Extracorporeal Life Support Organization Registry International Report 2016

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Data on extracorporeal life support (ECLS) use and survival submitted to the Extracorporeal Life Support Organization's data registry from the inception of the registry in 1989 through July 1, 2016, are summarized in this report. The registry contained information on 78,397 ECLS patients with 58% survival to hospital discharge. Extracorporeal life support use and centers providing ECLS have increased worldwide. Extracorporeal life support use in the support of adults with respiratory and cardiac failure represented the largest growth in the recent time period. Extracorporeal life support indications are expanding, and it is increasingly being used to support cardiopulmonary resuscitation in children and adults. Adverse events during the course of ECLS are common and underscore the need for skilled ECLS management and appropriately trained ECLS personnel and teams. *ASAIO Journal* 2017; 63:60–67.

Key Words: extracorporeal life support, Extracorporeal Life Support Organization Registry report, survival, adverse events.

Extracorporeal life support (ECLS) or extracorporeal membrane oxygenation (ECMO) is used to support critically ill patients with cardiorespiratory dysfunction when conventional treatments have failed. The Extracorporeal Life Support Organization's (ELSO) registry collects data on ECLS use and outcomes in children and adults. The organization periodically publishes a summary of data reported to the registry to help improve knowledge of ECLS outcomes and adverse events. Since the first registry report in 1988, eight subsequent reports have been published, with the most recent report from 2012.[1–8] Similar to the prior reports, this 2016 ELSO registry report summarizes current information on outcomes for children and adults requiring ECLS support, using data reported to the registry.

Materials and Methods

Details of ELSO, the ECLS registry, and information collected by the registry have been described in the 2012 registry report by Paden *et al*.[8] ELSO member centers report data to the registry using standardized data collection forms. Data reported include demographic information, pre-ECLS illness severity and support, diagnosis and procedures (using *International Classification of Diseases 9th Version* [ICD-9], Common Procedural Terminology, and locally developed codes), ECLS indication, equipment used for ECLS support, details of ECLS course, ECLS complications, and survival to hospital discharge or another facility from the ECLS center. Additional data are collected for specific subpopulations (*e.g.*, ECLS support after cardiac surgery in children via the Cardiac Addendum since 2001), indications (ECLS used to support cardiopulmonary resuscitation [ECPR]; ECPR Addendum since 2011), and therapies (renal replacement therapies for renal failure; Renal Failure Addendum 2012). These additional data addenda collect important information from a specialized population to help better understand ECLS outcomes in these unique situations.

For purposes of this report, we analyzed data from patients reported to the registry from its inception in 1989 through July 1, 2016, and summarized in the ECLS Registry Report International Summary, July 2016.[9] Reporting was incomplete for the calendar year 2016, thus figures only display data through calendar year 2015. This report contains data reported from both US and international ECLS centers. Extracorporeal Life Support Organization registry definitions for indications, mode of ECLS, and complications were used to categorize patients in this report. Patient age at the time of ECMO deployment was categorized as neonatal (≤30 days), pediatric (respiratory ECLS >30 days to ≤18 years; cardiac ECLS: >30 days to 16 years), and adult (respiratory ECLS >18 years and cardiac ECLS >16 years). Data from the specialized addenda were not included in this report. Data are reported as numbers and proportions.

Results

General Information

The ELSO registry currently contains data from 78,397 children and adults supported with ECLS (**Table 1**). During 2015, the last full year of data collection the registry received data from 7,901 patients managed at 310 centers around the world (**Figure 1**). Overall 70% successfully weaned off ECLS, and 58% survived to hospital discharge (**Table 1**). Survival varied by age and ECLS indication. For all ages, survival to discharge was higher in patients supported with ECLS for respiratory compared with cardiac failure or in support of cardiopulmonary resuscitation (CPR). Of note, approximately 10–20% of patients who successfully weaned off ECLS died before hospital discharge.

