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Characteristics, risk factors & outcomes of extracorporeal membrane oxygenation use in pediatric cardiac intensive care units: a report from the PC4 Registry

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Abstract

Objective—Cardiopulmonary failure in children with cardiac disease differs from the general pediatric critical care population, yet the epidemiology of ECMO support in cardiac intensive care units has not been described. We aimed to characterize ECMO utilization and outcomes across surgical and medical patients in pediatric CICUs.

Design—Retrospective analysis of the Pediatric Cardiac Critical Care Consortium registry to describe ECMO frequency and outcomes. Within strata of medical and surgical hospitalizations, we identified risk factors associated with ECMO use through multivariate logistic regression.

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Setting—Tertiary-care children's hospitals.

Patients—Neonates through adults with cardiac disease.

Interventions—None.

Measurements & Results—There were 14,526 eligible hospitalizations from 8/1/14–6/30/16; 449 (3.1%) included at least one ECMO run. ECMO was used in 329 (3.5%) surgical and 120 (2.4%) medical hospitalizations. Systemic circulatory failure and E-CPR were the most common ECMO indications. In the surgical group, risk factors associated with post-operative ECMO use included younger age, extracardiac anomalies, pre-operative comorbidity, higher STAT category, bypass time, and post-operative mechanical ventilation and arrhythmias (all $p<0.05$). Bleeding requiring re-operation (25%) was the most common ECMO complication in the surgical group. In the medical group, risk factors associated with ECMO use included acute heart failure and higher vasoactive inotropic score at CICU admission (both $p<0.0001$). Stroke (15%) and renal failure (15%) were the most common ECMO complications in the medical group. Hospital mortality was 49% in the surgical group and 63% in the medical group; mortality rates for hospitalizations including E-CPR were 50% and 83%, respectively.

Conclusions—This is the first multicenter study describing ECMO use and outcomes specific to the CICU and inclusive of surgical and medical cardiac disease. Mortality remains high, highlighting the importance of identifying levers to improve care. These data provide benchmarks for hospitals to assess their outcomes in ECMO patients and identify unique high-risk subgroups to target for quality initiatives.

Keywords

extracorporeal membrane oxygenation; heart disease; congenital heart defects; intensive care unit

Introduction

Extracorporeal Membrane Oxygenation (ECMO) now represents standard therapy for cardiopulmonary failure in pediatric patients, and this is particularly true in cardiac intensive care units (CICU). Patients cared for in the CICUs experience unique disease processes that differentiate them from pediatric intensive care unit (PICU) and neonatal intensive care unit (NICU) populations, most notably that ECMO is deployed in CICUs primarily for cardiac indications. Other clinical factors such as the overwhelming use of venoarterial ECMO even in respiratory failure, unique risks of bleeding and thrombotic complications in post-operative cardiac surgical patients, and the high rate of central cannulation represent important differences. As such, the epidemiology and outcomes of ECMO in the pediatric CICU may be quite different than that in other critical care environments.

However, ECMO use in the pediatric CICU has not been comprehensively studied to date. Multiple reports delineate ECMO outcomes in specific populations of patients with cardiovascular disease (1–8), but the majority of this literature reflects single institution experience. Reports from large databases such as the Extracorporeal Life Support Organization (ELSO) Database and the Society of Thoracic Surgeons Congenital Heart Surgery (STS) Database have provided some insight into ECMO epidemiology, but these

registries do not focus on the CICU and are limited on details important in the care of patients with acquired and congenital heart disease in this environment. There are no previous multi-institutional studies fully characterizing ECMO use in the pediatric CICU among patients with both surgical and medical cardiac disease. As such, there is a need to identify the highest risk subgroups, clinical predictors of ECMO use, and morbidity and mortality associated with ECMO in this environment. Further, limited data exist regarding the time course for ECMO cannulation and the onset of complications on ECMO. These knowledge gaps impede efforts to improve outcomes for patients with critical cardiovascular disease who receive ECMO.

The objective of this multicenter study was to analyze contemporary ECMO utilization and outcomes of children with critical cardiovascular disease, including frequency, indications, risk factors, and morbidity and mortality across surgical and medical cohorts of children in a database specific to cardiac critical care. We conducted this analysis using the Pediatric Cardiac Critical Care Consortium (PC⁴) clinical registry to provide data on ECMO epidemiology across a group of hospitals with dedicated CICU teams.

