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Extracorporeal life support for victims of drowning☆

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ABSTRACT

Aim: Unintentional drowning is a significant public health concern in the United States and represents a leading cause of death in the pediatric population. Extracorporeal life support (ECLS) may be used to support drowning victims, but outcomes have not been well defined. This study examined survival rates and risk factors for death in this population.
Methods: Retrospective data from the Extracorporeal Life Support Organization registry was examined to determine outcomes of ECLS and risk factors for death in drowning victims.
Results: Two hundred forty-seven patients who received ECLS following a drowning event between 1986 and 2015 were identified. Eighty-four (34%) did not experience cardiac arrest prior to ECLS, whereas 86 (35%) experienced a pre-ECLS cardiac arrest but had return of spontaneous circulation prior to ECLS, and 77 (31%) were placed on ECLS during cardiopulmonary resuscitation (ECPR). Overall survival was 51.4%; 71.4% in patients who did not experience a cardiac arrest, 57.0% in patients who required cardiopulmonary resuscitation prior to ECLS, and 23.4% in patients who received ECPR ($p < 0.001$). Logistic regression analysis identified ECPR, venoarterial mode of ECLS, renal failure, and cardiopulmonary resuscitation during ECLS as risk factors associated with mortality.
Conclusions: Outcomes in drowning victims supported with ECLS are encouraging; particularly in patients who do not experience cardiac arrest. These data suggest that early initiation of ECLS in drowning patients with respiratory insufficiency may be beneficial to reduce the likelihood of complete cardiopulmonary failure and ECPR. Additionally, ECLS appears to improve survival in patients who experience post-drowning cardiac arrest.

Introduction

Unintentional drowning represents a significant public health problem, affecting approximately 4000 people in the United States each year.[1] The World Heath Organization estimated that 88,000 people worldwide died due to drowning in 2004.[2] Drowning is the second leading cause of unintentional death in children aged 1–14 years and the fifth leading cause of unintentional injury-related death in all age groups in the United States.[3] Overall survival after unintentional drowning is difficult to determine given the inherent heterogeneity of victims but there is evidence that survival is as low as 2–8% in patients who experience post-drowning cardiac arrest.[4,5]

Extracorporeal life support (ECLS) may be used to provide cardiopulmonary support for drowning victims with life-threatening lung injury, cardiac dysfunction, and cardiac arrest that is refractory to conventional therapy. Information related to the use of ECLS in drowning victims is currently limited to case reports and small case series.[6–9] We examined the Extracorporeal Life Support (ELSO) international registry to characterize survival rates and risk factors for death in drowning victims who received ECLS.

Methods

The ELSO international registry was queried for patients who received ECLS following drowning between January 1986 and

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September 2015. ICD-9 codes for drowning (994.1, E910.0-E910.9) were used to identify patients. Clinical and demographic data are submitted to the ELSO registry by contributing centers on a voluntary basis using standardized data collection forms. At present, over 400 international centers submit data to the ELSO registry. Data collection is limited to the hospitalization during which a patient receives ECLS. The institutional review board of each participating center approves registry data submission. The ELSO Steering Committee and the University of Michigan Institutional Review Board review analyses and reports based on ELSO registry data prior to publication.

Among patients with multiple courses of ECLS, only data from the index ECLS exposure were included. Variables analyzed included demographic information (age, weight, gender, and race), pre-ECLS support, mode and duration of ECLS support, ECLS complications, and outcome. Patients were categorized into three mutually exclusive categories: ECLS without preceding arrest (No Arrest group), cardiac arrest prior to ECLS support but with return of circulation prior to ECLS cannulation (Arrest group), and ECLS during cardiopulmonary resuscitation (ECPR). The main outcome of interest was survival to hospital discharge or transfer. Patient race/ethnicity was categorized as black, Asian, Hispanic, White, or other. ECLS era was categorized into three equal time periods: 1986–2004, 2005–2011 and 2012–2015. Pre-ECLS mechanical ventilation was categorized as high frequency ventilation (HFV) for high frequency oscillatory or jet ventilation, whereas all other modes of ventilation were classified as conventional mechanical ventilation. Additional pre-ECLS variables included medications, mechanical ventilation parameters (FiO_2, peak inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), mean airway pressure (MAP), ventilator type, and duration), and the worst arterial blood gas measurements (pH, $PaCO_2$, PaO_2, and SaO_2) prior to ECLS. Patients with a blood pH in the lowest tertile (pH < 6.95) were categorized as having acidosis.

Complications that occurred during ECLS were categorized as mechanical or physiologic, using data entry codes established by the ELSO registry. Mechanical complications included oxygenator failure, ECLS pump malfunction, heat exchanger malfunction, ECLS cannula malfunction, and fractures of circuit connectors. Thrombus that developed within the ECLS circuit and rupture of ECLS circuit tubing were analyzed separately. Physiologic complications were categorized as: (1) neurologic injury, including clinical or electrographic evidence of seizures, radiographic evidence of CNS hemorrhage or infarction, and brain death; (2) acute kidney injury (AKI) resulting in serum creatinine >1.5 mg/dL or the need for renal replacement therapy (hemodialysis, continuous hemofiltration); (3) hemorrhage (surgical site, cannulation site, gastrointestinal, or pulmonary); (4) metabolic abnormalities, including acidosis (pH < 7.20), alkalosis (pH > 7.60), hypoglycemia (<40 mg/dL), hyperglycemia (serum glucose > 240 mg/dL), (5) cardiac failure (cardiopulmonary resuscitation or use of inotropic agents while on ECLS); (6) blood stream infections; and (7) other complications that necessitated intervention (pneumothorax, cardiac dysrhythmia, tamponade and hypertension).