Both ECMO patient volume and centers reporting to ELSO have increased since the last report (**Figure 1**). **Figure 2** shows

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Table 1. ECLS Cases and Survival to Discharge

	No. Cases	Survived ECLS, N (%)	Discharged, N (%)
Neonatal			
Respiratory	29,153	24,488 (84)	21, 545 (74)
Cardiac	6,475	4,028 (62)	2,695 (42)
ECPR	1,336	859 (64)	547 (41)
Pediatric			
Respiratory	7,552	5,036 (67)	4,371 (58)
Cardiac	8,374	5,594 (67)	4,265 (51)
ECPR	2,996	1,645 (55)	1,232 (41)
Adult			
Respiratory	10,601	6,997 (66)	6,121 (58)
Cardiac	9.025	5,082 (56)	3,721 (41)
ECPR	2,885	1,137 (39)	848 (29)
Total	78,397	54,866 (70)	45,345 (58)

ECLS, extracorporeal life support; ECPR, ECLS to support cardiopulmonary resuscitation.

location of reporting centers across the globe illustrating the international nature of the dataset. **Table 2** shows center type based on age and ECLS indication.

Trends in ECLS use, based on age and ECLS indications, are shown in **Figure 3**. In 2015, adults supported with ECLS for cardiac and respiratory indications were the largest group of patients reported to the registry. Use of ECLS to support neonates with respiratory failure decreased, whereas ECLS use for pediatric respiratory, and neonatal and pediatric cardiac indication remained unchanged.

Neonatal Respiratory Extracorporeal Life Support

Neonates with respiratory failure supported with ECLS remained the largest single cumulative group of patients in the registry (37%; **Table 1**). A total of 29,153 neonates supported with ECLS have been reported to the registry with survival to hospital discharge of 74%. During 2015, 813 ECLS runs were reported in this category with 63% surviving to hospital discharge. A continued decreasing trend for ECLS use was noted in this population (**Figure 4A**).

Common diagnosis associated with ECLS use in this population included meconium aspiration syndrome (MAS), persistent pulmonary hypertension (PPHN) of newborn, and congenital diaphragmatic hernia (CDH) (**Table 3**). **Table 3** shows survival to hospital discharge neonatal respiratory ECLS based on diagnosis. Decreased survival to discharge, over time, for neonates supported with ECLS for respiratory failure was noted. Meconium aspiration syndrome, PPHN, and respiratory distress syndrome (RDS) of newborn had the best, whereas patients with CDH had the worst survival in this cohort of patients. Average ECLS duration for patients with MAS, PPHN, and RDS was shorter compared with patients with CDH.

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) remained the most commonly used ECLS mode in neonates with respiratory failure (**Table 4**). Neonates with respiratory failure supported with venovenous ECMO (VV-ECMO) had higher survival compared with those supported with VA-ECMO (**Table 4**).

Pediatric Respiratory Extracorporeal Life Support

The registry collected information on 7,552 pediatric (age >30 days to <18 years) patients, with survival to hospital discharge of 58% (**Table 1**). In 2015, there were 561 ECLS runs in this category with 60% survival to hospital discharge. **Figure 4B** shows trends for ECLS use in pediatric patients with respiratory failure.

Infection as the cause of respiratory failure was the leading condition associated with the ECLS use in pediatric respiratory disease (**Table 5**). Patient with viral and aspiration pneumonia had the highest survival in this cohort of patients. The average duration of ECLS was longer in pediatric patients compared with neonates with respiratory failure. Venovenous ECMO was more commonly used in children with respiratory failure compared with VA-ECMO and had higher survival to discharge (**Table 6**).

Adult Respiratory Failure

The registry contained 10,601 adults with 58% survival to hospital discharge (**Table 1**). In 2015, 2,046 ECLS runs were reported with 57% survival to hospital discharge and represented the largest age-based cohort for the year (during 2014, 1,961 ECLS runs with 61% survival was reported). Use of ECLS

