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Review

Extracorporeal membrane oxygenation for pediatric cardiac failure: Review with a focus on unique subgroups

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ABSTRACT

Extracorporeal membrane oxygenation (ECMO) is a widely used form of mechanical circulatory support for infants and children with refractory cardiac and respiratory failure. The use of ECMO in infant and pediatric cardiac failure continues to increase over the last decade with 51% survival to discharge. Despite improvements in short term survival, ECMO remains an invasive and expensive therapy with significant associated complications and both short and long term sequelae. The focus of this review is to provide clinicians with a better understanding of the evolving indications, implementation, complications, outcomes and utilization in unique subgroups of pediatric cardiac ECMO patients.

1. Introduction

Extracorporeal membrane oxygenation (ECMO) is a widely used form of mechanical circulatory support for infants and children with refractory cardiac and respiratory failure [1]. The majority of growth in pediatric ECMO use in the most recent era has been in the cardiac population. Of these patients, most children have been placed on ECMO during the peri-operative period surrounding palliation or correction of congenital cardiac defects [2]. Indications for ECMO have also increased and extracorporeal life support as a bridge to transplant, more permanent mechanical assist device placement, and as an adjunct to cardiopulmonary resuscitation (extracorporeal cardiopulmonary resuscitation [ECPR]) have all been described. Despite the increasing applications, ECMO remains a highly invasive therapy with significant cost, complications, high short term mortality, and long term dysfunction in survivors.

In this paper, we describe trends in pediatric cardiac ECMO (children and infants > 30 days of age). We excluded neonates because two recent reviews focused specifically on neonatal cardiac patients [2,3]. Consequently, neonates are only included in the discussion of larger studies when the two age groups are not clearly separated. Prior reviews on pediatric cardiac ECMO mostly focus on neurologic outcome. Thus, we focused on trends in pediatric cardiac ECMO use over time, indications for use, implementation, complications, and short and long term outcomes with attention to unique subgroups of pediatric cardiac ECMO patients.

2. Trends in Cardiac ECMO

Cardiac ECMO use has continued to grow in the pediatric population as shown in Fig. 1. The Extracorporeal Life Support Organization (ELSO) was officially formed in 1989 by a group of centers using ECMO to support patients with cardiopulmonary failure. Almost 300 centers now contribute data regarding patient outcomes, complications, and indications to the organization registry. Registry data is used to support individual ELSO centers, regulatory agencies, and clinical research which has enhanced our understanding of ECMO [4]. Over 8000 cases of pediatric cardiac ECMO have been reported to the ELSO registry as of January 2016. Pediatric cardiac ECMO runs make up almost 10% of overall cases in the registry and 45% of pediatric ECMO non-ECPR runs. The majority of these patients are placed on ECMO due to congenital cardiac defects followed by cardiomyopathy and myocarditis [4].

The most common congenital cardiac diagnoses as well as outcome data in infants (31 days–1 year) and children (1 year–16 years) are shown in Table 1. Additional growth in the pediatric cardiac ECMO population has been seen in myocarditis, cardiomyopathy, and ECPR.

3. Evolution of Pediatric ECMO Use Over Time

Indications for ECMO initiation have continued to evolve since the first pediatric cardiac case over 45 years ago. In general, ECMO has

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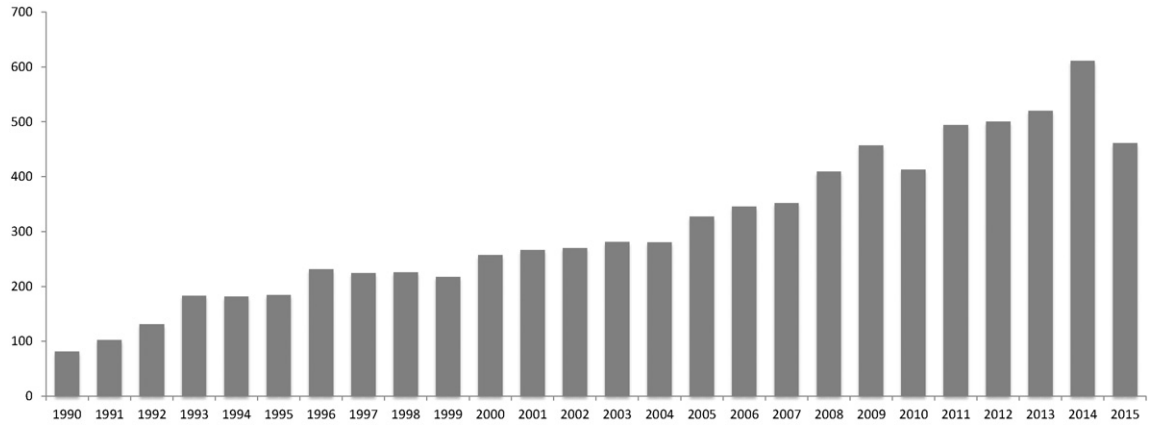

Fig. 1. Annual pediatric cardiac ECMO runs. ECMO = extracorporeal membrane oxygenation. Data from http://www.elsonet.org[3].

become an accepted modality in pediatric patients when cardiac failure is both refractory to conventional therapy and due to a potentially reversible condition [5]. Indications for ECMO in pediatric heart disease include severe cardiac dysfunction unresponsive to medical therapy in the preoperative period, failure to separate from cardiopulmonary bypass, post-cardiotomy low cardiac output states, for refractory arrhythmias, cardiac arrest unresponsive to CPR, and cardiac catheterization procedures in critically ill children [5–9]. In general, pediatric ECMO patients in the current era are believed to be more medically complex than in the past. New indications are developing with improvements in technology and changing culture.