Materials and Methods

Data Source

The Pediatric Cardiac Critical Care Consortium is a quality improvement collaborative that collects data on all patients with primary cardiac disease admitted to the CICU service of participating hospitals (9). PC⁴ maintains a clinical registry to support research and quality improvement initiatives. At the time of this analysis, 23 hospitals were submitting cases to the PC⁴ Registry.

Each participating center has a trained data manager who has completed a certification exam. The data managers collect and enter data in accordance with the standardized PC⁴ Data Definitions Manual. The PC⁴ registry shares common terminology and definitions with applicable data points from the International Pediatric and Congenital Cardiac Code (IPCCC), STS Congenital Heart Surgery Database, and American College of Cardiology Improving Pediatric and Adult Congenital Treatment (IMPACT) Registry, as previously described (9). Participating centers are audited on a regular schedule and audit results suggest complete, accurate and timely submission of data across centers, with the most recent published results demonstrating a major discrepancy rate of 0.6% across 29,476 fields (10). The University of Michigan Institutional Review Board provides oversight for the PC⁴ Data Coordinating Center; this study was reviewed and approved with waiver of informed consent.

Patient population

All hospitalizations in the database included at least one CICU admission by definition. We analyzed all hospitalizations and excluded those where patients were admitted to the CICU service but did not have primary cardiac disease (n=131) or where the primary reason for admission to the CICU was for hospice/comfort care (n=9).

Classification as medical or surgical is determined at discharge. Hospitalizations were defined as surgical if it included a STS index operation at any time: operations with cardiopulmonary bypass or cardiovascular surgery without bypass, exclusive of patients <2.5kg undergoing isolated patent ductus arteriosus repair (11). Medical hospitalizations were those that did not include an index operation. As placement of a ventricular assist device (VAD) is not a STS index operation, a patient who underwent VAD placement remained a medical patient. A heart failure or VAD patient who underwent heart transplant was classified as surgical.

Data Collection

All variables included in this analysis are strictly defined in the PC⁴ data definitions manual (available upon request and available at PC4quality.org). Demographics, non-cardiac comorbidities, and other patient factors were collected for each CICU admission during a hospitalization. Age categories were defined as: preterm neonate, <30 days old and <37 weeks gestation; full-term neonate, <30 days old and 37 weeks gestation; infant, 30 days-1 year; child, 1 year-18 years; adult, >18 years. Weight-for-age z-score was calculated using World Health Organization or Centers for Disease Control standards, according to patient age (12). Surgical complexity was characterized using the Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STAT) mortality categories (11). For medical hospitalizations, we created a composite “acute heart failure” diagnosis at time of CICU admission consisting of cardiomyopathy, myocarditis, or acute decompensated heart failure (regardless of underlying structural cardiac diagnosis.) Vasoactive-inotropic score (VIS) was calculated according to the methods delineated by Gaies et al (13–14). For analysis, peak VIS within 2 hours of CICU admission was used. For post-operative variables of mechanical ventilation and arrhythmia, these were assessed as present or absent 2 hours after CICU admission.

Each ECMO run is recorded in the registry; a CICU admission and hospitalization could include multiple ECMO runs. For each ECMO run, the exact time and date of initiation of flow (start time) and decannulation (end time) was recorded. Timing of ECMO cannulation relative to the patient’s index operation for surgical hospitalizations or CICU admission time for medical hospitalizations were calculated. Timing of complications and other clinical events on ECMO were calculated relative to ECMO start time. Complications occurring during the course of ECMO are reported. We do not report complications occurring after ECMO decannulation since these are not directly attributable to ECMO care.

The primary indication for ECMO was chosen for each run. We combined the indications of low cardiac output syndrome, ventricular dysfunction, and cardiac failure to create a composite of systemic circulatory failure. If the patient was cannulated to ECMO during active cardiopulmonary resuscitation (CPR), this was designated as the indication, regardless of the underlying etiology leading to cardiopulmonary arrest. We also evaluated each cardiopulmonary arrest event; methods to define these events have been previously described (15).

Statistical analysis

Hospitalizations represented the primary episode of analysis. For cardiopulmonary arrest analyses, the episode of analysis was an individual arrest event. Patient characteristics, complications, other clinical events, and outcomes are described using standard measures of central tendency based on the distribution of the data and within each stratum (surgical vs. medical).