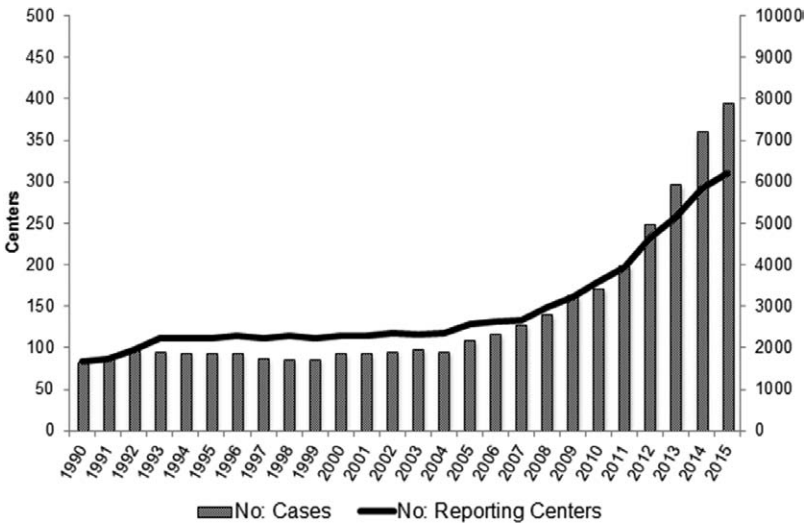

Figure 1. Extracorporeal life support volume and Extracorporeal Life Support Organization member centers.

Figure 2. Extracorporeal Life Support Organization reporting centers from www.elso.org. full color online

to support adults with respiratory failure showed the most growth among all ECLS indications (**Figure 3**). Survival for adults supported with ECLS showed continuous improvement over time (**Figure 4C**).

Table 2. ELSO Member Center Type by Age and ECLS Indication

ECLS Indication	No. Reporting Centers*
Total number of centers in 2015	310
Respiratory ECLS	
Neonatal	197
Pediatric	253
Adult	303
Cardiac ECLS	
Neonatal	202
Pediatric	249
Adult	295
ECPR	
Neonatal	134
Pediatric	175
Adult	209

Data from www.elso.org.

*Based on centers reporting to ELSO in the last 5 years; some centers provide ECLS for all ages and indications and are included in multiple categories.

ECLS, extracorporeal life support; ELSO, Extracorporeal Life Support Organization.

Infectious disease resulting in respiratory failure was also common diagnosis associated with adult ECLS use (**Table 7**). The average duration of ECLS was similar to those with pediatric respiratory failure. Similarly, the majority of adults with respiratory failure were supported with VV-ECMO (**Table 8**). Survival was higher for patients supported with VV-ECMO compared with those supported for VA-ECMO. Survival for patients supported for viral pneumonia was 65%.

Trends in the use of VV-ECMO for respiratory ECLS among neonates, pediatric, and adult patients are shown in **Figure 5**.

Neonatal and Pediatric Cardiac Extracorporeal Life Support

To date, 6,475 neonates have been supported with ECLS for cardiac indications with 42% surviving to hospital discharge (**Table 1**). The registry contained information on 8,374 pediatric patients undergoing cardiac ECLS with 51% surviving to hospital discharge. In 2015, neonatal and pediatric cardiac ECLS reported included 446 neonates, 319 infants (age: >30 days to <1 year), and 281 children (age: 1 to < 16 years) with survival to discharge of 45%, 55%, and 61%, respectively. Use and survival for this cohort was higher in the most recent time period and in older children (**Figure 6, A** and **B**).

Congenital heart disease (commonly for postoperative support after corrective or palliative cardiac surgery), cardiogenic

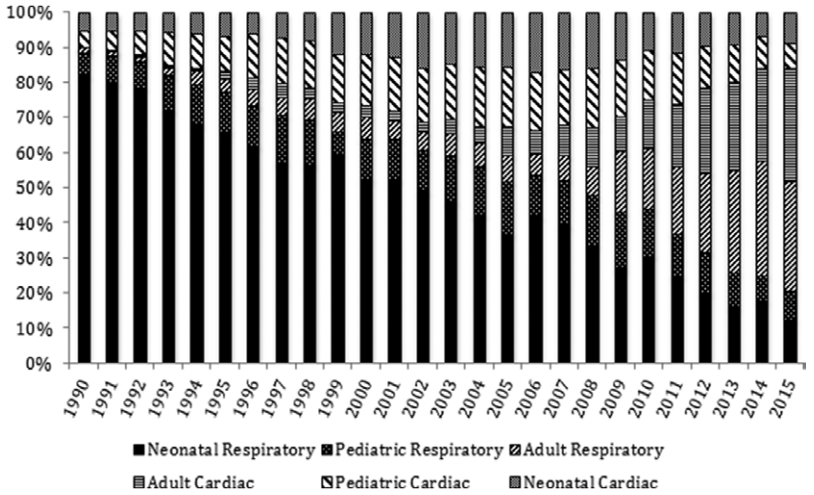

Figure 3. Trends in extracorporeal membrane oxygenation indications.

