and Quality 2001; Romley, Jena, and Goldman 2011). The analysis also controlled for hospital- and community-level factors, as we now describe.

METHODS

Study Sample

The Kids' Inpatient Database (KID) from the Healthcare Cost and Utilization Project was used to identify a nationally representative sample of children undergoing surgery for CHD at U.S. community nonrehabilitation hospitals in 2003, 2006, and 2009 (Agency for Healthcare Quality and Research 2009). The Institutional Review Board at the RAND Corporation exempted these deidentified data from human subjects review. The KID database includes a systematic random sample of 10 percent of uncomplicated in-hospital births, 80 percent of complicated in-hospital births, and 80 percent of all other pediatric cases from all hospitals in its sampling frame. The number of hospitals in the KID database grew from 3,348 in 2003 to 4,121 in 2009. The database provides demographic and clinical data on each patient, including age, gender, race/ethnicity, month/year of hospital admission, length of stay, primary and secondary diagnoses, primary and secondary procedures, discharge outcome (e.g., discharge to home, in-hospital mortality), and billed hospital charges. Diagnoses and procedures are coded according to the International Classification of Diseases, Ninth Revision (ICD-9).

The sample of children undergoing surgery for CHD was identified using the Agency for Healthcare Research and Quality's Pediatric Quality Indicators (version 4.2) (Agency for Healthcare Quality and Research 2010). Specifically, the AHRQ quality measure for pediatric heart surgery mortality includes children under the age of 18 with a procedure code for CHD, or codes for a CHD diagnosis and heart surgery, who do not meet a set of exclusion criteria. Detailed inclusion/exclusion criteria are reported in the appen-

dix. A relevant variable was missing for 1.2 percent of observations in the KID database.

Hospital Costs and Other Characteristics

For the patient sample, hospital charges were converted into costs using cost-to-charge ratios from the KID (Lagu et al. 2012), and adjusted for local labor costs using the Medicare hospital wage index (Centers for Medicare and Medicaid Services 2012). Hospital costs were converted into 2010 dollars using the producer price index for general medical and surgical hospitals (Bureau of Labor Statistics 2012).

Following prior research (Wennberg et al. 2008), we adjusted costs for patient age (Ungerleider et al. 1997; Scott and Fixler 2001; Brown et al. 2003; Connor, Gauvreau, and Jenkins 2005; Panni, Ashfaq, and Amanullah 2011; Pasquali et al. 2011), gender (Burstein et al. 2011), race/ethnicity (Burstein et al. 2011), and also for All Patient Refined-Diagnosis Related Group (APR-DRG) and APR-DRG severity (Ungerleider et al. 1997; Scott and Fixler 2001; Connor, Gauvreau, and Jenkins 2005; Agency for Healthcare Quality and Research 2010; Pasquali et al. 2011), using a linear regression with fixed effects for each hospital-year. Patient-level costs were logged for the regression, and then retransformed using Duan's nonparametric smearing factor (Duan et al. 1983; Buntin and Zaslavsky 2004).

Additional hospital characteristics from the KID included quartile of the annual volume of CHD surgery cases (Luft, Hunt, and Maerki 1987; Hannan et al. 1998; Halm, Lee, and Chassin 2002; Spiegelhalter 2002; Allen et al. 2003; Dagan et al. 2003; Checchia et al. 2005; Berry et al. 2006; Bazzani and Marcin 2007; Hirsch et al. 2008; Welke et al. 2008, 2009; Stukel et al. 2012), teaching status (Fisher et al. 2003a; Berry et al. 2006; Romley, Jena, and Goldman 2011; Stukel et al. 2012; Romley et al. 2013), and pediatric orientation. Teaching status was defined by the presence of an American Medical Association–approved residency, membership in the Council of Teaching Hospitals, or a ratio of full-time equivalent house staff to beds of 0.25 or higher (Agency for Healthcare Quality and Research 2009). Pediatric-oriented facilities included children's general hospitals, children's specialty hospitals, and children's units of general hospitals, as reported by the National Association of Children's Hospitals and Related Institutions. Finally, hospital size was measured by the number of pediatric medical and surgical beds, where available, in

American Hospital Association Annual Surveys (American Hospital Association 2006). The primary analysis included the 332 hospitals that treated the study population.

