Extracorporeal membrane oxygenation after stage 1 palliation for hypoplastic left heart syndrome

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Objective: To report the outcomes from a large multicenter cohort of neonates requiring extracorporeal membrane oxygenation (ECMO) after stage 1 palliation for hypoplastic left heart syndrome.

Methods: Using data from the Extracorporeal Life Support Organization (2000–2009), we computed the survival to hospital discharge for neonates (age ≤30 days) supported with ECMO after stage 1 palliation for hypoplastic left heart syndrome. The factors associated with mortality were evaluated using multivariate logistic regression analysis.

Results: Among 738 neonates, the survival rate was 31%. The median age at cannulation was 7 days (interquartile range, 4–11). Black race (odds ratio [OR], 2.0; 95% confidence interval [CI], 1.2–3.6), mechanical ventilation before ECMO (>15–131 hours: OR, 1.6; 95% CI, 1.1–2.4; >131 hours: OR, 1.9; 95% CI, 1.3–2.9), use of positive end expiratory pressure (>6–8 cm H_2O: OR, 1.7; 95% CI, 1.1–2.7; >8 cm H_2O: OR, 1.9; 95% CI, 1.2–3.1), and longer ECMO duration (per day, OR, 1.2; 95% CI, 1.1–1.3) increased mortality. ECMO support for failure to wean from cardiopulmonary bypass (OR, 1.6; 95% CI, 1.02–2.4) also decreased survival. ECMO complications, including renal failure (OR, 1.9; 95% CI, 1.2–3.1), inotrope requirement (OR, 1.5; 95% CI, 1.1–2.1), myocardial stun (OR, 3.2; 95% CI, 1.3–7.7), metabolic acidosis (OR, 2.9; 95% CI, 1.3–6.7), and neurologic injury (OR, 1.7; 95% CI, 1.1–2.6), during support also increased mortality.

Conclusions: Mortality for neonates with hypoplastic left heart syndrome supported with ECMO after stage 1 palliation is high. Longer ventilation before cannulation, longer support duration, and ECMO complications increased mortality. (J Thorac Cardiovasc Surg 2012;144:1337-43)

Extracorporeal membrane oxygenation (ECMO) is commonly used in neonates with refractory cardiopulmonary failure after palliative surgery for single ventricle congenital heart disease, including hypoplastic left heart syndrome (HLHS).[1] Previous reports have indicated that 8% to 12% of patients undergoing stage 1 palliation (S1P) require postoperative ECMO, and ECMO use in patients with HLHS is increasing.[2,3] Despite the increasing use, the reported survival to hospital discharge is variable and poor (28%–64%).[2,4,5] This wide variability in survival might reflect differences in patient selection, timing of ECMO deployment, ECMO management, and experience among reporting institutions. With the frequency of S1P surgery and ECMO use in HLHS, the costs of ECMO, and the evolution of mechanical circulatory support devices for children, it is important to understand the ECMO outcomes for infants supported with ECMO after S1P.

The purpose of the present study was to describe the usage trends, survival to hospital discharge, and factors associated with mortality for neonates with HLHS supported with ECMO after S1P using multicenter data reported to the Extracorporeal Life Support Organization's (ELSO) data registry.

METHODS

Data Source and Study Population

We retrospectively analyzed data obtained from the ELSO Registry for neonates with HLHS supported with ECMO after S1P. The Registry collects data on ECMO use from patients of all ages from 116 centers.[1] Participating centers voluntarily report data to the registry using a standardized data form. The data reported includes demographics, procedural information, pre-ECMO status, ECMO support details and complications, and patient outcomes. HLHS anatomic variants and S1P shunt types are not collected in the Registry. The data are reported to ELSO after approval from each center's institutional review board. A data user agreement allows the release of limited de-identified data for research to member centers.

The study population included all neonates (≤30 days of age at ECMO) reported to the ELSO Registry from January 1, 2000, to December 31, 2009, with a primary admission diagnosis of HLHS (*International*

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass
ECMO = extracorporeal membrane oxygenation
ELSO = Extracorporeal Life Support Organization
HLHS = hypoplastic left heart syndrome
S1P = stage 1 palliation

Classification of Diseases, 9th revision, code 746.7) and a primary procedure code for S1P (Common Procedural Terminology code 33619). For patients with primary cardiac disease using ECMO after January 1, 2001, an addendum (Cardiac Addendum) containing details of the cardiac surgical procedure and cardiac indication for ECMO were also available for analysis. The Committee on Clinical Investigation at Children's Hospital Boston approved the present study.