shock, and cardiomyopathy were the most common diagnoses in this cohort (**Table 9**). Patients with myocarditis and cardiomyopathy had the highest survival. Venoarterial ECMO (97%) was the most commonly used mode of ECLS. There was wide variability in survival based on type of congenital heart disease. Children with left heart lesions had lower survival compared with those with right heart congenital disease. Extracorporeal membrane oxygenation duration was shorter in neonates and

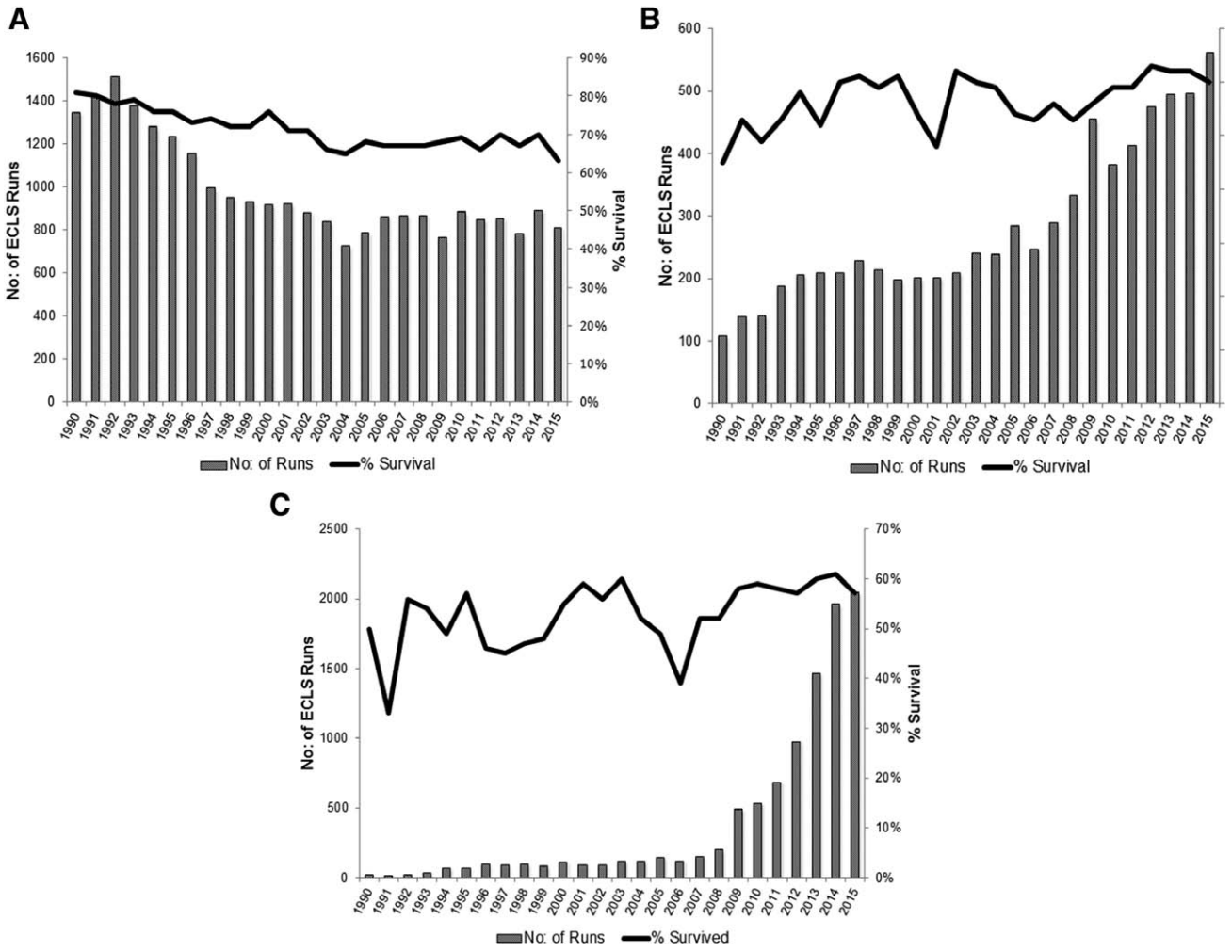

Figure 4. Extracorporeal life support use and survival in respiratory disease. **A**: Neonates. **B**: Pediatric patients. **C**: Adults.