The primary outcome for analysis was receipt of ECMO at any time during the hospitalization for medical patients and post-operative ECMO for surgical patients. Similar stratified analyses were conducted for surgical and medical hospitalizations. Univariate analyses to determine association with ECMO use included chi-square, Fisher's exact, and Wilcoxon rank sum tests, as appropriate. When analyzing predictors of post-operative ECMO use from the early post-operative period (<2 hours after post-operative CICU admission), we accounted for the possibility that patients who exited the operating room on ECMO may have values that appeared more "normal" than other patients. For instance, a patient cannulated to ECMO in the operating room may have a lower VIS than a similarly decompensated patient not on ECMO. Our method involved imputation of each variable to the median value of the entire population for those patients on ECMO out of the operating room.

Variables associated with ECMO at $p < 0.1$ in univariate analysis were included in a multivariate logistic regression model to identify independent predictors of ECMO. Generalized estimating equations were used to account for clustering within hospitals. All analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC) or STATA Version 14 (Stata Corp, College Station, TX.)

Results

A total of 14,526 hospitalizations were eligible for inclusion, of which 64% were surgical hospitalizations (Table 1.) Overall, 449 hospitalizations (3%) included at least one ECMO run; 74% of these (N=329) were surgical. Fifty-two (11.6%) of ECMO hospitalizations had more than one ECMO run. Most ECMO runs occurred during the initial CICU admission (390/449, 86.9%). Across 23 hospitals, annual CICU admission volume ranged from 167–1,022 admissions. Median annual ECMO caseload was 14 with a range of 2–36 cases.

Systemic circulatory failure and cardiac arrest were the most common indications in both strata (Table 2.) Hypoxia was the indication in only 11.2% of all ECMO hospitalizations. Shunt occlusion was listed as the primary indication for cannulation in only 2 hospitalizations.

Surgical Hospitalizations

Utilization and timing—Of 329 surgical hospitalizations where ECMO was deployed (3.5% of overall surgical hospitalizations), 33 (10%) included preoperative ECMO only and 296 (90%) included post-operative ECMO. There were a total of 384 ECMO runs across these hospitalizations. In hospitalizations utilizing post-operative ECMO, the timing of initial cannulation was pre-operative in 7% (N=22), intraoperative in 38% (N=111), and

post-operative in 55% (N=163). For those patients cannulated for the first time post-operatively, the median time to cannulation was 33 hours (interquartile range 10–270 hours.)

Predictors of post-operative ECMO use—Univariate associations with post-operative ECMO use are reported in Supplementary Table 1. Multivariate analysis (Table 3) demonstrated several statistically significant predictors of post-operative ECMO use: younger age; extracardiac anomalies; preoperative comorbidities such as cardiac arrest, shock, and organ dysfunction; preoperative mechanical ventilation; operative complexity; longer bypass time; early post-operative mechanical ventilation. Peak VIS in the first two hours after surgery was not associated with ECMO use in multivariate analysis.

Medical Hospitalizations

Utilization and timing—Characteristics of the medical hospitalization cohort and univariate associations are shown in Supplementary Table 2. Of 120 hospitalizations (2.3% of overall medical hospitalizations) where ECMO was deployed, 76 (63%) were in patients with no history of cardiothoracic surgery, 16 (13%) were in patients with a history of surgery for single ventricle disease at a previous hospitalization, and 28 (23%) were in patients with history of two ventricle repair or thoracic surgery at a previous hospitalization. There were a total of 125 ECMO runs across these hospitalizations. Median time from CICU admission to initial cannulation was 9 hours (interquartile range 0.9–47 hours.)

Predictors of ECMO use—Table 4 shows the results of multivariate analysis identifying predictors of ECMO support in medical hospitalizations. Acute heart failure and higher VIS in the first 2 hours after CICU admission were associated with ECMO use. Of note, unlike surgical hospitalizations, age and extra-cardiac anomalies were not significantly associated with ECMO use. Chronic heart failure, transplant rejection, and pulmonary hypertension were also not associated with ECMO use.

