# Extracorporeal membrane oxygenation in patients undergoing superior cavopulmonary anastomosis

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**Objective:** Patients who have undergone the superior cavopulmonary anastomosis (Glenn procedure) have unique cardiopulmonary-cerebral physiology that may limit the success of cardiopulmonary resuscitation and extracorporeal membrane oxygenation (ECMO). Limited data published to date suggest grim morbidity and mortality when ECMO is used. We utilized the Extracorporeal Life Support Organization registry database to more thoroughly assess outcomes in these patients.

**Methods:** Data from the Extracorporeal Life Support Organization registry from 1999 to 2012 for children with Glenn physiology aged 3 months to 1 year were retrospectively analyzed. Demographics and ECMO characteristics were compared between survivors and nonsurvivors. Factors associated with mortality were evaluated using multivariate logistic regression.

**Results:** Of 103 infants, 42 (41%) survived to hospital discharge. Neurologic complications (eg, seizure, hemorrhage, or embolic stroke) were documented in 23% of patients (24 of 103) and 14% of survivors (6 of 42). In univariate analysis, inotropic requirement before ECMO, duration of ECMO, mechanical complications with the ECMO circuit, renal failure, and pulmonary hemorrhage or pneumothorax were predictors of mortality. In multivariate logistic regression, inotrope requirement (odds ratio [OR], 3.6; 95% confidence interval [CI], 1.3-9.8), longer duration of ECMO support (OR, 7.2; 95% CI, 1.8-28), combined cardiopulmonary indication for ECMO (OR, 3.7; 95% CI, 1.4-9.7), and renal failure (OR, 4.2; 95% CI, 1.5-12) were associated with mortality.

**Conclusions:** Mortality in infants with Glenn physiology supported with ECMO is lower than that previously reported, but the incidence of neurologic injury is high. These data support use of ECMO in patients with Glenn physiology with refractory cardiopulmonary failure. (J Thorac Cardiovasc Surg 2014;148:1512-8)

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Extracorporeal membrane oxygenation (ECMO) is an important tool with the potential to rescue patients from circulatory and respiratory failure when medical management is insufficient. ECMO has been used successfully to support a broad range of pediatric patients with cardiac disease and/or cardiopulmonary arrest; outcomes have varied with patient anatomy and indication.[1-9] There is some variability in surgical approach and therefore the nomenclature; however, the physiology of the subtypes of superior cavopulmonary connection is essentially the same. We will refer to this group as patients with Glenn physiology.

Installation of a superior cavopulmonary anastomosis (Glenn procedure) is typically the second stage of a 3-part surgical palliation strategy for a heterogeneous group of patients with single ventricle physiology. In this operation, the superior vena cava (SVC) is divided from the right atrium and sewn to the right pulmonary artery. SVC drainage returns passively to a common atrium via the pulmonary vascular bed, whereas the inferior vena cava (IVC) drains directly to the common atrium. There is some variability in surgical approach and therefore the nomenclature; however, the physiology of the subtypes of superior cavopulmonary connection is essentially the same. This anatomic and physiologic arrangement presents unique challenges for cardiopulmonary resuscitation (CPR) and CPR with immediate cannulation to ECMO (ECPR), particularly related to cannulation strategy and adequate ECMO support.[10-12]

Surgical outcomes for patients who have undergone the Glenn procedure are typically very good and ECMO use in this population is relatively uncommon.[13] As a consequence, there are very few studies describing outcomes or predictors of morbidity and mortality in this cohort. A case report in 2002 described the successful peripheral venoarterial (VA) ECMO support of an infant with respiratory syncytial virus pneumonitis after a Glenn operation.[10] The

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**Abbreviations and Acronyms**

CPR = cardiopulmonary resuscitation
ECMO = extracorporeal membrane oxygenation
ECPR = Cardiopulmonary resuscitation with immediate cannulation to extracorporeal membrane oxygenation
ELSO = Extra Corporeal Life Support Organization
IVC = inferior vena cava
SVC = superior vena cava
VA = venoarterial
VV = venovenous

largest study was published by Booth and colleagues[11] in 2004 and described single-center outcomes in 6 patients. Three patients were successfully decannulated, but all 3 had significant neurologic or other end organ injury. Two of these 3 patients died before discharge, and the 1 patient who did survive to discharge after heart transplant experienced serious neurologic injury. Since 2004, there has been 1 additional case report of successful use of venovenous (VV) ECMO in a severely hypoxemic patient following palliation with the Glenn procedure[12] and 1 published series describing ECMO in 4 patients who have undergone the Glenn procedure with no survivors.[14]

The Extracorporeal Life Support Organization (ELSO) registry database has been used in the past to describe survival and predictors of survival of ECMO in the first and third stages of palliation of single ventricle physiology.[15,16] The ELSO registry is now used to describe the outcome and predictors of morbidity and mortality in patients who have undergone the Glenn procedure who require ECMO support.