Statistical Analysis

The primary analysis estimated a hierarchical logistic regression model, specifically, the following random effects logit (Dimick, Staiger, and Birkmeyer 2010):

$$\text{logit} [\Pr (\text{Death}_{i,h} | \text{pred_mortality}_i, \text{cost}_h, \text{other patient factors}_i, \text{other hospital factors}_h, \zeta_h)] = \beta_0 + \beta_1 \text{pred_mortality}_i + \beta_2 \text{other patient factors}_i + \beta_3 \text{cost}_h + \beta_4 \text{other hospital factors}_h + \zeta_h + \varepsilon_{i,h}$$

The dependent variable $\text{Death}_{i,h}$ was an indicator for death of patient i in hospital h . The first level of the hierarchical model corresponded to the patients nested within hospitals; this level included patient-level predicted mortality risk pred_mortality_i and other factors, as described below. The second level of the model corresponded to the hospital and included adjusted cost during the year of admission cost_h and other measured hospital factors. Cost was specified as a polynomial function for flexibility (Fisher et al. 2003a). The term $\zeta \sim N(0, \sigma^2)$ was a hospital random effect, assumed to be independent across hospitals; the term $\varepsilon_{i,h} \sim N(0, \theta^2)$ was the within-hospital residual, assumed independent across hospitals and patients. Individual observations were weighted with discharge sample weights from the KID, aggregated to the hospital-year level.

Health status and other factors affecting inpatient mortality were addressed by applying risk adjustments from the AHRQ quality indicator for pediatric heart surgery mortality. These indicators were designed to deal with the special challenges of quality measurement in the pediatric population; their development involved literature review, clinical panel review, empirical analysis, and peer review by numerous stakeholders (McDonald et al. 2006). The AHRQ risk parameters were estimated from the 2003 KID database. These parameters were used to obtain patient-level predicted mortality risk (pred_mortality_i) based on a patient's age (Panni, Ashfaq, and Amanullah 2011), birth weight, Risk Adjustment in Congenital Heart Surgery-1 (RACHS-1) category, and other factors such as transfer from another hospital. The RACHS-1 risk adjustment method was developed by a nationally representative panel of pediatric cardiologists and

pediatric cardiac surgeons for the purpose of adjusting for the risk of in-hospital mortality among children undergoing surgery for CHD (Jenkins et al. 2002). The AHRQ risk parameters are reported in the Appendix; costs were not a factor in the AHRQ risk model. Hospital-level factors included teaching status, annual CHD surgery volume, and Census region. The base specification also included indicator variables for the years 2006 and 2009.

Stata, version 12, was used for statistical analyses, and 95 percent confidence intervals (CI) were used for inference. Given a level of costs, risk-adjusted mortality was predicted based on the method of predictive margins (Graubard and Korn 1999).

Sensitivity Analysis

In a sensitivity analysis, length of stay was included in the logistic model because hospitals with shorter stays may be more likely to discharge patients alive (Drye et al. 2012). In another analysis, recent evidence on regional variation in diagnostic intensity (Song et al. 2010; Welch et al. 2011) was addressed by adding the average level of predicted mortality risk within a hospital referral region (HRR) to the model, and interacting predicted patient mortality risk with the HRR average (Romley et al. 2013). Next, we linked each discharge record to community-level characteristics from the 2000 U.S. Census similar to prior research (Fisher et al. 2003a). Hospital zip code was used unless missing; then county and state were used. Specific variables included median annual household income and the percentage of the population who were living below poverty level, employed, had less than a high school education, Hispanic, single, and lived in an urban area. In another specification, hospital size and state-level indicator variables were added, the latter to help deal with unobserved confounders. Another analysis measured costs among decedents. This approach has been argued to be more closely related to a hospital's overall approach to care rather than to patients' severity of illness (Fisher et al. 2003a; Wennberg et al. 2008). An additional specification excluded the case with the highest cost in each hospital-year, to assess whether the measured association between spending and mortality is driven by the costly rescue of patients who were not expected to survive (Detsky et al. 1981). A final analysis excluded all premature infants (the AHRQ measure for pediatric heart surgery excludes premature infants whose only cardiac procedure was a PDA closure). In the latter two specifications, hospital costs were adjusted based on the samples of interest.