ECMO for cardiopulmonary arrest events

Table 5 shows the frequency of cardiac arrest within the CICU and extracorporeal cardiopulmonary resuscitation (E-CPR) support subsequent to these events. There were 417 arrests over 320 surgical hospitalizations and 225 cardiac arrests over 165 medical hospitalizations. For cardiac arrest in the CICU, E-CPR was initiated in 24% of surgical cardiac arrests and 16% of medical cardiac arrests. Median CPR duration for E-CPR events was 38 minutes and 49 minutes in surgical and medical cardiac arrests, respectively. Median CPR duration was 10 and 13 minutes in surgical and medical cardiac arrests, respectively, not ending in E-CPR.

Epidemiology of complications and mortality

Table 6 shows complications and time to onset of the complications. The most frequent complications in the surgical group were bleeding requiring re-operation and unplanned re-operation. For the medical group, stroke, renal failure requiring dialysis, intracranial hemorrhage, and hepatic failure were the most common complications. Stroke, intracranial hemorrhage, and hepatic failure were nearly twice as likely in the medical group compared to the surgical group. Although the rate of brain death was low overall, it was more frequent

in the medical group than the surgical group. Rates of seizures and IVH were similar in both groups. We analyzed time to onset of complications within each stratum. Some comparisons were limited by small numbers but for the complications of stroke, intracranial hemorrhage, renal failure requiring dialysis, and hepatic failure, time to onset was similar in both cohorts. Infection was the only complication with differing time to onset; surgical hospitalizations developed infection in a median of 2 days and medical hospitalizations in a median of 4.5 days.

Outcomes for both groups are reported in Table 7. Median length of ECMO support was similar in both groups. Approximately 5% in each group were listed for transplant. Lengths of stay were significantly longer for surgical patients in both survivor and non-survivor groups. Hospital mortality rates were 49% in surgical ECMO hospitalizations and 63% in medical ECMO hospitalizations. The mortality rate after E-CPR was 50% in surgical hospitalizations and 83% in medical hospitalizations. The in-hospital mortality rate in those with a single ECMO run was 49.4% versus the in-hospital mortality rate in those with multiple ECMO runs was 78.8%.

Discussion

To our knowledge, this is the first multi-institutional study of ECMO use and outcomes focused entirely in the unique environment of the pediatric CICU. ECMO is deployed in 3% of hospitalizations, yet morbidity and mortality are high suggesting that it is an important therapy to consider in the context of improving outcomes in the CICU.

This analysis reveals several findings not previously reported in single institution studies or from registries such as ELSO and STS. We identified high-risk populations who are more likely to require ECMO. By comparing surgical and medical cohorts, we found that the two groups have notably different risk factors for ECMO use. ECMO was used more frequently in surgical hospitalizations and it was used most often in the post-operative phase. Those who were sicker pre-operatively, those with longer intra-op support time, and those with more complex repairs were more likely to need ECMO support post-operatively. Medical hospitalizations including ECMO are less common. Patient factors such as age, weight, and comorbid conditions were not associated with ECMO use in the medical cohort. Rather, diagnosis and markers of illness severity were the variables predicting receipt of ECMO. An admission diagnosis of acute heart failure, which included cardiomyopathy and myocarditis, and higher VIS within 2 hours of admission were the only variables associated with ECMO use. Identifying these high-risk groups may allow teams to anticipate patient care and affect outcomes.

We report novel data regarding complications while on ECMO where the epidemiology differed importantly between the two cohorts. Surgical patients are most likely to experience bleeding and need for re-intervention, whereas medical patients are more likely to experience more serious complications related to organ dysfunction such as neurologic injury, renal injury, hepatic injury, and even infection at much higher rates. It is not clear if this reflects severity of illness when placed on ECMO, delays in initiation of ECMO support, or different anticoagulation strategies in these 2 subgroups. The 2016 ELSO and

Pediatric ELSO reports have the broadest report of complications in cardiac ECMO patients (16–17) and describe similar rates of surgical site bleeding, central nervous system hemorrhage, renal failure, and infection, but this report does not differentiate cardiac patients by medical and surgical disease.

Stroke represents a devastating, potentially mortal complication for ECMO patients, so it is important to examine our findings related to stroke in the context of previous literature. We found a higher rate of stroke (11%) compared to that reported by ELSO: 3–6% in neonatal, pediatric, and adult cardiac patients. This may be related to differences in definitions of the patient population and/or the outcome. Polito et al investigated neurologic injury in neonates with congenital heart disease during ECMO and found that 12% had intracranial hemorrhage and 2% had stroke (18). This is a higher ICH rate and lower stroke rate than our study, but their focus was on neonates where ICH is more common. Werho et al investigated hemorrhagic and ischemic stroke in post-operative pediatric cardiac patients requiring ECMO support, reporting a higher rate of ICH (10%) and lower rate of ischemic stroke (3.3%) compared to our study (19). That study also included a higher proportion of neonates and infants than the current analysis (83.4% vs 65%).