Data Categorization

Noncardiac abnormalities were categorized using *International Classification of Diseases,* 9th revision, codes for major structural abnormalities including tracheo-esophageal fistula, cleft palate, urogenital abnormalities, and musculoskeletal anomalies. The mode of ECMO was dichotomized as venoarterial or other, including venovenous or a combination of modes. Arterial cannulation sites were categorized as aorta, right common carotid, or other, including left common carotid and femoral artery sites. Venous cannulation sites were grouped into right atrium or other, including right or left internal jugular or femoral veins. The duration of mechanical ventilation before ECMO was the cumulative duration of mechanical ventilation from endotracheal intubation to ECMO deployment and included mechanical ventilator support in the pre- and postoperative periods.

For patients with additional Cardiac Addendum data (n = 506), the indication for ECMO included low cardiac output, failure to wean from cardiopulmonary bypass (CPB), and hypoxia. ECMO complications were categorized using complication codes created by ELSO, as previously described by Thiagarajan and colleagues.[6] Data regarding the type of HLHS and type of pulmonary blood flow established in the S1P procedure (Blalock-Taussig shunt vs right ventricle to pulmonary artery conduit) were not collected by the Registry and were not available for analysis.

Statistical Analysis

Survival was defined as survival to hospital discharge to home or to another facility. The demographic, pre-ECMO, ECMO support, and complication data were compared between survivors and nonsurvivors. The Mann-Whitney *U* test was used to compare continuous data, and the chi-square test was used for categorical data. Fisher's exact test was used when the expected counts in more than 20% of cells was less than 5. The data are presented as the median with interquartile ranges (25th to 75th percentile) or frequencies with percentages, unless specified otherwise. For patients with multiple ECMO runs (n = 28), only data from the first run were analyzed. The trends in ECMO use and survival were analyzed using the chi-square test for linear trend.

Three multivariate logistic regression models were created to explore the factors associated with mortality. The candidate variables for inclusion were selected from the bivariate analysis based on a P value of $\leq .1$, entered into the regression model using a forward-selection procedure, and retained if their adjusted P value was $\leq .05$. 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 the criteria for linearity were divided into categories according to their distribution (eg, trichotomized) and refitted in the model as categorical variables. The data were analyzed using SPSS, version 18.0 (SPSS, Chicago, Ill) and Stata, version 11.0 (StataCorp, College Station, Tex).

RESULTS

Study Population

A total of 738 neonates with HLHS (26% of all neonatal cardiac ECMO runs) underwent 767 ECMO runs after S1P and were reported to the ELSO Registry from 2000 to 2009. The median age was 7 days (interquartile range, 4–11) at cannulation, and the median weight was 3.1 kg (interquartile range, 2.69–3.4); 36 (5%) had noncardiac anomalies, and 237 (32%) had had cardiac arrest before ECMO use. Venoarterial ECMO (n = 711, 96%) was the most commonly used support mode. The ECMO indication included cardiac (n = 624, 85%), supporting cardiopulmonary resuscitation (extracorporeal cardiopulmonary resuscitation; n = 105, 14%), and respiratory (n = 9, 1%). Also, 28 patients (4%) required more than 1 ECMO run, with only 1 survivor.

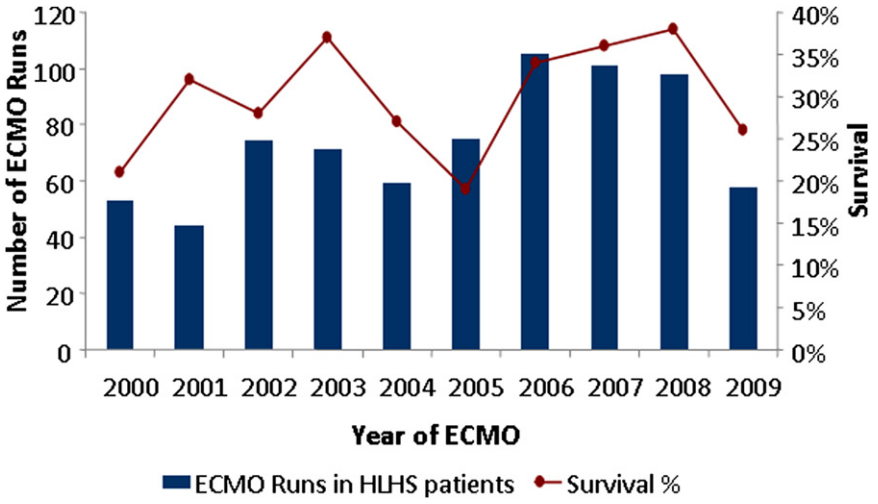

FIGURE 1. Neonatal hypoplastic left heart syndrome *(HLHS)* extracorporeal membrane oxygenation *(ECMO)* use and survival trends.

