ORIGINAL ARTICLE

Exploring Value in Congenital Heart Disease: An Evaluation of Inpatient Admissions

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ABSTRACT

Objectives. Understanding value provides an important context for improvement. However, most health care models fail to measure value. Our objective was to categorize inpatient encounters within an academic congenital heart program based on clinical outcome and the cost to achieve the outcome (value). We aimed to describe clinical and nonclinical features associated with value.

Design. We defined hospital encounters based on outcome per resource utilized. We performed principal component and cluster analysis to classify encounters based on mortality, length of stay, hospital cost and revenue into six classes. We used nearest shrunken centroid to identify discriminant features associated with the cluster-derived classes. These features underwent hierarchical clustering and multivariate analysis to identify features associated with each class.

Study Setting/Patients. We analyzed all patients admitted to an academic congenital heart program between September 1, 2009, and December 31, 2012.

Outcome Measures/Results. A total of 2658 encounters occurred during the study period. Six classes were categorized by value. Low-performing value classes were associated with greater institutional reward; however, encounters with higher-performing value were associated with a loss in profitability. Encounters that included insertion of a pediatric ventricular assist device (log OR 2.5 [95% CI, 1.78 to 3.43]) and acquisition of a hospital-acquired infection (log OR 1.42 [95% CI, 0.99 to 1.87]) were risk factors for inferior health care value.

Conclusions. Among the patients in our study, institutional reward was not associated with value. We describe a framework to target quality improvement and resource management efforts that can benefit patients, institutions, and payers alike.

Key Words. Heart Defects; Congenital; Value; Mortality; Length of Stay; Cost

Introduction

Health care in the United States is increasingly losing value. Despite the highest cost per person of any country,[1] health outcomes are the same or worse than those in other countries.[2–5] Unchecked, spending on health care is anticipated to exceed 20% of the gross domestic product by 2020. In general, the US health care system does not routinely measure value, creating systems in which patients, providers, and payers are often misaligned in their goals for quality of care, profitability, and cost containment.[6]

Chronic conditions such as congenital heart disease (CHD), which is associated with some of the highest hospital charges, length of stay (LOS), and mortality compared with other birth defects, pose substantial health and resource burdens.[7] Understanding value in the treatment of CHD is important to every stakeholder involved in health care delivery. Each year in the United States, an estimated 32 000 children are born with CHD.[8] Hospitalization rates have increased by more than 25%,[8] and the number of hospital admissions for adults with CHD in the United States has more than doubled over the past decade.[9] Previous studies have shown considerable variation in resource utilization by state, age, and surgical strategy.[10–13] However, reducing resource utilization is not synonymous with improving value. Innovative programs for health reform are progressively focusing on plans that are value based. Yet for many institutions, cost reduction and quality improvement programs are parallel but detached priorities, which obscure understanding of value.

In response to the need for value-based care, there have been several important efforts to standardize clinical practice to reduce resource utilization while maintaining standard care.[14–17] However, the applications of these expensive programs, framed predominantly by disease or procedure, are not guided by an understanding of baseline value.[18] Without this consideration, programmatic resources may be allocated towards standardization work with comparatively little or, paradoxically, more costly results. Additionally, successful reduction in resource utilization, in the absence of external financial reimbursement adjustments, may culminate to potentially deleterious revenue strategies for health care institutions.[19] Evaluating baseline value within a service line considering all encounters, as opposed to by disease or procedure, may help with situational awareness to broadly identify encounter types at greatest need for reform to prioritize resource appropriation. The identification of encounter types that are at risk for poor value can enable structural cost reduction with optimal return on investment while rewarding services that are efficient and high quality.

We did an analysis of an enterprise data warehouse at an academic congenital heart program consisting of a diverse population of patients with CHD admitted to the hospital for medical or surgical management based on value. We aimed to describe patterns of patient and hospital features associated with value.

Methods

Patient Population

The Children's Heart Center at Stanford University is a nonprofit, fee-for-service center of excellence within a free-standing academic children's hospital. The center experiences approximately 800 hospital admissions per year and provides all of the hospital services for cardiology and cardiovascular surgery, treating children and adults with CHD and children with non-CHD. We included all patients admitted with at least one overnight hospitalization to the center between September 1, 2009, and December 31, 2012, in our study. Patient visits that were exclusively ambulatory or urgent care were excluded from the analysis. The Institutional Review Board at Stanford University approved the study and certified that it met the criteria for a waiver of informed consent.