Overall mortality rates for patients on ECMO support in the pediatric CICU remain quite high and, in our cohort, varied based on medical or surgical cardiac disease. Surgical patients requiring ECMO had a 50% mortality rate across these hospitals. Mascio et al analyzed the STS database and found a similar mortality rate for children requiring post-operative ECMO (20). We found a higher mortality rate in medical patients.

Use of E-CPR in the pediatric CICU is common. In our study, 24% of all cardiac arrest events in the surgical group and 16% of those in the medical group lead to E-CPR. By comparison, in a large study by Lasa and colleagues, overall E-CPR rate was 16% among all pediatric arrests lasting >10 minutes, events with the highest likelihood of requiring E-CPR (21). Hospital mortality rates were approximately the same for surgical patients who received ECMO whether that was for E-CPR or some other indication (~50%). However, mortality rates were much higher for medical patients who required E-CPR (83% vs. 63%). It is not clear why the mortality rate increases in this group, but it may be due to severity of illness when placed on ECMO. Several authors have reported E-CPR outcomes in mostly single institution studies (22–25). Overall mortality rates in these studies have ranged from 29–63%. Not all studies include medical and surgical patients, but for those that did, existing data does not show a consistent mortality difference between surgical and medical patients.

The ultimate goal within PC4 is to use these data for quality improvement. Active collaboration between centers has been demonstrated to improve practice and outcomes in other fields (26–28). PC4 is unique in the field of pediatric cardiovascular care in that it provides real-time, transparent (i.e. hospitals are individually identified) benchmarked data to participating CICUs. We provide real-time reports to hospitals on metrics, such as ECMO use, across sites. Participating hospitals can access data at any time on the PC4 website and compare themselves to other hospitals across the country. As each hospital can be identified by the PC⁴ clinical champion at each participating site, hospitals can contact the champions at high performing centers to gain insight on structure, resources, and care processes that

might influence outcomes. This application promotes collaborative learning, assists hospitals looking to improve outcomes, and generates quality improvement opportunities.

The aggregate outcomes across the many CICUs presented in this study provide an opportunity to benchmark clinical ECMO outcomes against peer institutions, and the value of these comparisons will increase as more cases accrue in the database. Understanding outcome differences represents a key initial step toward eventual quality improvement. Elucidation of variation in outcomes across hospitals should motivate investigation into practice or organizational differences that might underlie the variation. Other CICUs, PICUs and NICUs can use these data to compare their results on similar cohorts of patients and to note differences in complications, mortality, and other outcomes between different patient subgroups.

The limitations of our study are inherent of any observational analysis using clinical registry data, most notably the absence of certain predictor and outcome variables. As PC4 is not a dedicated ECMO registry, some details such as type of ECMO equipment, cannulation site, and anticoagulation used are not reported here. There are patient-specific data crucial to analyzing outcomes, particularly in the cardiac population, not available in ELSO and other registries that have more ECMO specific data. For example, PC4 is time-stamped so we could analyze time to events, standard cardiac nomenclature is used for anatomy and diagnosis, and patients are classified as medical or surgical, allowing more in-depth analyses. An optimal approach to answering further questions about ECMO use could include linking databases, such as ELSO and STS, to the PC⁴ registry. These complementary data sources could produce a very powerful dataset to explore this population further. Some outcome measures, such as renal replacement therapy, are initiated based on provider and institutional preferences and may reflect this practice variation rather than physiologic differences in the patients. We cannot speak to the organizational environment and human factors component of ECMO management at each site. Additionally, we did not include data on residual lesions which may impact post-operative physiologic derangement and need for ECMO among surgical patients.

