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RESEARCH ARTICLE

Extracorporeal Cardiopulmonary Resuscitation in Pediatric Cardiac Patients: A Single-center Experience

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ABSTRACT

Objectives: Extracorporeal cardiopulmonary resuscitation (ECPR) has been shown to increase survival rates after in-hospital pediatric cardiac arrest. The aim of this study was to describe our experience with ECPR in pediatric cardiac patients.

Methods: We performed a retrospective analysis of our experience from a single institution with 54 patients who underwent ECPR between 2016–2024. The endpoint of the study was survival to discharge.

Results: Twenty-seven patients (50%) were female, and the median age at the time of ECPR was 5 months (IQR, 0.7–23 months). Seventeen (31.5%) of the patients were neonates, and 44 patients (81.5%) had biventricular physiology. Forty-eight patients (88.8%) underwent open chest cannulation, and 6 patients (11.2%) underwent peripheral cannulation. There were 24 survivors (44.4%) and 30 (55.6%) non-survivors after ECPR. Forty-four of the patients were postoperative (81.5%), and 23 of them survived. The survival rate in postoperative patients (52.3%) was significantly higher than in non-postoperative patients (10%) (p=0.015). Forty-five patients (83.3%) had cardiac arrest in the intensive care unit (ICU), and the survival rate was significantly higher in ICU cardiac arrest patients (51.1% vs. 11.1%, p=0.029). The survival rate without neurological sequelae was 31.4%. The median duration of ECMO support was 5 days (IQR, 2–8 days).

Conclusion: Extracorporeal cardiopulmonary resuscitation is a vital application in pediatric cardiac patients. Patients who had cardiac arrest in the ICU had better outcomes than non-ICU patients (p=0.029). Survival rates of postoperative patients were found to be better than those of non-postoperative patients (p=0.015).

Keywords: Congenital heart disease, extracorporeal membrane oxygenation, pediatric extracorporeal cardiopulmonary resuscitation

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Introduction

Conventional cardiopulmonary resuscitation (CCPR) can maintain only 25–30% of cardiac output.[1] If return of spontaneous circulation (ROSC) is not possible despite adequate CCPR after cardiac arrest (CA), the chance of recovery is very low.[1] Survival rates to hospital discharge with CCPR after in-hospital pediatric CA are poor, ranging from 14% to 41%.[2,3]

Rapid implementation of extracorporeal membrane oxygenation (ECMO) during ongoing refractory CPR (ECPR) after pediatric cardiac surgery was first reported by Del Nido et al.[4] in 1992. The incidence of ECPR has increased significantly in recent years, accounting for 18% of all pediatric ECMO cases compared to 5% in 2004.[5,6] According to the Extracorporeal Life Support Organization (ELSO) Registry, the discharge rate for pediatric ECPR is 42%, with more than 70% of cases being performed with the indication of cardiac disease.[5,7] Several studies demonstrated that survival rates after ECPR in pediatric cardiac patients are better than in non-cardiac patients.[8–10]

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Neurological outcomes after ECPR remain an important issue. Extracorporeal Life Support Organization reports show that 22% of ECPR patients have acute neurological injury, and a recent systematic review demonstrated 30% survival with intact neurological outcomes.[11,12] However, exact data on the long-term neurological outcomes of ECPR patients are not available. In this study, we examined a single-center experience with ECPR in the pediatric cardiac population. We investigate different risk factors that may change results in patients undergoing ECPR.

Methods

Medical records of 54 consecutive patients who underwent ECPR between January 2016 and December 2024 were retrospectively reviewed. In our institution, ECPR is defined as ECMO cannulation during ongoing CPR or within the first 20 minutes after cessation of chest compressions. Patients who underwent ECMO support electively or semiurgently and transitioned from cardiopulmonary bypass to ECMO in the operating room were excluded from the study. The data were collected retrospectively from the patients' previous hospital records.

Our study received (numbered E-28001928-604.01-261748337) institutional approval on 06/12/2024 and was conducted in accordance with the principles of the Declaration of Helsinki.

Data collected included patient age, sex, weight, the preoperative diagnosis of the cardiac pathology, type of cardiac operations (if applicable), in-hospital CA location, serum lactate level before ECMO cannulation, type of cannulation (peripheral or open chest), duration of ECMO, length of intensive care unit (ICU) and hospital stays, and neurological outcome.

Institutional indications for ECMO support are based on the Pediatric ECPR ELSO guidelines; lack of improvement in cardiac function within 5–10 minutes of initiating CPR, absent contraindications for mechanical support including preexisting irreversible brain damage or intracranial hemorrhage, extremes of prematurity or low birth weight (<1.5 kg), and severe chromosomal abnormalities (e.g., Trisomy 13 or 18).[13]

ECPR Procedure

The surgical cannulation site is determined by the patient's condition, cardiac anatomy, and the procedure (surgical or interventional) performed. Open chest cannulation is usually performed in patients who are in the early postoperative period and allows decompression of the left atrium and ligation of a shunt or ductal stent when necessary.