Sources of Data

We constructed an enterprise data warehouse consisting of various sources of institutional and census data as follows: (1) All data from the electronic medical record were incorporated including patient demographic information, laboratory tests and results, radiographic tests, prescriptions, and diagnoses. Complications were identified according to the *International Classification of Diseases, 9th Revision, Clinical Modification* while primary cardiac procedures were identified according to the *Surginet* Classification System; (2) key performance indicators; (3) hospital cost and revenue data; and (4) data from the US Census Bureau. We categorized patients by complexity utilizing the Risk Adjustment for Congenital Heart Surgery (RACHS-1)[20] score where applicable. Socioeconomic status was estimated from residence zip codes. Patients were categorized by payer mix as having commercial insurance, out-of-state Medicaid, California-based Medicaid (Medi-CAL), and other miscellaneous payer types.

Definition of Value

Value was defined as health indicator achieved per resource utilized. The numerator of the equation in our population encompassed health status achieved through the encounter (survival) and efficiency of the encounter (length of hospitalization), representing the top two tiers of the outcome measures hierarchy.[6] In-hospital mortality represented a categorical variable, while length of hospitalization was expressed as an ordinal variable. The denominator of the value equation is composed of total hospital cost calculated in the following manner: For each patient encounter, total hospital cost was determined. Costs were not weighted or adjusted. The cost types utilized were direct costs—costs directly related to providing patient care that could be specifically traced to or identified with a particular product or service (e.g., nursing care or an x-ray). Direct costs included fixed (e.g., room cost) and variable components (e.g., physician ordering practices). Discrete costs for services or products were assigned to the encounter, while direct costs distributed across a unit (e.g., nurse manager) were averaged per unit per day or per service encounter. Indirect costs not related to patient care that could not be specifically traced to or identified with an individual service or group of services were not included. Neither hospital charges nor charge-to-cost conversions were used to calculate cost.

Additionally, to identify areas where incentives to improve are potentially conflicting between health care stakeholders, we included profitability as a surrogate for reward, utilizing net hospital revenue per patient encounter. Net revenue was determined by the institution's financial department after review of section and term requirements of payer contracts with input parameters and qualifications. Though cost (and charges) for services are the same and agnostic of payer type, reimbursement rates vary between insurance types. Net revenue was expressed as profitable or not profitable (positive or negative) reflecting a combination of actual and expected net revenue.

Statistical Analysis

k-Means Cluster Analysis

On all patient admissions, principal component analysis (PCA)[21] was applied to orthogonally transform data based on the value equation into six linearly uncorrelated principal components while at the same time preserving 95% of the input information. We then used *k*-means cluster analysis on the six principal components to classify patient admissions with similar patterns. This method allowed us to partition the data into six distinctive groups used in our final analysis. To verify distinctiveness of each class, we compared the outcomes of patient mortality, LOS, hospital cost, and revenue, respectively, with one-way ANOVA.

Nearest Shrunken Centroid Analysis

"Nearest shrunken centroid" (NSC)[22] approach was utilized through a 10-fold cross-validation to identify clinical and nonclinical variables associated with the cluster-defined classes. Features were identified by false discovery analysis[23,24] taking into account a false discovery rate of less than 1%. These features were subjected to hierarchical clustering using Euclidean distance to identify patterns associated with each cluster-derived class. Generalized linear model multivariable analysis was performed to test the NSC-derived features for association with the class of encounters with inferior clinical effectiveness (Figure 1).

Results

A total of 2628 patient admissions occurred during the study period. The median age of the study population was 3 years (IQR 0,11), and 1229 of the subjects (47%) were female. Nearly half of the encounters (48%) underwent an operation that could be classified according to the RACHS-1 method; the median RACHS-1 score was 3 (IQR 2,3). Sixty encounters (2.3%) consisted of a heart transplantation. Almost half of the patients had commercial insurance (50%).

Approximately 6.6% of the population experienced a hospital-acquired infection (catheter-associated urinary tract infection, catheter-associated bloodstream infection, surgical site infection). Of the different types of pediatric and adult ventricular assist devices (VAD), the Berlin Heart EXCOR pediatric VAD was the most common device implanted (Table 1).