## METHODS

### Data Source and Study Population

We retrospectively analyzed data obtained from the ELSO registry from the years 1999 to 2012 for infants who underwent a Glenn operation between ages 3 and 12 months. The registry collects data on ECMO use from patients of all ages from 288 international centers. Participating centers voluntarily report data to the registry using a standardized data form. The data reported include demographic, diagnostic, and procedural information, pre-ECMO status, ECMO support details, complications, and outcomes. The data are reported to ELSO after approval from each center's institutional review board. The data use agreement allows the release of limited de-identified data to member centers for the purposes of research and scientific publication without the need for additional institutional review board approval.

All children reported to the ELSO registry with single ventricle congenital heart disease whose procedure included a code for Glenn (ie, common procedural terminology codes 33766 [Classic Glenn] and 33767 [Bidirectional Glenn Shunt]; and ELSO registry procedure codes 2733 [Classic Glenn] and 2734 [Bidirectional Glenn Shunt]) from 1999 until June 2012 were included. Patients with a common procedural terminology code for Fontan were excluded. Cardiac addendum information was available for all patients.

### Data Categorization

The surgical approach to ECMO cannulation was variable. Arterial cannulation sites were categorized as aorta, right common carotid, left common carotid, or other. Venous cannulation sites were grouped into right atrium or right internal jugular vein. Cannulation via open chest was distinguished from closed chest by cannulation site with presence of aortic, right atrium, or pulmonary artery cannulation. The duration of mechanical ventilation was cumulative from endotracheal intubation to ECMO deployment and included mechanical ventilator support in the pre- and postoperative periods.

### Statistical Analysis

Survival was defined as survival to hospital discharge to home or another facility. The demographic, pre-ECMO, ECMO support, and complication data were compared between survivors and nonsurvivors. The Mann-Whitey $U$ test was used to compare continuous data, and the $\chi^2$ test was used for categorical data. Fisher exact test was used when the expected counts in more than 20% of cells was <5. The data are presented as median with interquartile range (IQR) (25th-75th percentile) or frequencies with percents, unless specified otherwise. For patients with multiple ECMO runs (n = 4), only data from the first run were analyzed.

Multivariate logistic regression modeling was used to explore the factors associated with mortality. The candidate variables for inclusion were selected from the bivariate analysis based on $P$ values $\leq .1$, entered into the regression model using a stepwise selection process, and retained if their adjusted $P$ values were $\leq .05$. A continuous variable retained in a model was evaluated for a linear association with mortality and only retained as a continuous variable if this assumption was satisfied. Variables not meeting criteria for linearity were divided according to their distribution (eg, trichotomized) and refitted into the model as categorical variables. The data were analyzed with SAS version 9.3 (SAS Institute, Inc, Cary, NC).

## RESULTS

### Study Population: Demographic and Pre-ECMO Data

A total of 103 infants who have undergone Glenn procedure aged 3 to 12 months underwent 107 ECMO cannulations. This represented 4.7% of total cardiac ECMO data collected by ELSO for children of approximately similar ages (1-12 months) over the same time period. The median (IQR, 25th-75th percentile) age at cannulation was 158 days (IQR, 124-214), and the median (IQR) weight was 5.6 kg (IQR, 5.0-6.4). None of the patients had documented major noncardiac anomalies. VA cannulation was used in the majority of patients (96%). The majority of mutually exclusive indications for ECMO reported in the primary ELSO data set were cardiac (cardiac, n = 90, 87%; ECPR, n = 9, 9%; and pulmonary, n = 4, 4%).

Sixty-eight patients (66%) were successfully decannulated, ECMO was discontinued on family request in 4 patients (4%), 7 patients (7%) had a diagnosis incompatible with life, and 24 patients (23%) had single or multiple organ failure. Four patients (4%) required >1 ECMO run, 2 of whom survived. In Table 1 the duration of ECMO is shown for survivors and nonsurvivors. Sixty-eight patients (66%) survived to decannulation. Of these 68 patients, 42 (61%) survived to discharge. In patients who survived to decannulation, the median (IQR) for ECMO duration was 97 hours (IQR, 65-148 hours). For patients who were both