Hospital Costs for Neonates and Children Supported with Extracorporeal Membrane Oxygenation

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Objective To assess the characteristics associated with high hospital cost for patients receiving extracorporeal membrane oxygenation (ECMO) to identify a cohort of high-resource users.

Study design Cost for hospitalization, during which ECMO support was used, was calculated from hospital charges reported in the 2012 Health Care Cost and Use Project Kid's Inpatient Database. Patients were categorized into 6 diagnostic groups: (1) cardiac surgery; (2) nonsurgical heart disease; (3) congenital diaphragmatic hernia; (4) neonatal respiratory failure; (5) pediatric respiratory failure; and (6) sepsis. We categorized cost into 4 groups based on quartiles. We compared ECMO cost with hospital cost for bone marrow, liver, and kidney transplants performed during the same year.

Results Median hospital cost for children supported with ECMO (n = 1465) was $230 425 (IQR: $126 599-$420 960). In a multivariable model, lower cost was associated with neonatal respiratory failure (OR: 0.19) and sepsis (OR 0.53) compared with cardiac surgery (OR: 1.88), whereas greater cost was associated with smaller hospital bed-size <99 (OR: 3.49) and 100-399 beds (OR: 3.03) compared with hospitals >400 beds, hospital location (Midwest [OR: 1.74] and West [OR 2.18] compared with North-East), and complications such as renal failure (OR: 3.77) and thromboembolic complications (OR 1.60). Hospital cost per survivor was greater for ECMO ($519 450) than bone marrow transplantation ($207 212), liver ($231 755), or kidney transplantation ($82 008) groups.

Conclusions Hospitalization cost for children supported with ECMO is high. Diagnosis, hospital characteristics, and presence of complications are associated with increased cost. *(J Pediatr 2016;169:69-75)*.

Since its first implementation in 1972,[1] extracorporeal membrane oxygenation (ECMO) has been used successfully to support neonates and children with life-threatening cardiac and/or respiratory failure, sepsis,[2,3] rescue children with cardiac arrest who do not respond to conventional cardiopulmonary resuscitation (ie, ECMO for cardiopulmonary resuscitation),[4] and as a bridge to heart or lung transplantation.[5,6] Although life-saving in many instances, providing ECMO support is expensive and requires considerable resources. Patients supported with ECMO require intensive care, frequent laboratory testing and radiological imaging, surgical and nonsurgical therapies, and use considerable quantities of blood products for circuit maintenance and management of bleeding complications. The complexity of the ECMO circuit, including ECMO pumps, oxygenators, and circuit, requires specialized personnel to be trained and available at the bedside at all times to provide high-quality ECMO care. These issues can result in considerable expenses for running and maintaining an ECMO program.

Previous studies have examined survival, incidence of complications, and risk factors for mortality associated with ECMO support in different pediatric populations.[7-9] Few studies have assessed hospitalization cost associated with the use of ECMO in critically ill children.[10] These studies have been focused primarily on patients within a single diagnostic category, such as respiratory distress syndrome,[11,12] or single indication for ECMO use such as ECMO for cardiopulmonary resuscitation.[13] To date, studies that compare cost of hospitalization in neonates and children who require ECMO support for a broad range of ECMO indications are not available. Knowledge of hospital cost and factors associated with high ECMO cost can help ECMO programs plan budgets and stimulate cost-reduction efforts.

In these analyses, we evaluated cost of hospitalization for ECMO use for all indications, and compared these with costs associated with other cost-intensive therapies such as bone marrow transplantation (BMT), liver transplantation, and kidney

BMT	Bone marrow transplantation
CDH	Congenital diaphragmatic hernia
ECMO	Extracorporeal membrane oxygenation
HCUP	Health Care Cost and Use Project
ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
KID	Kid's Inpatient Database
LOS	Length of hospital stay
NRF	Neonatal respiratory failure
PRF	Pediatric respiratory failure

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transplantation. We evaluated the association of patient demographics, ECMO complications, geographic location, and hospital characteristics with high hospital cost to identify a cohort of high-resource users.