Conclusion

In conclusion, this is the first multicenter study describing contemporary ECMO use and outcomes in pediatric CICU patients with all forms of cardiac disease. ECMO is a rare therapy, yet mortality remains high, highlighting the importance of identifying levers to improve care. We identified unique high-risk subgroups to target for quality initiatives within medical and surgical cohorts, and provide contemporary benchmark data for hospitals to use in assessing their ECMO outcomes in the CICU. Understanding outcome differences across hospitals creates opportunities for quality improvement initiatives as further research elucidates the reasons for these differences. Further investigation is warranted to determine how residual lesions impact outcomes, to evaluate patients undergoing multiple ECMO runs, and to identify the characteristics and practices at high-performing hospitals that either prevent decompensation leading to ECMO cannulation and/or achieve low rates of morbidity and mortality in those who do require ECMO therapy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Study population characteristics, all hospitalizations (N=14,526)

Demographic	N (%) or Median (IQR)
Hospitalization type	
Surgical	9301 (64%)
Medical	5225 (36%)
Ever on ECMO	449 (3.1%)
ECMO during initial CICU hospitalization	390 (2.7%)
Age at initial CICU admit (years)	1 (0,8)
Preterm neonate	414 (2.9%)
Full-term neonate	2229 (15.3%)
Infant	4315 (29.7%)
Child	6442 (44.4%)
Adult	1126 (7.8%)
Weight Status at first CICU admit	
Underweight	3105 (21.4%)
Normal	10716 (73.8%)
Overweight	644 (4.4%)
Male gender	8098 (55.8%)
Antenatal diagnosis [†]	1483 (56.1%)
Extra-cardiac abnormality	2366 (16.3%)
Chromosomal abnormality	1680 (11.6%)
Syndrome	2906 (20.0%)

[†] If < 30 days

Continuous variables are reported as Median (25th, 75th percentile).
 Categorical variables are reported as Frequency (%).

Table 2

ECMO indications, all ECMO runs (n=509)

Indication	N (%)
Surgical (N=384)	
Systemic circulatory failure	187 (48.7%)
E-CPR	122 (31.8%)
Hypoxemia	43 (11.2%)
Arrhythmia	12 (3.1%)
Hypercarbic respiratory failure	8 (2.1%)
Bleeding	8 (2.1%)
Shunt occlusion	2 (0.5%)
Multi-system organ failure	2 (0.5%)
Medical (N=125)	
E-CPR	52 (41.6%)
Systemic circulatory failure	43 (34.4%)
Hypoxemia	14 (11.2%)
Arrhythmia	7 (5.6%)
Multi-system organ failure	7 (5.6%)
Hypercarbic respiratory failure	2 (1.6%)

E-CPR, extracorporeal cardiopulmonary resuscitation

Table 3

Multivariate analysis of risk factors for post-operative ECMO in surgical hospitalizations.

Covariate	Odds ratio (95% CI)
Age *	
Preterm neonate	4.9 (2.8–8.4)
Full term neonate	2.4 (1.6–3.6)
Infant	1.3 (0.9–1.9)
Adult	0.6 (0.3–1.3)
Chromosomal anomaly	0.6 (0.4–0.9)
Extra-cardiac anomaly	1.5 (1.1–2.0)
High risk pre-op **	3.3 (2.3–4.7)
Pre-operative mechanical ventilation	2.0 (1.5–2.8)
Pre-operative risk factors “other”	1.3 (1.0–1.7)
STAT category †	
2	2.4 (1.2–4.8)
3	1.9 (0.9–3.9)
4	3.4 (1.7–6.8)
5	7.8 (3.7–16.6)
Uncategorized	16.5 (6.5–41.5)
Bypass time	1.01 (1.006–1.009)
Post-operative mechanical ventilation	4.3 (2.0–9.5)
Post-operative arrhythmia	0.9 (0.6–1.3)
Post-operative VIS	1.0 (1.0–1.002)

Clustering within hospitals controlled for by using GEE in multivariable logistic regression model

* Child is reference

** Pre-operative CPR, shock at time of surgery, hepatic or renal dysfunction, seizure, cerebrovascular accident, or intracranial hemorrhage within 48 hours of surgery

† STAT category 1 is reference value

STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery; VIS, vasoactive-inotropic score

Table 4

Multivariate analysis of risk factors for ECMO in medical hospitalizations

Covariate	Odds ratio (95% CI)
Weight status *	
Underweight	0.8 (0.4–1.6)
Overweight	1.4 (0.8–2.6)
Extra-cardiac Anomaly	0.7 (0.5–1.2)
Prior cardiothoracic surgery **	
prior single ventricle prior	0.7 (0.4 – 1.3)
other cardiothoracic surgery	0.9 (.5 – 1.5)
Acute heart failure	5.2 (3.5–7.6)
Peak VIS in first two hours after CICU admission	1.1 (1.04–1.07)