TABLE 1. Demographic and pre-ECMO features of survivors and nonsurvivors

Variable	Survivors (n = 226)	Nonsurvivors (n = 512)	*P* value
Age (d)			.68
Median	7	7	
Interquartile range	5–10	4–11	
Male gender	142 (63)	302 (59)	.51
Weight (kg)			.03*
Median	3.2	3.0	
Interquartile range	2.8–3.4	2.6–3.4	
Race			.02*
White	159 (70)	312 (61)	
Black	20 (9)	85 (17)	
Other	43 (19)	109 (21)	
Noncardiac anomalies	10 (4)	26 (5)	.70
Pre-ECMO arterial blood gas values			
pH†			.24
Median	7.29	7.28	
Interquartile range	7.21–7.37	7.17–7.39	
Partial pressure of carbon dioxide (mm Hg)†			.73
Median	47	46	
Interquartile range	41–57	38–58	
Partial pressure of oxygen (mm Hg)†			.52
Median	37	39	
Interquartile range	30–49	29–53	
Standardized bicarbonate (mmol/L)†			.02*
Median	23	21.9	
Interquartile range	20–26	18–25	
Peripheral oxygen saturation (%)†			.49
Median	70	67	
Interquartile range	57–81	51–85	
Fraction of inspired oxygen			.87
Median	0.96	0.94	
Interquartile range	0.35–1.00	0.35–1.00	
Pre-ECMO status and support			
Bicarbonate administration	79 (35)	155 (30)	.21
Neuromuscular blockade	123 (54)	294 (57)	.45
Inotrope requirement	188 (83)	442 (86)	.27
Temporary pacemaker use	18 (8)	47 (9)	.59
Cardiac arrest	74 (33)	163 (32)	.81
High-frequency oscillatory ventilation	3 (1)	11 (2)	.33
Inhaled nitric oxide	43 (19)	110 (22)	.45
Ventilation duration before ECMO (h)			<.001*
Median	27	73	
Interquartile range	7.5–139.5	13–175.5	
≤15	98 (43)	145 (28)	.001*
>15–131	65 (29)	172 (29)	
>131	58 (26)	180 (26)	
Missing	5 (2)	15 (2)	
Year of ECMO			.09
2000–2001	25 (11)	72 (14)	
2002–2003	47 (21)	98 (19)	
2004–2005	30 (13)	104 (20)	
2006–2007	72 (32)	134 (26)	
2008–2009	52 (23)	104 (20)	
Heart transplantation	2 (1)	8 (2)	.37

Data presented as numbers, with percentages in parentheses, unless otherwise noted. *ECMO,* Extracorporeal membrane oxygenation. *Statistically significant. †Variables with >10% missing data (pH, n = 119; peripheral oxygen saturation, n = 190; partial pressure of carbon dioxide, n = 120; partial pressure of oxygen, n = 121; standardized bicarbonate, n = 182).

Ten patients underwent cardiac transplantation, with two survivors. Overall, 438 (59%) were weaned from ECMO, and 226 patients (31%) survived to hospital discharge.

The trends in cardiac ECMO use and survival are shown in Figure 1. A significant increase in the number of patients supported with ECMO after S1P was seen during the study period ($P = .02$); however, no improvement was seen in survival ($P = .2$).

ECMO Survivors Versus Nonsurvivors

Demographic and pre-ECMO data. The demographic and pre-ECMO features of survivors and nonsurvivors are listed in Table 1. The nonsurvivor group had significantly lower weight, a greater percentage of infants of black race, lower serum bicarbonate values, and a longer duration of mechanical ventilation before ECMO cannulation compared with the survivor group.

ECMO-related factors. The ECMO-related features of the survivors and nonsurvivors are listed in Table 2. Nonsurvivors required greater positive end-expiratory pressure at 24 hours after ECMO deployment and longer ECMO duration.