PCA was used to examine the population with 60 887 741 features from 20 235 distinct categories within the electronic medical record (Table 2). Six cluster-derived classes were created using *k*-means analysis (Figure 2) where classes 1 through 6 represented superior to inferior value. The majority of encounters (68%) segregated into class 1, which was characterized by comparatively low mortality, shorter median hospital LOS, and low average total cost. Ensuing classes demonstrated incremental worsening in patient outcomes at higher average total cost. Classes 3 through 6 consisted of a total of 333 patient encounters (12.7%) and exhibited inferior value. Class 6, which included 1% of admissions, represented patient encounters that had the worst outcomes (mortality 25.9%; median hospital LOS of 151 days, IQR 120 187) at the highest average total cost ($2 209 650.19 ± 985 686.66), indicating a population at greatest risk of poor value (Table 3). In general, classes exhibiting inferior value were associated with greater institutional reward, although the classes with best and poorest value were associated with net negative revenue for the institution (Figure 3).

To correct for multiple comparisons in a multiple hypothesis testing, we identified 50 features

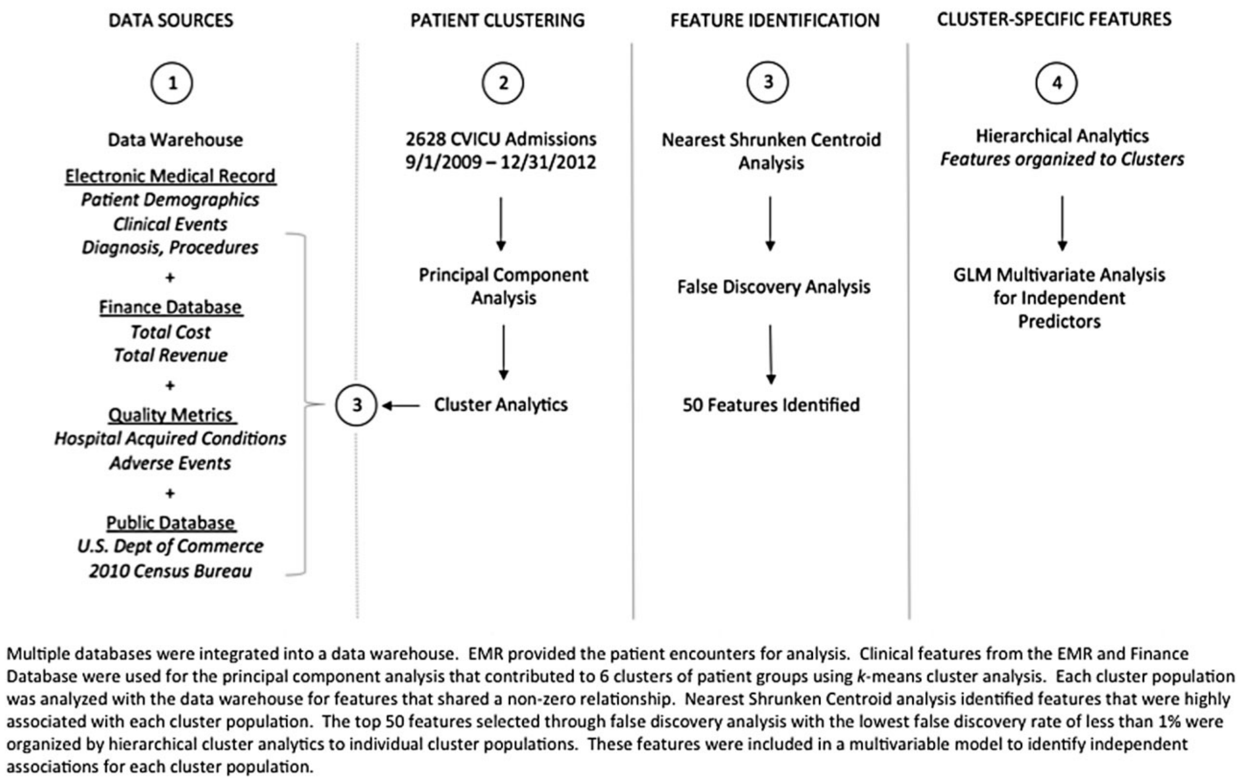

Figure 1. Study outline, patient clustering, and discriminatory feature discovery.
Each cluster population was analyzed for features that shared a nonzero relationship. The top 50 features selected through false discovery analysis were organized by hierarchical cluster analytics. These features were included in a multivariate model to identify predictors for each population. CVICU, cardiovascular intensive care unit; EMR, electronic medical record; GLM, generalized linear model.

in our data warehouse by false discovery analysis. Figure 4 summarizes the NSC analysis and hierarchical clustering analysis, demonstrating the association of each feature and groups of features with each class. Those features that clustered together as associated with class 6 were included in the multivariable model.