RESULTS

The study sample included 35,446 patients admitted to 332 U.S. hospitals in 2003, 2006, and 2009 (Table 1). The patients included in the study represent 58,181 discharges in the United States, based on sample weights in the KID database. Inpatient mortality was 4.0 percent. The mean age of patients was 2.7 years, and less than half (44.8 percent) were female. In terms of severity, more than half (55.5 percent) were in RACHS-1 category 1 or 2, whereas 3.3 percent were in category 5 or 6. Nearly 95 percent of patients ($n = 32,806$) were treated in one of 137 pediatric facilities (52 percent at 102 children's units within general hospitals, and 48 percent at 35 children's general hospitals). Almost all the CHD cases were treated at teaching hospitals in urban areas.

There were differences between low- and high-cost hospitals, defined by the median of the distribution of adjusted cost per stay (\$48,754). As shown in the rightmost columns of Table 1, patients treated at hospitals with high adjusted costs were significantly more likely to have severe cases (e.g., 9.9 percent with RACHS-1 category 5 or 6 in high-cost hospitals, versus 8.2 percent in low-cost hospitals). High-cost hospitals were more likely to be large pediatric facilities, to have longer length of stays, and to be located in the Midwest.

Adjusted costs per stay varied substantially across hospital-years, as shown in Figure 1. The 25th percentile of the adjusted cost distribution was \$37,091, whereas the 75th percentile was \$59,791; thus, the interquartile range was \$22,700. While adjusted cost reached a maximum of \$219,045, 99 percent of patients were treated at hospitals with a cost of \$92,148 or less.

Figure 2 shows how inpatient mortality rates varied with adjusted hospital cost and RACHS-1 severity, based on smoothed scatter plots from locally weighted regressions (Cleveland 1979). For any level of costs, observed mortality was lowest in the lowest severity group (RACHS-1 categories 1 and 2) and highest in the highest severity category group (categories 5 and 6). For example, at the 25th percentile of adjusted cost, observed mortality among low-severity patients was 2.55 percent, but 5.21 percent for patients with moderate severity and 25.1 percent for high-severity patients. Mortality as predicted by the AHRQ model also increased with severity; the risk model is based in part on RACHS scores. Within the low- and medium-severity groups, the predicted mortality rate increased with cost, whereas the observed mortality rate decreased with cost. For example, among the least severe patients, predicted mortality increased from 2.14 percent at hospitals at the 25th percentile of adjusted cost to 2.31 percent at hospitals at the 75th cost per-

Table 1: Summary Statistics for Children Undergoing Surgery for Congenital Heart Disease, 2003, 2006, and 2009