ECMO complications. The ECMO complications in survivors and nonsurvivors are also listed in Table 2. Nonsurvivors had a greater frequency of mechanical complications, surgical bleeding, disseminated intravascular coagulation, neurologic injury, renal failure, cardiopulmonary resuscitation, metabolic acidosis (arterial blood pH <7.2), need for inotropic support, cardiac arrhythmias, myocardial stun, pulmonary complications (ie, pneumothorax or pulmonary hemorrhage), culture-proven infection, and hypoglycemia during ECMO support.

Cardiac Addendum. The Cardiac Addendum variables in survivors and nonsurvivors are listed in Table 3. The proportion of neonates requiring ECMO for failure to wean from CPB was greater in the nonsurvivor group. The duration of CPB, aortic crossclamp time, and interval from surgery to ECMO cannulation were longer in the nonsurvivors than in the survivors.

TABLE 2. ECMO variables and complications in survivors and nonsurvivors

Variable	Survivors (n = 226)	Nonsurvivors (n = 512)	*P* value
Support type			.67
ECPR	34 (15)	71 (14)	
Cardiac or respiratory	192 (85)	441 (86)	
ECMO mode (venoarterial)	218 (97)	493 (96)	.91
Arterial cannulation site			.88
Aorta	178 (79)	388 (76)	
Right common carotid artery	36 (16)	94 (18)	
Venous cannulation site			.27
Right atrium	185 (84)	397 (80)	
ECMO flow at 24 h (mL/kg/min)			.20
Median	131	136	
Interquartile range	100–169	109–173	
Ventilator type during ECMO			.10
Conventional	143 (63)	292 (57)	
HFOV or other	0 (0)	6 (1)	
Ventilator breath rate			.05*
Median	15	14	
Interquartile range	10–22	10–20	
Fraction of inspired oxygen (%)			.28
Median	30	25	
Interquartile range	21–40	21–40	
Positive end expiratory pressure (cm H_2O)			.004*
Median	5	6	
Interquartile range	5–8	5–8	
Duration of ECMO duration (h)			<.001*
Median	71	122	
Interquartile range	47–118	69–189	
Multiple ECMO runs	1 (0.4)	27 (5.3)	<.001*
Mechanical complications			
Circuit complications	16 (7)	86 (17)	<.001*
Air embolism	6 (3)	20 (4)	.40
Circuit thrombosis	45 (20)	168 (33)	<.001*
Complications			
Surgical bleeding	79 (35)	239 (48)	.003*
Disseminated intravascular coagulation	2 (1)	21 (4)	.02*
Neurologic injury	33 (15)	132 (26)	<.001*
Renal failure	24 (11)	126 (25)	<.001*
CPR during ECMO	1 (0.5)	19 (4)	.01*
Arterial blood pH <7.2 during ECMO	7 (3)	57 (11)	<.001*
Need for inotropes during ECMO	135 (60)	368 (72)	<.001*
Myocardial stun during ECMO	6 (3)	55 (11)	<.001*
Arrhythmias during ECMO	20 (9)	88 (17)	.003*
Tamponade during ECMO	10 (4)	41 (8)	.08
Respiratory complications†	3 (1)	35 (7)	<.001*
Gastrointestinal hemorrhage	1 (0.5)	6 (1)	.40
Hyperbilirubinemia‡	7 (3)	33 (6)	.06
Culture proven infection	8 (4)	42 (8)	.02*
Hypoglycemia (<40 mg/dL)	0	19 (4)	.003*
Hyperglycemia (>240 mg/dL)	37 (16)	88 (17)	.80

(Continued)

Data presented as numbers, with percentages in parentheses, unless otherwise noted. *ECMO,* Extracorporeal membrane oxygenation; *ECPR,* extracorporeal cardiopulmonary resuscitation; *HFOV,* high-frequency oscillatory ventilation; *CPR,* cardiopulmonary resuscitation. *Statistically significant. †Respiratory complications included pneumothorax or pulmonary hemorrhage. ‡Hyperbilirubinemia indicated by total serum bilirubin of >15 mg/dL or direct >2 mg/dL.

Factors associated with mortality. Three multivariate regression models of factors associated with mortality are listed in Table 4. Model 1 evaluated the demographic, pre-ECMO, and ECMO variables. Black race, longer mechanical ventilation duration before ECMO (>15 hours), the need for greater positive end-expiratory pressure (>6 cm H_2O) at 24 hours after ECMO deployment, and longer ECMO duration were associated with increased mortality. The use of multiple ECMO runs was not considered for inclusion in the model, because only 1 patient survived.