In the multivariable analysis, patient encounters that included the acquisition of a hospital-acquired infection (log OR 1.42 [95% CI 0.99, 1.87], $P < .001$), the insertion of a pediatric VAD (log OR 2.51 [95% CI 1.78, 3.43], $P < .001$), and inclusion in Medi-CAL insurance (log OR 1.64 [95% CI 0.94, 2.69], $P < .001$) type were significantly associated with class 6. In selecting covariates for inclusion in the final model, features were chosen based on results from the hierarchical cluster analysis.

Discussion

In this study, which profiles a diverse population of patients with CHD who were admitted to the hospital for medical or surgical management, we portrayed six classes of patient encounters with different levels of value. We observed that financial recompense for the institution was not associated with value and, in fact, was inversely related for most of the patient admissions. In characterizing these classes, we found that approximately one-eighth of the encounters demonstrated inferior value with the poorest performance represented in 1% of admissions, which accrued 14-fold higher hospital costs compared with the overall population. In an analysis of class-specific features, hospital-acquired infections, pediatric VAD, and California-based Medicaid insurance were associated with class 6, exhibiting the poorest profile for value and institutional remuneration.

Our study endeavors to understand value in order to provide an important context for improvements in quality and cost. Value is a nascent concept in health care with no consensus on definition or scope. It is important to note that our definition of value at the institution level, restricted to inpatient survival weighted to dura-

Table 1. Baseline Characteristics of the Congenital Heart Disease Population at LPCH between 9/2009 and 12/2012*

Features	n = 2628
Demographic features	
Age, year, median(IQR)	3 (0,11)
Prematurity (EGA < 37 weeks), %	1.6
Weight at admission, kg	23.6 ± 25.3
z Score weight at surgery, mean	−1 ± 1.9
Female gender, %	46.8
Patients classifiable by RACHS, %	48.1
RACHS score, median(IQR)	3 (2,3)
Patients not classifiable by RACHS, %	51.9
Heart transplantation, %	2.3
Trisomy 21, %	4.8
Chromosome 22q11.2 deletion syndrome, %	5.4
Chromosomal abnormality (other), %	10.3
Quality measures	
Unplanned reoperation, %	1.7
>3 Hospital admissions, %	21
Readmission to CVICU <24 hours, %	0.8
Hospital-acquired condition†, %	6.6
Advance medical technology	
Pediatric ventricular assist device‡, %	1
Adult ventricular assist device§, %	0.2
ECMO¶, %	2.5
Payer-type distribution	
Commercial, %	49.7
Medical (California), %	38.2
Medicaid, OOS, %	8
Other, %	4.1
Ecological features	
Distance from the hospital, km	150.6 ± 142.5
High school degree or higher, %	82.7 ± 13.1
Bachelor's degree of higher, %	30.7 ± 18.4
Median family income, $	78 631.6 ± 32 722.6

*Plus–minus values are means ± SD.
†Hospital-acquired conditions include catheter-associated urinary tract infection, catheter-associated bloodstream infection, surgical site infection. Infection is represented as incidence, not rate, within the population.
‡Berlin EXCOR pediatric VAD, Impella, Heartmate II.
§Thoratec device.
¶Veno-arterial and veno-venous ECMO.
CLABSI, central line-associated bloodstream infection; CVICU, cardiovascular intensive care unit; ECMO, extracorporeal membrane oxygenator; EGA, estimated gestational age; OOS, out of state; SD, standard deviation; SSI, surgical site infection; UTI, urinary tract infection; VAD, ventricular assist device.