Clustering within hospitals controlled for by using GEE in multivariable logistic regression model

* Normal weight status is reference value

** None is reference value

VIS, vasoactive-inotropic score

Table 5

CICU cardiac arrest events and extracorporeal cardiopulmonary resuscitation use

Hospitalization type (N=14526)	1 cardiac arrest (N=485)	Total cardiac arrest count (N=642)	CPR duration (minutes)*	Cardiac arrests with E-CPR	CPR duration among E-CPR (minutes)**
Surgical (N=9301)	320 (3.4%)	417	10 (3–30)	101 (24.2%)	38 (22–64)
Medical (N=5225)	165 (3.2%)	225	13 (3–36)	36 (16.0%)	49 (30–69)

Continuous variables are reported as Median (25th, 75th percentile)

* Exclusive of E-CPR.

** Duration until full flow achieved.

E-CPR, extracorporeal cardiopulmonary resuscitation

Table 6

Complications post-cannulation and during ECMO support among surgical hospitalizations and medical hospitalizations. N=449.

Complication Type	Surgical N=329	Medical N=120	Time to onset (days)
Bleeding requiring reoperation	83 (25.2%)	4 (3.3%)	1.4 (0.5–3.5)
Unplanned reoperation or re-intervention	74 (22.5%)	8 (6.7%)	2.2 (1.0–4.0)
Hemothorax requiring intervention	16 (4.9%)	1 (0.8%)	2.1 (0.5–3.4)
Stroke	29 (8.8%)	18 (15.0%)	2.9 (0.8–5.6)
Seizure	37 (11.3%)	13 (10.8%)	1.2 (0.5–2.3)
IVH > grade II	8 (2.4%)	2 (1.7%)	0.7 (0.2–6.0)
Intracranial hemorrhage	21 (6.4%)	14 (11.7%)	2.2 (1.1–7.1)
Brain death	2 (0.6%)	7 (5.8%)	1.7 (1.0–6.0)
CRRT	42 (12.8%)	18 (15.0%)	2.8 (0.9–5.5)
Infection [*] †	21 (6.4%)	12 (10.0%)	4 (2–7)
Necrotizing enterocolitis [†]	6 (1.8%)	2 (1.7%)	5.5 (3–6.5)
Hepatic failure	18 (5.5%)	14 (11.7%)	2 (0–6.5)

Continuous variables are reported as Median (25th, 75th percentile).

Categorical variables are reported as Frequency (%).

* Infection: pneumonia, catheter associated-blood stream infection, sepsis, surgical site infection, deep-surgical site infection, urinary tract infection, meningitis.

† Infections and necrotizing enterocolitis must occur 1+ day after cannulation to ECMO

IVH, intraventricular hemorrhage; CRRT, chronic renal replacement therapy

Table 7

Outcomes (N=449 hospitalizations)

Outcome	Surgical hospitalizations (n=329)	Medical hospitalizations (n=120)
Length of ECMO support (days)	4.7 (2.4–8.2)	5.6 (2.4–10.3)
Successful decannulation (N=total ECMO runs)	297 (n=384, 77.3%)	297 (n=125, 56.0%)
VAD placed	13 (4.0%)	1 (0.8%)
Time to VAD placement (days)	7.0 (2.9–11.7)	3
Listed for transplant	21 (6.4%)	6 (5.0%)
Time to transplant listing (days)	5 (3–20)	4.5 (2–7)
Mortality		
Overall mortality	161 (48.9%)	76 (63.3%)
E-CPR patient mortality	58 (n=116, 50%)	43 (n=52, 82.7%)
30 day in-hospital mortality	122 (37.1%)	74 (61.7%)
Length of Stay (days)		
Survivors		
CICU	33.6 (18.0–53.9)	16.0 (8.4–27.2)
Hospital	50 (31–83)	27 (12–40.5)
Non-survivors		
CICU	23.8 (13.0–48.6)	10.1 (3.9–20.8)
Hospital	25 (16–59)	11.5 (4–24)

Continuous variables are reported as Median (25th, 75th percentile). Categorical variables are reported as Frequency (%).

VAD, ventricular assist device; E-CPR, extracorporeal cardiopulmonary resuscitation