Model 2 identified the ECMO complications associated with mortality. After adjusting for the duration of ECMO support, the continued need for inotropic support, occurrence of myocardial stun, metabolic acidosis, neurologic injury, and renal failure during ECMO increased the odds of mortality. Hypoglycemia was not included in the multivariate analysis because there were no survivors. The association between ECMO duration and complications using interaction terms and mortality was not tested.

Model 3 fitted the qualifying Cardiac Addendum variables into a model containing variables retained in Model 1. Longer mechanical ventilation before ECMO, longer ECMO duration, and ECMO for failure to separate from CPB were all associated with increased mortality; however, CPB duration and interval from surgery to ECMO initiation were not.

Distribution of nonsurvivors by ECMO duration. Figure 2 shows the distribution of survivors and nonsurvivors stratified by ECMO duration. There were few survivors after 9 days of ECMO (Figure 2, *A*). Figure 2, *B* shows the proportion of survivors and nonsurvivors by day of ECMO. The proportion of nonsurvivors was greater immediately after ECMO deployment and after 5 days of ECMO support.

DISCUSSION

In 738 neonates with HLHS supported with ECMO in the postoperative period after S1P, the overall survival to hospital discharge was poor (31%). Despite increasing ECMO use after S1P during the 10-year period, survival has not improved. We found increased mortality in those who required longer mechanical ventilation before ECMO, those with lung injury, reflected by the use of greater positive end-expiratory pressure within 24 hours of ECMO deployment, those who were unable to wean from CPB after S1P, and those who needed longer

TABLE 3. Cardiac Addendum variables in survivors and nonsurvivors

Variable	Survivors (n = 155)	Nonsurvivors (n = 351)	*P* value
Indication for ECMO*			
Low cardiac output	107 (69)	241 (69)	.93
Failure to wean from CPB	53 (34)	156 (44)	.03†
Hypoxia	37 (24)	78 (22)	.68
Cardiopulmonary bypass time (min)			<.001†
Median	156	186	
Interquartile range	126–201	138–251	
Aortic crossclamp time (min)‡			.04†
Median	58	62	
Interquartile range	43–72	47–83	
Interval from surgery to cannulation (h)‡			.04†
Median	9	11	
Interquartile range	5–21.3	7–23	

Data presented as numbers, with percentages in parentheses. *ECMO,* Extracorporeal membrane oxygenation; *CPB*, cardiopulmonary bypass. *Categories not mutually exclusive. †Statistically significant. ‡Variables with >10% missing data (crossclamp time, n = 70).

TABLE 4. Multivariate regression models: predictors of mortality in S1P HLHS neonates requiring ECMO

Variable	OR	95% CI	*P* value
Model 1: demographic and ECMO support			
Race			
White	1.0		
Black	2.0	1.2–3.6	.01*
Other	1.4	0.9–2.1	.16
Ventilation duration before ECMO (h)			
≤15	1.0		
>15–131	1.6	1.1–2.4	.02*
>131	1.9	1.3–2.9	.003*
Missing	1.2	0.4–3.7	.8
PEEP at 24 h after ECMO onset (cm H_2O)			
≤5	1.0		
>5–6	1.2	0.7–2.2	.6
>6–8	1.7	1.1–2.7	.02*
>8	1.9	1.2–3.1	.02*
Missing	3.1	1.7–5.9	.001
ECMO duration (d)	1.2	1.1–1.3	<.001*
Model 2: ECMO Complications			
ECMO duration (d)	1.2	1.1–1.23	<.001*
Inotrope use	1.5	1.1–2.1	.03*
Myocardial stun	3.2	1.3–7.7	.01*
Blood pH <7.2	2.9	1.3–6.7	.01*
Neurologic injury	1.7	1.1–2.6	.02*
Renal failure	1.9	1.2–3.1	.01*
Model 3: Cardiac Addendum			
Ventilation duration before ECMO (h)			
≤15	1.0		
>15–131	1.7	1.1–2.7	.03*
>131	3.1	1.8–5.2	<.001*
Failure to wean cardiopulmonary bypass	1.6	1.02–2.4	.04*
ECMO duration (d)	1.3	1.2–1.35	<.001*

Model 1, n = 728; area under the curve, 0.70; model 2, n = 738; area under the curve, 0.73; and model 3, n = 494; area under the curve, 0. *HLHS*, Hypoplastic left heart syndrome; *OR*, odds ratio; *CI*, confidence interval; *ECMO*, extracorporeal membrane oxygenation; *PEEP*, positive end expiratory pressure. *Statistically significant.