Statistical analysis

Baseline demographics, pre-ECLS variables and ECLS complications were analyzed by Arrest/ECPR groups, survivor vs non-survivors and adults (>18 years) vs pediatric patients. Data are summarized as percentages for categorical variables, and median with interquartile range (IQR) for continuous variables. The primary outcome measure was survival to hospital discharge or transfer. Categorical variables were analyzed with the Chi-square or Fisher's exact test while non-normally distributed data were analyzed using the Mann–Whitney test or Kruskal–Wallis test. The trend test was used to examine trends in ordinal variables. Logistic regression was used to examine the potential association between clinical factors and mortality. Variables that were significantly associated with mortality in the univariate analysis (p-value < 0.05) were considered for inclusion in the logistic regression model. Stata SE 12 software (Stata Inc., College Park, TX) was used for analysis. The authors had full access to the data and take responsibility for its integrity.

Results

Two hundred fifty-one ECLS exposures following drowning were identified, representing 247 unique patients (Table 1). Cardiac arrest with a return of circulation prior to ECLS (Arrest) occurred in 86 (34.8%) patients, whereas ECLS was initiated during cardiac arrest (ECPR) in 77 (31.2%) patients and 84 (34.0%) patients did not experience cardiac arrest prior to ECLS (No Arrest). Overall survival was 51.4%, with a statistically significant trend of increased survival across Arrest/ECLS categories (No Arrest 71.4%, Arrest 57.0%, and ECPR 23.4%; $p < 0.001$). Significant variation in age was observed across treatment groups; patients in the No Arrest group were youngest and patients in the Arrest group were oldest (No Arrest: 4.2 years, Arrest: 8.9 years, ECPR: 5.9 years; $p = 0.044$). Total duration of ECLS was longest in the No Arrest group of patients (155 h), compared to Arrest (87 h), and ECPR (25 h) patients ($p < 0.001$). Patients who received ECPR had lowest pH, HCO_3 and SaO_2 and the highest pCO_2 prior to initiation of ECLS. Patients in the No Arrest group had the longest interval between intubation and ECMO cannulation (48 h), while the ECPR group had the shortest interval (2 h, $p < 0.001$). The ECPR group was more likely to be hypothermic at admission (ECPR 36.4%, Arrest 17%, No Arrest 0%, $p < 0.001$). A larger proportion of ECPR patients (59.74%) received inotrope/pressor support prior to ECLS than Arrest (54.64%) or No Arrest (32.14%) patients ($p = 0.001$).

Non-survivors were more likely to experience pre-ECLS cardiac arrest than survivors (80.0% vs. 52.8%; $p < 0.001$) (Table 2). No differences in age, sex, race, or treatment era were observed between survivors and non-survivors. Survivors had a longer time interval from intubation to ECMO cannulation (20 h vs. 7 h, $p < 0.001$). Median duration of ECLS was 117 h in survivors vs. 34 h in non-survivors ($p < 0.001$). Survivors presented with higher pH (7.18 vs. 6.90; $p < 0.001$), lower pCO_2 (60.4 vs. 64.0; $p = 0.024$), higher HCO_3 (21.0 vs. 16.4; $p = 0.013$), higher SaO_2 (84.5% vs. 70.0%; $p < 0.001$), and were less likely to present with hypothermia (9.5% vs. 25.8%, $p = 0.001$) than non-survivors and were more commonly supported with VV-ECLS (48.0% vs. 20.0%; $p < 0.001$).

Patients were stratified according by age into adult (>18 years) and pediatric (<18 years) cohorts (Table 3). There were a total of 49 ECLS exposures in adults, compared to 198 pediatric exposures. Adults had shorter ECLS duration (51 h vs. 89 h, $p = 0.024$) and lower pH (7.04 vs. 7.16, $p = 0.019$) at ECLS initiation. There was no difference observed between groups with regard to sex, ECLS mode, pre-ECLS MAP, and pre-ECLS SaO_2. Pediatric patients had a longer time interval from intubation to ECMO cannulation (18.5 h vs. 6 h, $p < 0.001$). Survival to hospital discharge was equivalent between groups, with adults having a 40.8% rate compared to 54.0% in pediatric patients.

A multivariate logistic regression model was created to identify patient and ECLS factors that were associated with mortality (Table 4). The need for ECPR (Odds Ratio (OR) = 2.46, 95% confidence interval (CI) = 1.01–6.03) was associated with increased mortality whereas venovenous ECLS (OR = 0.33; 95% CI = 0.16–0.67) was associated with decreased mortality when compared to venoarterial ECLS. The presence of renal failure (creatinine > 1.5 mg/dL, OR = 5.61; 95% CI = 1.63–19.3) and the need for cardiopulmonary