<i>Sample</i>	<i>Full</i>	<i>Low Cost</i>	<i>High Cost</i>
Patients, <i>n</i>	35,446	11,807	23,639
Weighted population	58,181	18,467	39,713
Observed inpatient mortality, %	4.0 (19.5)	4.3	3.8
Age, year	2.7 (4.3)	2.8	2.6
Female, %	44.8 (49.7)	45.1	44.7
White, %	41.3 (49.2)	38.5	42.5
Black, %	9.1 (28.7)	10.4	8.4
Hispanic, %	17.5 (38.0)	17.7	17.3
Asian or Pacific Islander, %	2.8 (16.6)	3.0	2.7
Native American, %	0.6 (7.7)	0.8	0.5
Other race, %	5.8 (23.4)	6.1	5.7
Race missing, %	23.0 (42.1)	23.4	22.8
RACHS-1 category 1, %	23.1 (42.1)	24.7	22.4
RACHS-1 category 2, %	32.4 (46.8)	33.3	32.0
RACHS-1 category 3, %	31.9 (46.6)	31.1	32.3
RACHS-1 category 4, %	9.3 (29.1)	8.2	9.9*
RACHS-1 category 5 or 6, %	3.3 (17.7)	2.7	3.5*
Transfer from another hospital, %	17.8 (38.3)	13.4	19.9
Length of stay, days	17.6 (28.6)	16.4	18.1*
Year treated	2006.1 (2.3)	2006.0	2006.2
Annual hospital volume, <i>n</i>	343.4 (241.4)	264.9	379.9
Treated at pediatric facility, %	94.3 (23.2)	89.7	96.4*
Treated at teaching hospital, %	95.8 (20.2)	92.7	97.2
Treated at large hospital, %	50.4 (50.0)	29.3	60.2*
Treated at urban hospital, %	99.5 (7.1)	99.8	99.4
Characteristics of hospital zip code			
Median annual household income, \$	\$40,415 (\$13,790)	\$40,429	\$40,409
Below poverty line, %	15.8 (8.7)	15.2	16.1
Urban, %	90.2 (13.0)	90.3	90.2
Hispanic, %	14.6 (15.6)	14.4	14.7
Single, %	51.4 (11.4)	50.4	51.8
Less than high school education, %	18.9 (8.6)	19.7	18.6
Employed, %	59.4 (6.6)	59.5	59.3
Northeast, %	12.6 (33.2)	21.2	8.5
Midwest, %	24.7 (43.1)	12.3	30.4*
South, %	31.3 (46.4)	39.0	27.7
West, %	31.4 (46.4)	27.5	33.3

Note. Standard deviations are in parentheses. High cost is defined as adjusted cost in excess of median hospital (\$48,754).

*Difference between low- and high-cost hospitals is statistically significant at the 5% level. Based on data from the Kids' Inpatient Database. Pediatric facilities included children's general hospitals, children's specialty hospitals, and children's units of general hospitals. A large hospital had as many pediatric medical/surgical beds (96) as the median hospital in which patients were treated. Weighted to match universe of community hospitals in AHA Annual Surveys.

Figure 1: Histogram of Adjusted Cost for Pediatric Congenital Heart Surgery in 332 U.S. Hospitals in 2003, 2006, and 2009

centile. By contrast, observed mortality *decreased* from 2.55 to 2.24 percent. For the high-severity group, the excess of observed mortality over predicted mortality decreased as cost increased.

In the multivariate regression of the base model, we first considered a quadratic specification for adjusted cost. A likelihood ratio test could not reject this specification in favor of a model with a third-order polynomial in cost ($P = .195$) (Wooldridge 2002). However, a linear specification could be rejected in favor of the second-order polynomial ($P = .018$). In the quadratic specification, adjusted hospital cost was significantly associated with risk-adjusted inpatient mortality ($P = .003$).

The relationship between risk-adjusted mortality and costs is shown in Figure 3 for the base model specification. Risk-adjusted mortality tended to decrease with hospital costs. For example, the risk-adjusted mortality rate was predicted to be 4.37 percent at the 25th percentile of hospital costs, but 3.78 percent at the 75th percentile for a relative reduction of 13.6 percent. The gradient of mortality with respect to costs did flatten in the higher

Figure 2: Observed Inpatient Mortality Rate and AHRQ Predicted Mortality Rate by Adjusted Hospital Cost and RACHS-1 Severity

Figure 3: Risk-Adjusted Mortality Rate, by Adjusted Hospital Cost

ranges of the cost distribution. Complete regression results are reported in Table S1.