ECMO support. The occurrence of ECMO complications also decreased survival. Poor outcomes despite the increasing use of ECMO in this population suggest a need for careful evaluation of the use of ECMO and exploration of other mechanical support devices for this population. Furthermore, our findings suggest that careful patient selection and minimizing ECMO complications might help improve survival in this population.

This survival rate reported for ECMO use in patients with HLHS after S1P is similar to the overall survival rate of 38% reported for all cardiac ECMO use in neonates with congenital heart disease by the ELSO Registry (2000–2009)[7] but lower than those reported for ECMO use after other operations such as arterial switch (43%).[1] The interpretation of the low survival rate in this population must take into account the inherent high-risk nature of S1P for HLHS and that many patients supported with ECMO have exhausted all other therapies and face imminent mortality. The lower survival rate in the present analysis compared with the greater survival rates reported by single-center reports might reflect a publication bias, as well as differences in the timing of ECMO deployment, ECMO management, and experience between centers, resulting in improved outcomes in some centers compared with others.

Hoskote and colleagues[4] in their report of ECMO use after palliative surgery for single ventricle lesions suggested that elective deployment before complications such as cardiac arrest might improve the outcomes. Allan and colleagues[2] in their study of ECMO outcomes for single ventricle patients reported improved outcomes when ECMO was used to support a reversible event such as acute Blalock-Taussig shunt obstruction than for support of myocardial dysfunction. These studies indicate that both early deployment and patient selection might be important determinants of outcomes in these patients. Morris and colleagues[8] showed, in 137 patients with congenital heart disease supported with ECMO, that prolonged mechanical ventilation before ECMO was associated with increased mortality. Similarly, we found that those who required a longer duration of mechanical ventilation before ECMO had greater odds of mortality. The need for longer mechanical ventilation might be a surrogate for both the severity of illness or possibly irreversible cardiopulmonary failure and thus might decrease the survival outcomes. We found that the cumulative proportion of nonsurvivors was greater at ECMO initiation and again after 5 days of ECMO support (Figure 2, *B*). In addition to the risks inherent to the technical aspects of ECMO cannulation, surgical bleeding, and bleeding owing to anticoagulant use during ECMO, its