4. Technical Considerations/Implementation

4.1. Cannulation Techniques

Venoarterial (VA) ECMO is used in over 95% of pediatric cardiac cases [2]. Cannulation may be central or peripheral depending on the clinical situation. Transthoracic cannulation with direct cannulation of the right atrium and aorta via a median sternotomy and cannulation of the right internal jugular vein and right carotid artery are most commonly used in pediatric patients. Rarely, femoral vein and femoral artery cannulation are performed in larger pediatric patients. The location of cannulation depends on the size of the vessels, presence of occluded vessels, cardiac anatomy, surgeon preference, and circumstances surrounding initiation of extracorporeal support [10–11]. Select patient populations may benefit from central versus peripheral cannulation but increased bleeding and infectious risks must be carefully considered [8, 10,12–13].

Table 1
Extracorporeal Life Support Registry Report international summary of survival rates by age and congenital cardiac diagnosis.

Age	Congenital cardiac diagnosis	Total runs	Survived to discharge
Infant (31 days to <1 year)	Left to right shunt	675	297 (44%)
	Left-sided obstructive	306	132 (43%)
	Hypoplastic left heart	390	153 (39%)
	Right-sided obstructive	145	76 (52%)
	Cyanotic increased pulmonary blood flow	103	45 (44%)
	Cyanotic increased pulmonary congestion	152	64 (42%)
	Cyanotic decreased pulmonary blood flow	337	153 (43%)
	Other	1192	622 (52%)
Children (1 year to <16 years)	Left to right shunt	299	135 (45%)
	Left-sided obstructive	195	105 (54%)
	Hypoplastic left heart	158	70 (44%)
	Right-sided obstructive	118	61 (52%)
	Cyanotic increased pulmonary blood flow	17	4 (24%)
	Cyanotic increased pulmonary congestion	12	4 (33%)
	Cyanotic decreased pulmonary blood flow	244	119 (49%)
	Other	554	258 (47%)

ECMO = extracorporeal membrane oxygenation. Data from http://www.elsonet.org[3].

Venovenous (VV) ECMO which is usually used for hypercapnia or hypoxemia in the setting of preserved cardiac function has been used infrequently in pediatric cardiac patients. In general, VV ECMO has a more favorable risk profile than VA ECMO [14]. Small observational studies have reported decreased inotropic score, improved systemic blood pressure, left ventricular shortening fraction, and aortic peak velocities in children placed on VV ECMO [15–16]. In a retrospective ELSO registry report, only 1.6% of pediatric cardiac patients were placed on VV ECMO. Of these patients, 42% survived to hospital discharge and 24% were converted to VA ECMO. Risk factors for failure of VV ECMO were identified (e.g. use of renal replacement therapy) but a specific population of cardiac patients likely to benefit from VV ECMO was not identified [17]. Most likely, the few cardiac patients who would benefit from VV ECMO would not have significant hemodynamic compromise. This was true in a single center study of children with cyanotic congenital heart disease placed on VV ECMO for hypoxemia due to inadequate pulmonary blood flow or viral pneumonia. None of the patients were converted to VA ECMO and all were weaned from VV ECMO with only one death prior to discharge [18]. Another study using ELSO registry data reported that patients with single-ventricle anatomy in respiratory failure placed on VV ECMO had 48% survival [19]. Therefore, VV ECMO may be appropriate albeit infrequently, for selected pediatric cardiac patients, but additional studies are needed to guide clinicians.

4.2. Timing of ECMO Initiation

ECMO support in the preoperative period as a bridge to surgical palliation or repair has been described in single center studies with good results [20–21]. In a large retrospective multicenter database study 14% of children required ECMO prior to surgical palliation or correction. Children placed on ECMO prior to their cardiac operation had improved survival compared to children placed on ECMO after their cardiac operations. When adjusted for patient and center characteristics there were no differences between the two groups in hospital length of stay, charges, or ECMO duration [22].

Unlike in pediatric respiratory failure, days of mechanical ventilation prior to ECMO initiation are not a consistent predictor of mortality in pediatric cardiac patients [23]. Contrasting studies fail to differentiate whether early ECMO initiation (i.e. in the operating room due to failure to separate from cardiopulmonary bypass) increases mortality [24–28].