Table 2. Types and Amount of Data Included for Analyses: 2628 Encounters

Data Elements	Categories	Records
Demographic attributes	245	651 210
Diagnosis (ICD-9 code and description)	2109	41 659
Billing (ICD-9 code and description)	601	16 317
Surgery/procedure	162	29 573
Clinical events	9037	56 062 204
Clinical orders	2629	3 710 267
Microbiology	633	15 156
Location history	11	30 592
Revenue	1	2628
Cost product	4807	328 135

International Classification of Diseases, 9th revision (ICD-9).

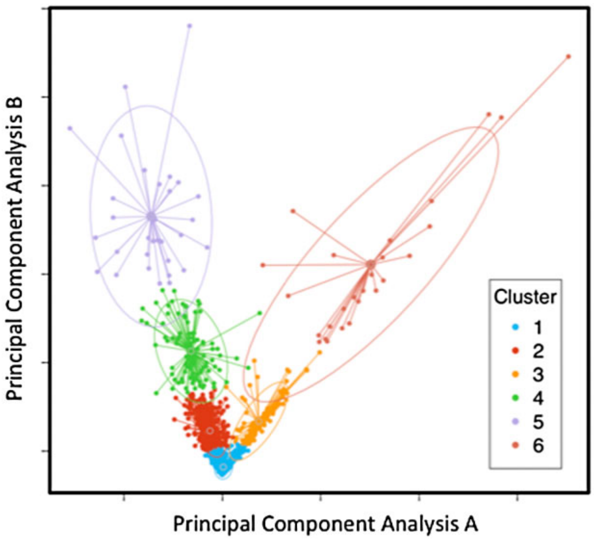

Figure 2. Principal component analysis. Unsupervised clustering using *k*-means cluster analytics. *k* Centroids were defined by 1. patient outcomes (in-hospital mortality and length of hospitalization); 2. resource consumption (total hospital cost); and 3. institutional outcome (total hospital revenue). Six distinct patient clusters were delineated.

tion of hospitalization and the cost/reward to achieve that outcome, does not account for value at the patient level. For example, the value to the patient undergoing a simple ventricular septal defect closure is arguably smaller than palliative single ventricle reconstruction surgeries as the health care gains, though at greater mortality risk and health care cost, are substantially higher. While examples such as case mix complexity are more evident in their relationship with value, we sought to identify important features of an inpatient encounter that are less obvious in their contribution to outcome and cost. Even less clear are the relative contributions of hospital performance, disease, and ecologic features such as socioeconomic status. Our study comparatively analyzes the multiple possible features contributing to value in a diverse population of patients along an institution's service line. Though the numerator of our value equation is limited to an end point measure (mortality and LOS) rather than a care-continuum measure, we aimed to achieve situational awareness of hospital encounters at greatest risk for poor outcome at high cost. By doing so, our study aids in the identification of opportunities to apportion resources to areas that are disparate in value and, most importantly, the identification of aligning features that benefit patients, providers, and payers alike.

Table 3. Cluster-Derived Classes According to the Components of Value in Congenital Heart Disease

	Class 1 (n = 1778)	Class 2 (n = 517)	Class 3 (n = 194)	Class 4 (n = 83)	Class 5 (n = 29)	Class 6 (n = 27)	*P* Value
Length of stay, days, median (IQR)*	4.7 (1,6)	14 (9,20)	32 (23,46)	51 (39,61)	92 (67,130)	151 (120,187)	<.001
Mortality, %†	1.9	1.7	10.3	15.7	20.7	25.9	<.001
Total hospital cost, USD, mean (SD)*	46 871.24 (40 796.89)	160 498.33 (86 562.13)	411 230.77 (219 223.93)	653 127.15 (209 470.55)	1 327 278.86 (474 802.42)	2 209 650.19 (985 686.66)	<.001
Profitability*	–	+	+	+	+	–	<.001

*Kruskal–Wallis test.
†Chi-squared test.
USD, United States dollar; IQR, interquartile range; SD, standard deviation.