Table 3. ECLS for Neonatal Respiratory Failure: Diagnosis and Survival

Diagnosis	Total Runs, N	Average Run Duration, hour	Survival, N (%)
MAS	8,994	133	8,414 (94)
PPHN	5,077	155	3,906 (77)
RDS	1,555	136	1,307 (84)
CDH	7,765	257	3,965 (51)
Sepsis	2,906	144	2,106 (72)

CDH, congenital diaphragmatic hernia; ECLS, extracorporeal life support; MAS, meconium aspiration syndrome; PPHN, persistent pulmonary hypertension of newborn; RDS, respiratory distress syndrome of newborn.

pediatric patients supported with ECLS for cardiac compared with respiratory indications. Patients with myocarditis had longer ECLS support duration compared with other indications and had the best survival.

Adult Cardiac Extracorporeal Life Support

The registry contains 9,025 adult (age >16 years) patients in the registry with 41% surviving to hospital discharge (**Table 1**). During 2015, 2,167 cases were reported to the registry with 42% surviving to hospital discharge. Cardiogenic shock was the most common diagnosis associated with ECLS use, with 42% surviving to hospital discharge (**Table 9**). Adults with congenital heart disease had the lowest survival (37%), and those with myocarditis had the best survival in this population. Similar to pediatric patients, average duration of ECMO was shorter compared with respiratory ECLS, and VA ECMO (98%) was used in the vast majority of patients. **Figure 6C** shows use and survival trends in adults supported with ECLS for cardiac indications.

Extracorporeal Life Support to Support Cardiopulmonary Resuscitation

The registry contained 4,332 pediatric and 2,885 adults supported with ECPR with survival to discharge of 41% in pediatric and 29% in the adult groups.

Adverse Events During Extracorporeal Life Support

Common adverse events encountered during the course of ECMO are shown in **Table 10**. Adverse events vary by age and indication for ECMO are shown in **Table 10**.

Table 4. Neonatal Respiratory ECLS Support Modes and Survival

Support Mode	Total Runs, N	Average Run Duration, hour	Survived, N (%)
VA	19,770	183	13,938 (71)
VA + V	1,423	182	1,030 (72)
VV	628	163	471 (75)
VVDL	5,988	150	5,034 (84)
VVDL + V	768	158	610 (79)

ECLS, extracorporeal life support; VA, venoarterial; VA + V, VA+ additional venous drainage; VV, venovenous; VVDL, VV using double lumen cannula; VVDL + V, VVDL with additional venous drainage.

Table 5. ECLS for Pediatric Respiratory Failure: Diagnosis and Survival

Diagnosis	Total Runs, N	Average Run Duration (hour)	Survival, N (%)
Viral pneumonia	1,637	317	1,076 (66)
Bacterial pneumonia	766	283	458 (60)
Aspiration pneumonia	328	242	225 (69)
ARF, non-ARDS	1,408	226	1,439 (52)

ARF, acute respiratory distress syndrome; ARDS, acute respiratory distress syndrome; ECLS, extracorporeal life support.

Table 6. ECLS for Pediatric Respiratory Failure: Modes and Survival

Support Mode	Total Runs, N	Average Run Duration (hour)	Survived, N (%)
VA	3,670	252	1,907 (52)
VA + V	290	236	133 (46)
VV	1,269	261	815 (64)
VVDL	1,560	257	1,084 (69)
VVDL + V	248	289	158 (64)

ECLS, extracorporeal life support; VA, venoarterial; VA + V, VA + additional venous drainage; VV, venovenous; VVDL, VV using double lumen cannula; VVDL + V, VVDL with additional venous drainage.

Table 7. ECLS for Adult Respiratory Failure: Diagnosis and Survival

Diagnosis	Total Runs, N	Average Run Duration, hour	Survival, N (%)
Viral pneumonia	926	325	600 (65)
Bacterial pneumonia	1,362	261	831 (61)
ARDS postop/trauma	461	256	262 (57)
ARDS not post-op/trauma	837	313	453 (54)
ARF, non-ARDS	1,984	275	1,131 (55)

ARF, acute respiratory distress syndrome; ARDS, acute respiratory distress syndrome; ECLS, extracorporeal life support.