Table 2 shows the results of the sensitivity analyses. To begin with, we compared the base specification just described to a model which did not adjust mortality or costs for the patient and hospital characteristics described previously. In the absence of any adjustment, predicted mortality *increased* by 25.8 percent as costs increased from the 25th to the 75th percentiles of the (unadjusted) cost distribution ($P = .003$). In the rest of the sensitivity analyses, mortality and costs were adjusted. When length of stay was included, predicted mortality decreased by 16.2 percent with an interquartile increase in adjusted costs ($P < .001$). Accounting for diagnosed mortality risk within HRRs (specification 4) led to quite similar results to the base specification in terms of risk-adjusted mortality at the 25th and 75th percentiles of the hospital cost distribution. When zip code characteristics were included, the mortality–cost relationship was unchanged ($P = .003$). Hospital size was also available for 200 hospitals. Adding hospital size and state-level indicator variables resulted in a significant mortality–cost relationship ($P < .001$), with risk-adjusted mortality decreasing by 30.1 percent as adjusted cost increased. Costs

based on decedents were available at 147 hospitals with decedent cases, and the results were similar based on this cost measure. When the highest-cost cases were excluded (specification 8), predicted risk-adjusted mortality decreased by 11.5 percent as adjusted costs increased from the 25th to the 75th percentile ($P = .003$). Finally, when all premature infants were excluded from the analysis, the mortality–cost gradient remained negative ($P = .032$).

DISCUSSION

We analyzed the relationship between hospital costs and inpatient mortality in a national sample of children admitted to U.S. acute-care hospitals in 2003, 2006, and 2009. When neither costs nor mortality was adjusted for patient health status or other factors, higher spending was positively associated with mortality. However, a spurious association could result from a positive correlation between patient severity and treatment intensity (McClellan, McNeil, and Newhouse 1994; Fisher et al. 2003a; Hussey, Wertheimer, and Mehrotra 2013).

After adjusting for a variety of patient, hospital, and community characteristics, higher hospital costs were generally associated with lower inpatient mortality for patients undergoing surgery for CHD. There are legitimate concerns about the validity of common risk adjustment methods. For example, recent studies demonstrate that areas which treat patients more intensively are also more likely to diagnose conditions which may be used in risk adjustment (Song et al. 2010; Welch et al. 2011); as a consequence, patients in high-cost areas may appear to be sicker than is truly the case. Our findings were not sensitive to alternative approaches to adjustment. In addition, the negative association between adjusted costs and mortality did not appear to result from a small number of outlier cases with high costs.

If all patients were treated at a hospital whose costs were at the 75th percentile instead of the 25th percentile, risk-adjusted mortality would be predicted to decrease by 13.6 percent. This mortality reduction is associated with a \$3.8 million increase in hospital costs per inpatient life saved, measured in 2010 dollars. This cost estimate is less than the cost-effectiveness thresholds sometimes used in U.S. policy making. For example, the Environmental Protection Agency has analyzed clean air standards for ozone—a pollutant with established significant adverse health effects for children and adults (Bell et al. 2004; Bell, Dominici, and Samet 2005; Perez et al. 2009)—based on a value of a statistical life of \$7.2 million in 2010 dollars (U.S. Environmental Protection Agency 2012). By this standard, hospital spending on surgery for

Table 2: Sensitivity Analysis of Relationship between Risk-Adjusted Inpatient Mortality and Adjusted Hospital Cost

Specification Number	Description	Sample		Risk-Adjusted Mortality, by Adjusted Cost Level		p-Value
		Patients	Hospitals	25th Percentile	75th Percentile	
1	Unadjusted mortality and hospital costs	35,446	332	0.0391	0.0492	.003
2	Base specification (Figure 3)	35,446	332	0.0437	0.0378	.002
3	Including length of stay	35,433	332	0.0444	0.0372	<.001
4	Accounting for diagnosed mortality risk within hospital referral region	22,283	212	0.0433	0.0359	.003
5	Including characteristics of hospital zip code	35,446	332	0.0437	0.0378	.003
6	Including zip characteristics, hospital size, and state-level indicators	25,283	200	0.0503	0.0352	<.001
7	Adjusted hospital costs based on decedents	33,886	147	0.0454	0.0395	<.001
8	Excluding outlier cases in terms of patient costs	34,161	221	0.0339	0.0300	.003
9	Excluding premature infants	33,555	260	0.0388	0.0358	.032

Note. Specifications 3–9 are relative to base specification (no. 2). Specification 2 includes a quadratic polynomial in cost. In other specifications, linear specification was used if likelihood ratio test of more parsimonious specification was not rejected. *p*-value in final column corresponds to hypothesis that all cost parameters equal zero. For specification 1, hospital costs were not adjusted for patient characteristics. For specification 8, the patient with the highest costs in each hospital-year was excluded from the analysis.