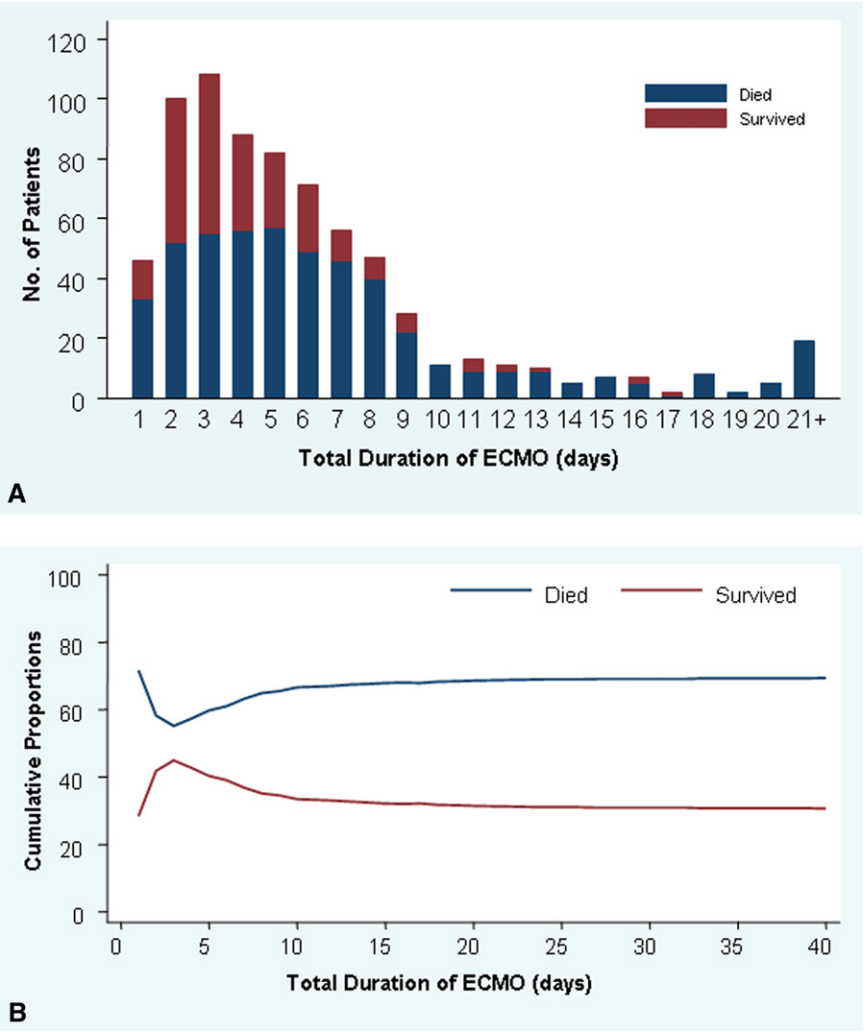

FIGURE 2. Distribution of survivors and nonsurvivors according to extracorporeal membrane oxygenation *(ECMO)* duration. A, Number of survivors and nonsurvivors stratified by day of ECMO. B, Cumulative proportion of survivors and nonsurvivors stratified by day of ECMO.

use after the onset of irreversible end-organ injury might also lead to early mortality with withdrawal of ECMO owing to a lack of early improvement or even futility. The causes of death and level of illness before ECMO deployment could not be precisely evaluated from our data. From our analysis and the existing knowledge in this area, we speculate that neonates placed on ECMO early after S1P, before the onset of irreversible end-organ injury, and those who have a reversible cause for cardiorespiratory failure (eg, Blalock-Taussig occlusion owing to shunt thrombosis) might be best suited for support with ECMO. We have also shown that few patients survived after 9 days of ECMO support (Figure 2, *A*). Thus, in addition to careful patient selection and ECMO deployment, investigation and correction of potentially reversible lesions after S1P (eg, atrioventricular regurgitation) might allow early weaning of ECMO support and might be important for improving survival. Alternatively, this period might serve as a guide for medical decision making such as listing for cardiac transplantation or prognostication.

Ravishankar and colleagues[5] in their report of ECMO use after S1P showed that a need for ECMO less than 24 hours after surgery was associated with decreased survival. Although they did not separately evaluate failure to wean from CPB, it is possible that some of their patients had ECMO initiated for this indication. Although we did not find an independent relationship between the interval from surgery to ECMO cannulation and mortality, we found ECMO initiated for failure to wean off CPB was associated with increased mortality. We speculate that these patients who failed to wean from CPB after S1P might have sustained irreversible myocardial injury during the course of their operation and were unlikely to survive despite ECMO support. We found that mortality was increased in patients of black race, supporting previously noted racial differences in ECMO outcomes.[8] The reasons for this

association are poorly understood and cannot be easily evaluated from our data. Similar to other reports, we found that ECMO complications increased mortality in our study population. Although some complications might be unavoidable, meticulous attention to limiting complications might improve survival. Finally, we observed a 28% mortality rate in patients successfully weaned from ECMO. The reasons for mortality after successful ECMO weaning could not be evaluated from these data but should be the focus of future research.

Our results are limited by the retrospective design and use of a multicenter database. The data reported to the ELSO Registry are not specific for the analysis of ECMO outcomes for patients with HLHS after S1P. Thus, important factors influencing mortality might have been missed. For example, the details of HLHS anatomic variants and shunt type used in S1P were not available for analysis. The missing values for many variables precluded their inclusion in the multivariate analysis. Other important information such as reporting center demographics and practice variability among centers regarding the use and treatment of patients on ECMO were not available for analysis because data user agreements between reporting centers and ELSO precluded the release of such information. Thus, the influence of important variables such as center size, volume, and ECMO management on outcomes could not be evaluated; this should be considered an important limitation of the present data. Finally, long-term survival, neurologic and functional outcomes, and quality of life measures for survivors were not available.

CONCLUSIONS

ECMO has been increasingly used to support patients with HLHS after S1P; however, mortality has remained high. Careful patient selection, the early deployment of ECMO, and the careful management of ECMO to avoid complications might help improve survival. Finally, future research exploring other strategies such as early consideration for transplantation and support with newer mechanical circulatory assist devices should be studied to improve the outcomes in this high-risk population.

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