Table 8. Adult Respiratory ECLS Support Modes and Survival

Support Mode	Total Runs, N	Average Run Duration (hour)	Survived, N (%)
VA	1,061	187	483 (46)
VA+V	80	211	34 (43)
VV	5,734	258	3,360 (59)
VVDL	2,801	285	1,1814 (65)
VVDL+V	136	389	87 (64)

ECLS, extracorporeal life support; VA, venoarterial; VA + V, VA + additional venous drainage; VV, venovenous; VVDL, VV using double lumen cannula; VVDL + V: VVDL with additional venous drainage.

Discussion

Extracorporeal life support is increasingly used worldwide to support patients with critical cardiopulmonary dysfunction refractory to conventional therapies. This report summarizes data collected by the ELSO data registry, and provides a summary of current global use and outcomes for ECLS. Since the last registry report in 2012, there has been an increase in ECLS volume and number of ECLS centers reporting to the registry, especially international centers, and the data contained in the

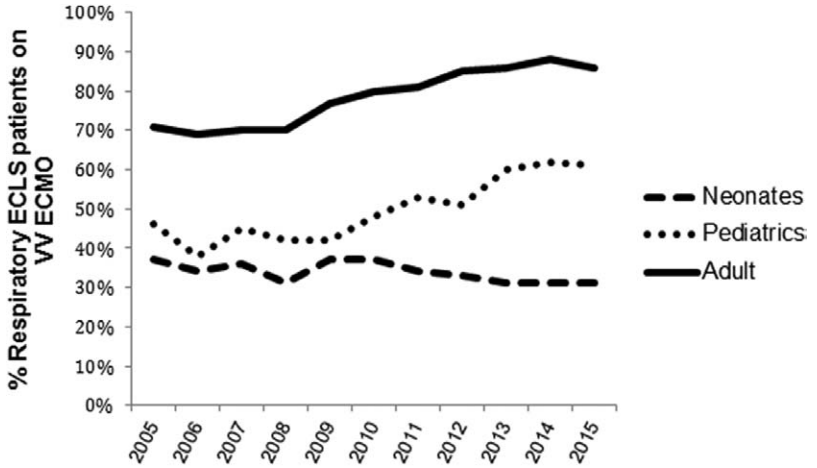

Figure 5. Trends in the use of venovenous extracorporeal membrane oxygenation in patients supported with extracorporeal life support for respiratory failure.

registry provide an accurate representation of ECLS use and outcomes worldwide.[9]

Adults supported with ECLS for respiratory and cardiac failure are now the largest group of patients being reported to the registry. The increased adult ECLS volume may represent a true change in ECLS use in adults. Alternatively, the large adult ECLS volume recently reported may be related to an increase in the number adult ECLS centers currently reporting to ELSO. However, our impression is that since the novel H1N1 influenza epidemic, and the publication of the CESAR trial, there has been a significant growth in the use of ECLS in adults with respiratory failure.[10,11] Use of ECLS for cardiogenic shock is the most common cardiac indication for ECLS use in adults. Extracorporeal life support has been used in this population to