CHD may be money well spent. However, the cost effectiveness of Medicaid expansion for children has been estimated at \$2.7 million per life saved (Currie and Gruber 1996), again in 2010 dollars. Other interventions save lives at even lower cost, in particular, a median cost of \$26,936 per life saved for medical interventions (Tengs et al. 1995).

This evidence of a negative association between costs and mortality among children undergoing surgery for CHD contrasts with some recent evidence. Pasquali and colleagues analyzed variation in treatment costs among children undergoing surgery for four specific congenital heart defects and found a positive association between costs and inpatient mortality for two relatively complex defects but no association for the others (Pasquali et al. 2011). Kim and colleagues investigated resource use among adults treated for CHD in pediatric hospitals and found higher inpatient mortality among high resource use (i.e., high-cost) admissions (Kim et al. 2011). These analyses of treatment costs and mortality did not adjust for patient risk, as the model used here did. Without any risk adjustment, the present analysis does not find a negative association between hospital costs and inpatient mortality. It is also possible that the relationship between costs and mortality in CHD surgery differs between adults and children.

This study did not specifically address the drivers of the cost–mortality association. Early adopters of new technologies or treatment modalities may achieve better outcomes, but at higher cost (Rogers 1995). Hospitals may deliver better care through investments in the recruitment and retention of leading providers and specialized staff (the analysis did account for teaching status; Berry et al. 2006). However, treatment in a dedicated pediatric cardiac intensive care unit is not associated with lower mortality than treatment in a general pediatric or neonatal ICU (Burstein et al. 2011). Preoperative management and treatment of associated noncardiac lesions may increase costs while improving outcomes (Brown et al. 2003; Boethig et al. 2004), yet high costs continued to be associated with lower risk-adjusted mortality even when length of stay was analyzed. Ideally, costs could have been disaggregated into specific and consistent categories of service (Keren et al. in press).

This observational analysis used an administrative database compiled by various state organizations and may not have fully accounted for factors that could confound the measured association between hospital costs and inpatient mortality. For example, while our analysis accounted for transfer cases, this approach may deal imperfectly with selective referral to centers of excellence for specific services. If patients treated in higher cost hospitals were sicker than otherwise predicted, the analysis would understate the beneficial effect of costs

on inpatient mortality; the opposite could also be true. While the RACHS risk classification scheme is a widely accepted method of assessing mortality risk in hospitals with differing referral sources and systems of care (Allen et al. 2003; DeMone et al. 2003; Gonzalez et al. 2003; Boethig et al. 2004; Connor, Gauvreau, and Jenkins 2005; Kim et al. 2011), CHD encompasses a multitude of defects, and there is continual evolution in treatment paradigms, and indeed in the severity of defects which are amenable to treatment. Another potential source of confounding is hospital leadership and culture (Hearld et al. 2008; Shipton et al. 2008), which could be positively correlated with cost (Skinner 2011).

Despite these limitations, our findings contribute to an expanding body of evidence that higher hospital spending and costs are associated with lower risk-adjusted mortality, in the present context, among a pediatric population with a rare but highly acute and complex condition. Critical questions need to be answered about the types of treatments and hospital care delivery systems that explain this association (Burstein et al. 2010, 2011; Jacobs et al. 2011).

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Table S1: Complete Hierarchical Random Effects Logistic Regression Results for Base Model Specification (Specification 2 from Table 2).

Appendix SA1: Author Matrix.