Methods

We performed a retrospective analysis of the 2012 Health Care Cost and Use Project (HCUP) Kid's Inpatient Database (KID).[14] KID is an administrative data set from participating hospitals in 44 US states and includes all patients ≤20 years of age. KID is coordinated through the Center for Organization and Delivery Studies within the federal Agency for Healthcare Research and Quality and is the largest publicly available, all-payer pediatric inpatient care database available in the US. The KID dataset includes >100 clinical and nonclinical variables, including 25 diagnoses, and 15 procedure variables for each hospitalization. Data are extracted from hospital discharge abstracts and systematic random sampling is used to generate the data set. The data set includes 80% of all pediatrics and adolescent hospital admissions, representing 80% of complicated in-hospital births, and 10% of uncomplicated in-hospital births from each participating state. The hospitals contributing data include specialty hospitals, public hospitals, and academic medical centers. The American Hospital Association's (www.aha.org) Annual Survey of Hospitals is used to determine hospital characteristics, location, teaching status, and size.

Neonates and children treated with ECMO were identified by the use of the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) procedure code 39.65 (ECMO). Demographic, diagnosis, and procedure information; length of hospital stay (LOS); hospital charges generated at discharge; and in-hospital mortality recorded in the database were used for purposes of these analyses. Neonates and children treated with ECMO were categorized into 6 predefined diagnostic groups using ICD-9-CM diagnosis codes (**Table I**; available at www.jpeds.com). These groups included: (1) cardiac surgical; (2) nonsurgical heart disease; (3) congenital diaphragmatic hernia (CDH); (4) neonatal respiratory failure (NRF) including meconium aspiration syndrome and primary pulmonary hypertension of newborn; (5) pediatric respiratory failure (PRF); and (6) sepsis (neonatal and pediatric). The diagnoses used to categorize our cohort into the group with nonsurgical heart disease are shown in **Table II** (available at www.jpeds.com). Age at admission was categorized into 5 age groups: neonates (≤1 month of age), >1 month to 1 year, >1 to 6 years, >6 to 12 years, and >12 years. We defined time to ECMO cannulation as the time between hospital admission and the ECMO cannulation procedure. Because hospital charges have a variable and inconsistent relationship to costs, we used the HCUP Cost-to-Charge Ratio files to convert hospital charges to costs. Each file contains hospital-specific cost-to-charge ratios based on all-payer inpatient cost for hospitals. Hospital total charge data were converted to hospital cost estimates by multiplying total charges with the appropriate cost-to-charge ratio.[15] Hospitalization costs for patients receiving ECMO were categorized into 4 groups by quartiles: ≤25th percentile, >25th-50th percentile, >50th-75th percentile, and >75th percentile. The ICD-9-CM diagnosis codes were used to categorize the presence of neurologic complications (intracerebral hemorrhage, seizures, stroke), thromboembolic complications (arterial and venous thrombosis), renal failure, and device-associated complications (hemorrhage, thrombosis, and infection; **Table I**). The size of hospital bed-size categories assigned by the HCUP, small (1-99 beds), medium (100-399 beds), and large (≥400 beds), were used to categorize hospital size. These numbers are based on the total number of beds, without distinction between dedicated children's hospital and nondedicated children's hospital beds. Hospital region was categorized as Northeast, Midwest, South, and West.

We also compared hospital cost for patients receiving ECMO with hospital cost for children hospitalized for 3 other cost-intensive procedures including BMT, kidney, or liver transplant performed during the same year and included in the KID database.[16] ICD-9-CM Procedure codes provided in the dataset were used to identify children undergoing these procedures (**Table I**).

Statistical Analyses

Univariate ordinal logistic regression was used to compare patient, diagnosis, and hospital characteristics among the 4 quartiles. Multivariable ordinal logistic regression using a backward selection procedure was used to determine factors associated with hospital cost quartile. Variables for inclusion in the multivariable model were selected using predefined cut off, P value <.10 in the univariate analysis, and retained in the multivariable model if the adjusted P value was <.05. Generalized estimating equations were used to evaluate the effect of clustering by center. The OR reported from the multivariable ordinal logistic regression model describes the odds of being in a greater cost quartile for the factor retained in the model. The Akaike information criterion was used to assess the cumulative quality of our regression model. The likelihood ratio test was used to compare differences between the baseline, and subsequent models at each addition.

A P value <.05 was considered statistically significant for all tests. All reported values in this study are absolute values without weighting for prevalence. Statistical analysis was performed with STATA version 14.0 (StataCorp, College Station, Texas). Categorical data are expressed as number and percentage (%), and continuous data are presented as median values with IQR (25th-75th percentile).

Results

Of the 3 195 782 pediatric hospitalizations included in the 2012 HCUP KID database, we identified 1465 (0.05%)