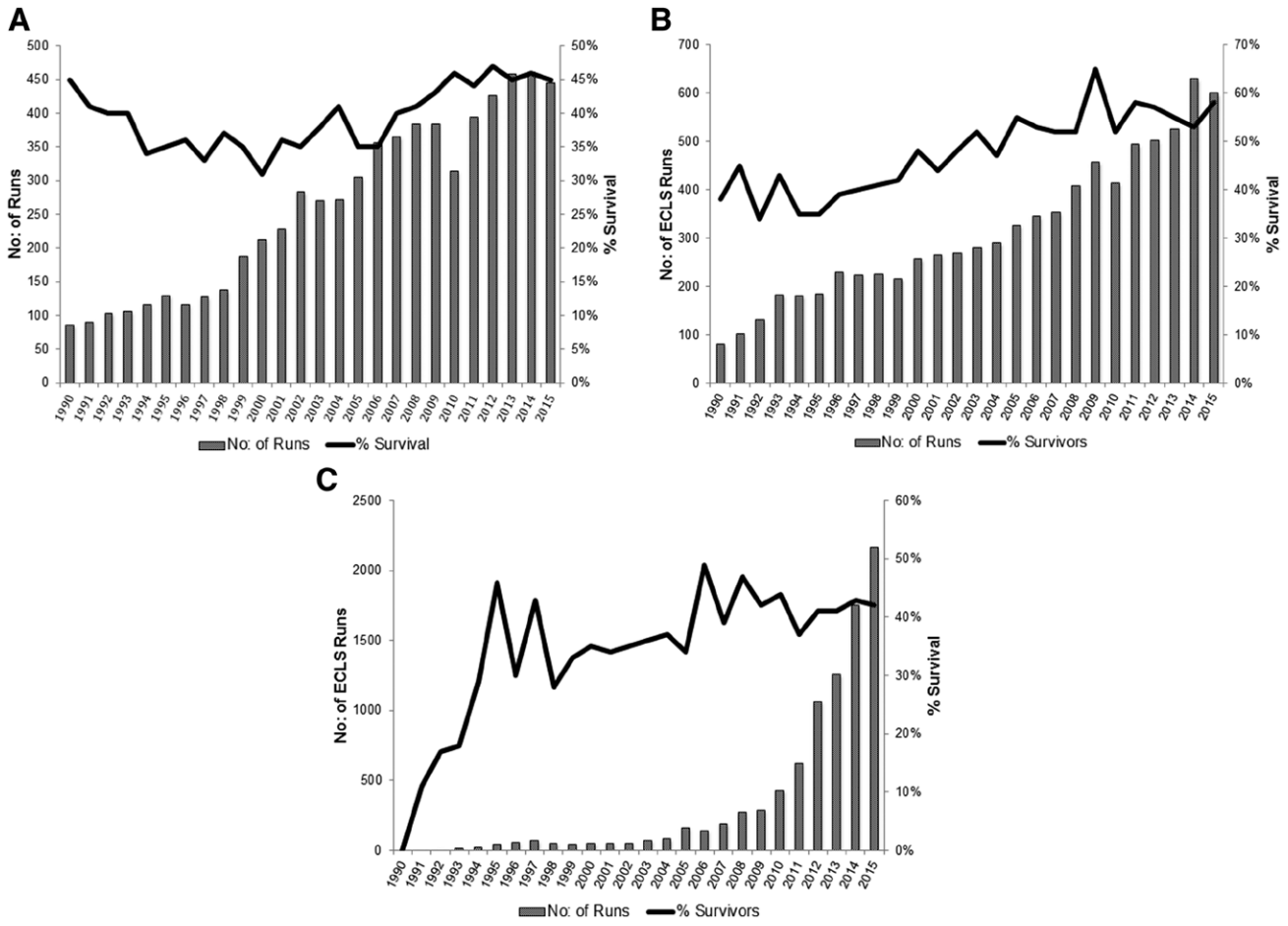

Figure 6. Extracorporeal life support use and survival in cardiac disease. **A**: Neonates. **B**: Pediatric patients. **C**: Adults.

Table 9. ECLS for Cardiac Indications

Diagnosis	No. Runs, N	Average ECLS Duration (hour)	Survival, N (%)
Neonate			
Congenital defect	5,825	143	2319 (40)
HLHS	1,551	135	527 (34)
LVOTO	509	148	175 (34)
RVOTO	239	133	97 (41)
Septal Defects	350	148	133 (38)
Cardiomyopathy	143	211	87 (61)
Myocarditis	87	263	44 (51)
Pediatric (1–16 years)			
Congenital defect	1,641	140	788 (48)
LVOTO	322	147	143 (44)
RVOTO	148	121	78 (53)
Septal defects	704	154	306 (43)
Cardiomyopathy	544	193	337 (62)
Myocarditis	314	181	222 (71)
Adult (>16 years)			
Shock*	2,083	144	882 (42)
Cardiomyopathy	704	162	358 (51)
Myocarditis	227	188	143 (65)
Congenital defect	420	129	156 (37)

*Cardiogenic shock.