We found drivers of costly encounters with poor outcome are not attributed to one particular pattern in health care utilization. With regard to patients with heart failure necessitating VADs, our study suggests the diffusion of this recent technology within the pediatric population has yet to be tempered by efforts to improve efficiency and cost in its application. In most of the cases with pediatric VADs, there are no comparable treatments, and VADs are typically implanted in desperate, life-threatening circumstances. Our findings suggest that prioritizing resources aimed at identifying optimal risk candidate patients and improving the quality, efficiency, and safety for the perioperative care would have a meaningful impact in the value of health care delivery in the pediatric cardiac population. In comparison, hospital performance indicators such as hospital-acquired infections share similar risk for poorly valued encounters to those patient encounters involving the placement of a VAD. There are insufficient reports of detailed data regarding the economic impact of hospital-acquired infectious processes,[25] and outcomes have been specifically aimed at attributable cost associated with various HAIs.[26,27] Beyond cost, our analysis finds that HAIs are importantly associated with value performance. Our study is not designed to estimate the attributable cost associated with HAIs; however, comparatively, programs to eradicate these preventable conditions are likely to be associated with greater rewards to providers, payers, and patients than improving most surgical outcomes.

A second finding of note was that institutional profitability was not linearly associated with value but, in fact, was inversely related for most patients. Counterintuitively, we found specific reimbursement structures to be penalizing to the institution in situations where patient care is most efficient. This raises the question of the relationship between profitability and medical appropriateness. Reimbursement rates are set through a complex process often with imperfect adjustments for payer type and hospital demographic characteristics. In our study, we postulate that the relationship of specific payer types with class 6 is predominantly due to comparatively different reimbursement structures, given that patients with Medi-CAL are proportionately prevalent in value class 1 as in class 6 and absent in value classes 3 through 5 (lower health care value). Given ongoing reimbursement challenges coupled with the expanding growth of Medicare spending,[28] our findings may provide a framework for reforms designed to align

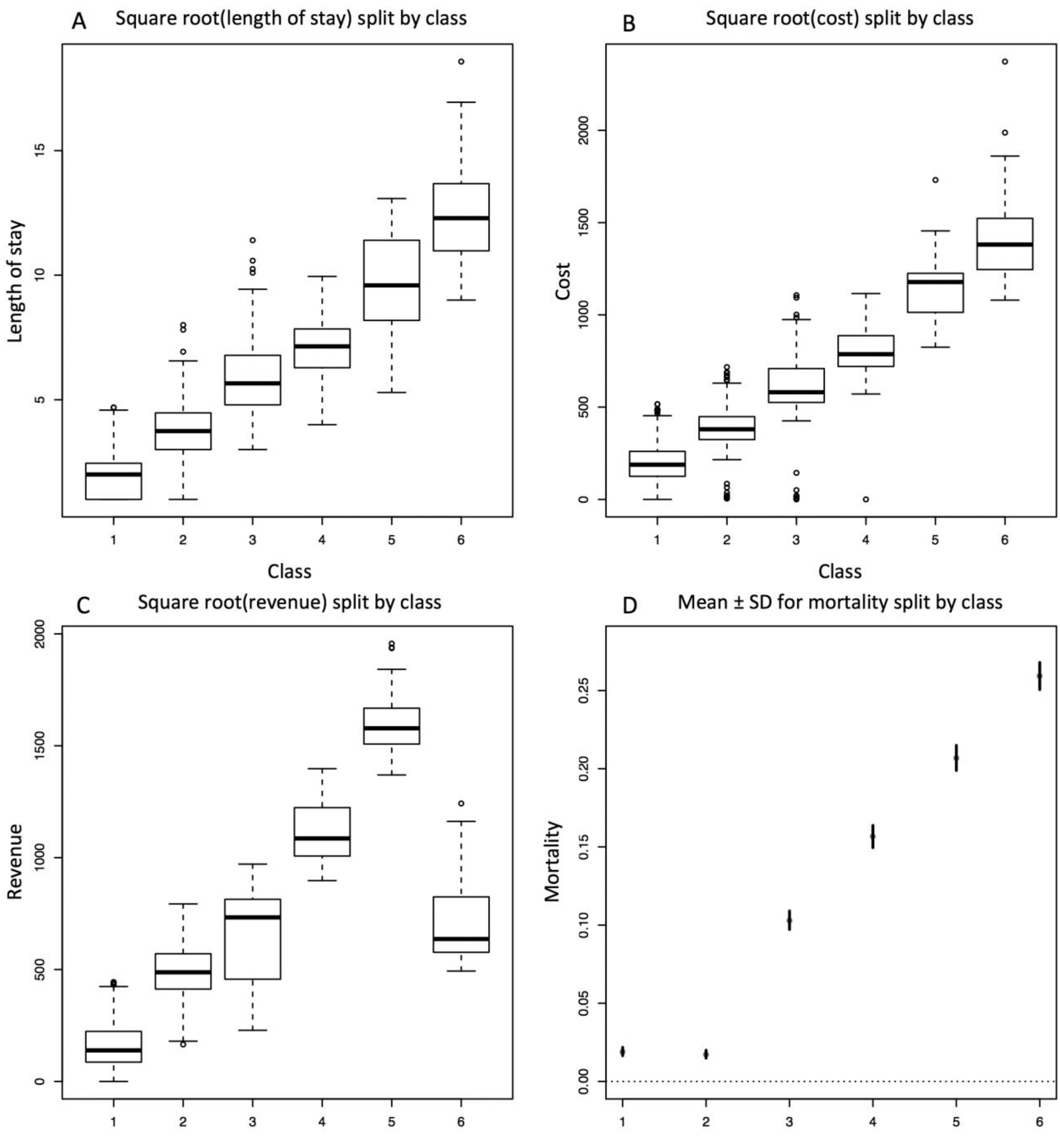

Figure 3. Independent relationships between length of stay, mortality, cost, and revenue with the cluster-derived classes. The components of value and their relationship with the classes: linear for length of stay (A), cost (B), and mortality (D); quadratic for revenue (C).

reimbursement with value, linking remuneration with good and efficient outcomes while creating accountability for inferior care.

Our study has several strengths that merit consideration. The inclusion of clinical features was broad and diverse, ascertained through the electronic medical record and included a variety of baseline risk factors, comorbidities, and complications. Accordingly, the methodology used in this study leveraged high-throughput analytical techniques that are—unlike hypothesis validation—more expansively considerate. This paradigm of hypothesis-generating research provided unique opportunities to compare and contrast clinical and nonclinical features to explore the emerging field of health care value. This report considered most