ECLS, extracorporeal life support; HLHS, hypoplastic left heart syndrome; LVOTO, left ventricular outflow obstruction; RVOTO, right ventricular outflow obstruction.

bridge patients in cardiogenic shock to coronary intervention procedures with good success.[12] Extracorporeal life support for support of adult respiratory and cardiac failure is expected to grow in the future.

Extracorporeal life support remains an important support modality for critically ill children. As previously described, the use of ECLS for neonatal respiratory failure is decreasing.[8] In addition, ECLS survival for neonatal respiratory failure has decreased. The reasons for the decline in survival are not clear; however, it is possible that with advances in mechanical ventilation and availability in inhaled nitric oxide, the risk profile of neonates with respiratory failure placed on ECLS represents a more critically ill population. Similar to adults, ECLS use for pediatric respiratory failure is increasing, and survival is excellent.[13] Extracorporeal life support remains an important support modality for neonatal and pediatric patients with cardiac disease. In these patients, ECLS is commonly used to support cardiac failure after surgery for congenital heart disease. Survival in the population is strongly influenced by type of congenital heart disease and the complexity of the cardiac surgical procedure.[14] Increased use of ECLS in neonates and children for cardiac indications may be expected to grow, given the increasing complexity of congenital heart surgery being performed in many centers.

Another important use of ECLS is to support failure to achieve spontaneous return of circulation during CPR (ECPR).[15,16] In 2015, approximately 17% of all pediatric and 14% of all adult ECLS patients reported to the registry received ECPR. Poor outcomes for cardiac arrest resuscitated with conventional CPR, improved ECLS technology, improved mobility of ECLS equipment, and ability to deploy at ECLS at point of care have increased the use of ECPR. Survival without neurologic injury is related to the quality of CPR provided before ECLS.

Although life saving in many instances, adverse events during ECLS are common, often resulting in mortality or permanent injury. Adverse events vary by age, indication for ECMO, and mode of ECMO used (higher in VA-ECMO).[17] Thus, successful ECLS requires appropriate patient selection, skilled ECMO management with trained providers, and health care infrastructure that can help prevent or manage adverse events and hence requires considerable resources and manpower and is expensive.[18] Recent reports describing an association between center ECMO volume and survival highlight these issues[19,20].

The ELSO registry has collected important information on ECLS use for centers worldwide and has helped understand ECLS use and outcomes. Variables collected in the registry have been recently revised to include pre-ECLS severity of illness, *International Classification of Disease 10th Version* (ICD-10) diagnosis and procedure codes, and newer adverse event variables. These changes will hopefully help enhance our understanding of severity of illness before ECLS and its influence on ECLS survival, as well as changing trends and challenges with ECLS use in the future. The ELSO registry remains an important and valuable source of ECLS information that will continue to influence the use of ECLS.

Table 10. Adverse Events During ECLS by Age and Indication

	Neonate (%)	Pediatric (%)	Adult (%)
Respiratory			
Mechanical: pump malfunction	1.6	2.2	1.5
Mechanical: oxygenator failure	5.7	10.6	9.1
Cannula hemorrhage	7.9	18.3	13.2
Surgical hemorrhage	6.3	12.6	10.5
Pulmonary hemorrhage	4.5	8.1	6.1
CNS hemorrhage	7.6	6.4	3.9
CNS infarction	6.8	4.2	2.0
Renal failure	7.8*	12.9*	9.3†
Hyperbilirubinemia	7.3	5.2	8.7
Infection	5.8	16.8	17.5
Cardiac			
Mechanical: pump malfunction	1.5	1.8	0.8
Mechanical: oxygenator failure	6.1	7.2	6.6
Cannula site hemorrhage	10.7	15.6	18.5
Surgical site hemorrhage	29.3	28.9	20.2
Pulmonary hemorrhage	5.2	5.3	3.1
CNS hemorrhage	11.3	5.3	2.2
CNS infarction	3.4	5.0	3.8
Renal failure	12.3*	7.2*	12.3†
Hyperbilirubinemia	4.9	7.2	12.2
Infection	7.1	11.0	13.0

Renal failure: serum creatinine *>1.5; †>3.0 mg/dl; hyperbilirubinemia: total bilirubin > 2 mg/dl or indirect bilirubin > 15 mg/dl.

CNS, central nervous system; ECLS, extracorporeal life support.

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