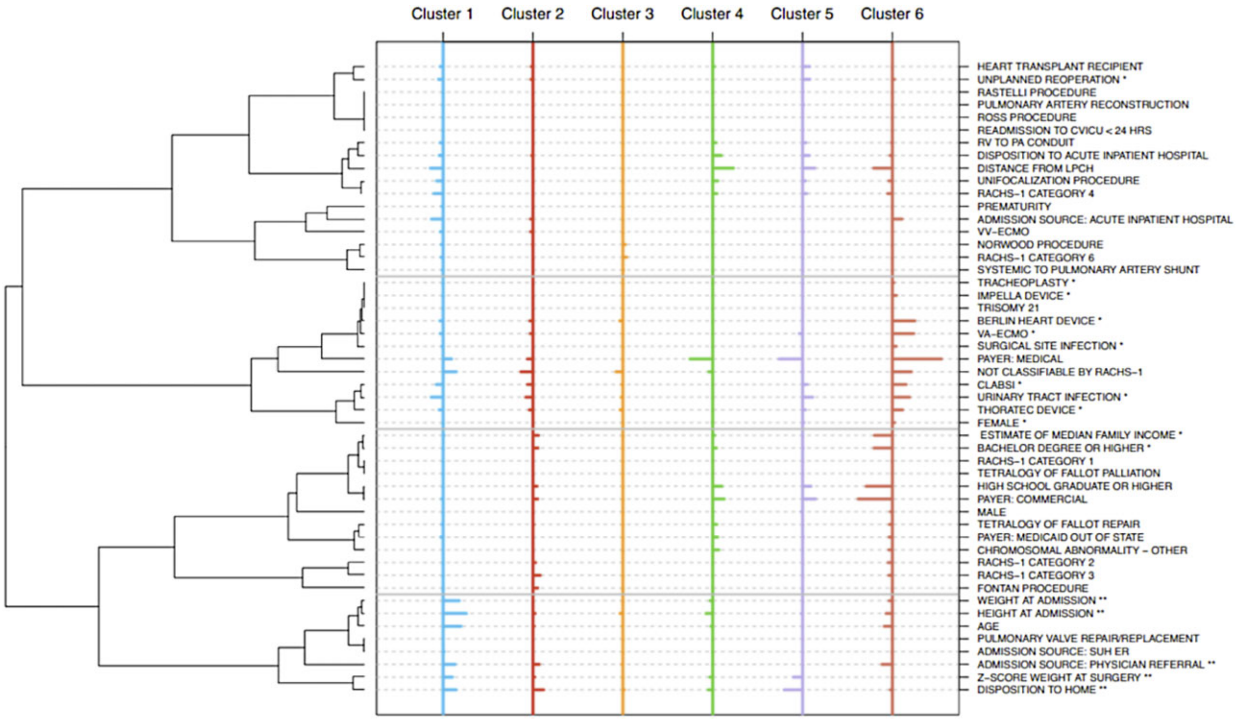

Figure 4. Feature selection. Shrunken differences for the top 50 clinical features having at least one nonzero difference. The dendrogram on the left represents a hierarchical cluster analysis organizing the features based on similarity in performance (based on Euclidian distance). CLABSI, central line-associated bloodstream infection; CVICU, cardiovascular intensive care unit; PA, pulmonary artery; RV, right ventricle; SUH ER, Stanford University Hospital Emergency Room; VA-ECMO, Veno-arterial extracorporeal membrane oxygenator; VV-ECMO, Veno-venous extracorporeal membrane oxygenator.

of the routine data generated in the process of direct patient care, hospital performance indicators, and patient-level characteristics, which would have been challenging to do so in an a priori hypothesis-driven paradigm. The features ultimately selected for analysis were done so in an unsupervised fashion allowing robust associations with our predetermined definition of value to be discovered rather than tested.

There are a number of important limitations to our study that deserve discussion. The first limitation pertains to the definition of value, which we limited to inpatient survival, duration of hospitalization, and the cost/reward to achieve that outcome. The broader definition of health care value should incorporate broader outcomes that encompass the full care cycle of the patient including quality of life, relief of symptoms, and satisfaction with the health care system. Unfortunately, many of these outcome metrics are inadequately tracked or absent altogether. While the goal of any hospital admission in the pediatric cardiac population is to treat an underlying condition and improve the child's health, outcome variables such as mortality and LOS have been applied as a surrogate of health care performance to achieve those ends. Similarly challenging is the proper measurement of cost, which may be influenced by the way care delivery is organized and billed for, and is often fragmented by the multiple care settings and care units involved in health care delivery. We measured cost only in the inpatient setting. Thus, costs originating from the ambulatory setting or primary care practice were not counted. We used ZIP code-level data to approximate household income and educational attainment. Although this approximation has been used previously, it may result in biases of undetermined significance or direction, and household experiences within a ZIP code may also differ from the neighborhood experience. Finally, leveraging local data from one institution may generate results that are tied to the unique systems of care and patient types at that institution, which may make generalizability of the study results to other institutions, notably non-children's hospitals or for-profit institutions, difficult. Future analysis examining the relationship between outcome and health care spending through collaboration on a regional and national scale would likely be beneficial.

In conclusion, we classified patients with CHD based on inpatient value. We found value was not associated with financial reward for the institution. Patients with the highest performance in value overall represented economic burdens for the institution; this phenomenon is likely related to specific reimbursement structures. The reduction of hospital-acquired infections and the optimal management of pediatric VADs emerged as clear features in this patient population that all stakeholders in health care delivery have incentives to improve. Further analysis will be necessary to achieve a more fundamental and broader understanding of value in this patient population, which may help target innovations aimed at health care efficiency and quality with improved stewardship for cost-containment.

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Author Contributions

Andrew Y Shin: Dr. Shin conceptualized and designed the study, obtained funding, interpreted the data, drafted the initial manuscript, and approved the final manuscript as submitted.

Zhongkai Hu and Xuefeng B Ling: Mr. Hu and Dr. Ling designed the study, carried out the initial analysis and interpreted the data, critically revised the manuscript for important intellectual content, and approved the final manuscript as submitted.

Bo Jin, Sangeeta Lal: Mr. Jin and Dr. Lal acquired the data, carried out the initial analysis and interpreted the data, critically revised the manuscript for important intellectual content, and approved the final manuscript as submitted.

Scott M Sutherland, David N Rosenthal, Bradley Efron, Paul J Sharek, Harvey J Cohen, Doff B McElhinney, Stephen J Roth: Drs. Sutherland, Rosenthal, Efron, Sharek, Cohen, McElhinney, and Roth interpreted the data, critically revised the manuscript for important intellectual content, and approved the final manuscript as submitted.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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