Peripheral cannulation is usually performed in non-postoperative patients and patients with medical heart disease. The carotid artery and jugular vein are used in infants and young children, while the femoral artery and vein are used in older children and adolescents. Distal femoral artery cannulation and perfusion are routinely performed in femoral artery cannulations to prevent distal ischemia.

Patients are administered heparin infusion to achieve an activated clotting time of 150–200 seconds, and the target ECMO flow is usually between 80–120 mL/kg/min. During the first 24–48 hours, the core temperature is kept between 33°C and 35°C. Higher flows are used to ensure adequate oxygen delivery in patients with systemic-to-pulmonary shunts or sepsis. In postoperative patients, inotropic agents are decreased as much as possible to reduce systemic vascular resistance and, if necessary, vasodilator infusion is initiated.

Weaning from ECMO is evaluated with a multidisciplinary approach depending on the patient's daily condition. Daily transthoracic echocardiography and angiographic evaluation are performed when necessary. Decannulation is performed after satisfactory cardiac function and oxygen delivery are achieved at low ECMO flow. On the first weaning day, due to the risk of requiring ECMO again, we fix the cannula snares without tying them and leave the sternum open. If the patient's hemodynamic status is stable, we tie the cannula sutures and close the sternum the next day.

Statistical Analysis

In the analysis of the data, SPSS version 25.0 software was used. The conformity of the variables to normal distribution was examined with histogram graphs and the Kolmogorov-Smirnov test. While presenting descriptive analyses, mean, standard deviation, median, and IQR values were used. Comparisons in 2×2 tables were made using Fisher's Exact Test. The Mann-Whitney U Test was used to evaluate non-normally distributed (non-parametric) variables between groups. Kaplan-Meier analysis was used in the survival of the patients. Cases where the p-value was below 0.05 were considered statistically significant results.

Results

In the period of our study, 54 patients underwent ECPR. Twenty-seven of them were female and 27 were male. The median age of the patients was 5.2 months (IQR, 0.7–23 months), and the median weight of the patients was 5.35 kg (IQR, 3–10 kg). Seventeen patients (31.5%) were neonates, 19 patients (35.2%) were infants, and 18 patients (33.3%) were children.

The primary diagnoses of the patients are listed in Table 1. Forty-four patients (81.5%) had biventricular physiology, and 10 patients (18.5%) had functional single-ventricle physiology. Non-postoperative patients were those with diagnosed acquired heart failure or congenital heart

Table 1. Patients' characteristics of the study

Characteristics	Total (n=54)	%
Male gender	27	50
Weight at surgery, kg	5.35 (IQR, 3–10)	
Median age at surgery, months	5.2 (IQR, 0.7–23)	
Diagnosis		
TOF	7	13
HLHS	5	9.3
Singleventricle non-HLHS	5	9.3
CAVSD	4	7.5
TGA+VSD+PS	4	7.5
TGA+VSD	3	5.5
Arcus hypoplasia+VSD	3	5.5
Arcus hypoplasia	3	5.5
Cardiomyopathy	3	5.5
TAPVC	2	3.7
Other biventricle	15	27.7
Ventricular physiology		
Biventricular	44	81.5
Single-ventricle	10	18.5

IQR: Interquartile range; TOF: Tetralogy of fallot; HLHS: Hypoplastic left heart syndrome, CAVSD: Complete atrioventricular septal defect, TGA: Transposition of the great arteries; VSD: Ventricular septal defect; PS: Pulmonary stenosis; TAPVC: Total anomalous pulmonary venous connection.

disease who had not undergone a surgical procedure during the hospitalization in which ECPR was performed. There were 44 postoperative patients (81.5%) and 10 non-postoperative patients (18.5%).

There were 24 survivors (44.4%) and 30 (55.6%) non-survivors after ECPR. Twenty-two of 44 patients (50%) with biventricular physiology survived, and 2 of 10 patients (20%) with single-ventricle physiology (p=0.083). The median age was 5.2 months (IQR, 0.65–21.5 months) in survivors and 5.25 months (IQR, 0.75–22.5) in non-survivors.

Twenty-three of the survivors (95.8%) were in the postoperative group, and 2 had single-ventricle physiology, 1 of whom had hypoplastic left heart syndrome (HLHS). Twenty-one of the non-survivors were postoperative patients (70%), and 7 (23%) had single-ventricle physiology, 4 of whom had HLHS.

There was a statistically significant difference in survival rate between postoperative (52.3%) and non-postoperative patients (10%) (p=0.015) (Fig. 1).

The median serum lactate level immediately before ECMO cannulation was 12.6 mmol/L (IQR, 8.8–16 mmol/L) in survivors and 14.4 mmol/L (IQR, 12–20 mmol/L) in non-survivors (p=0.2).

Cardiac arrest locations outside the ICU were the ward or catheterization laboratory. Forty-five patients (83.3%) had cardiac arrest in the ICU, and 9 patients (16.7%) had

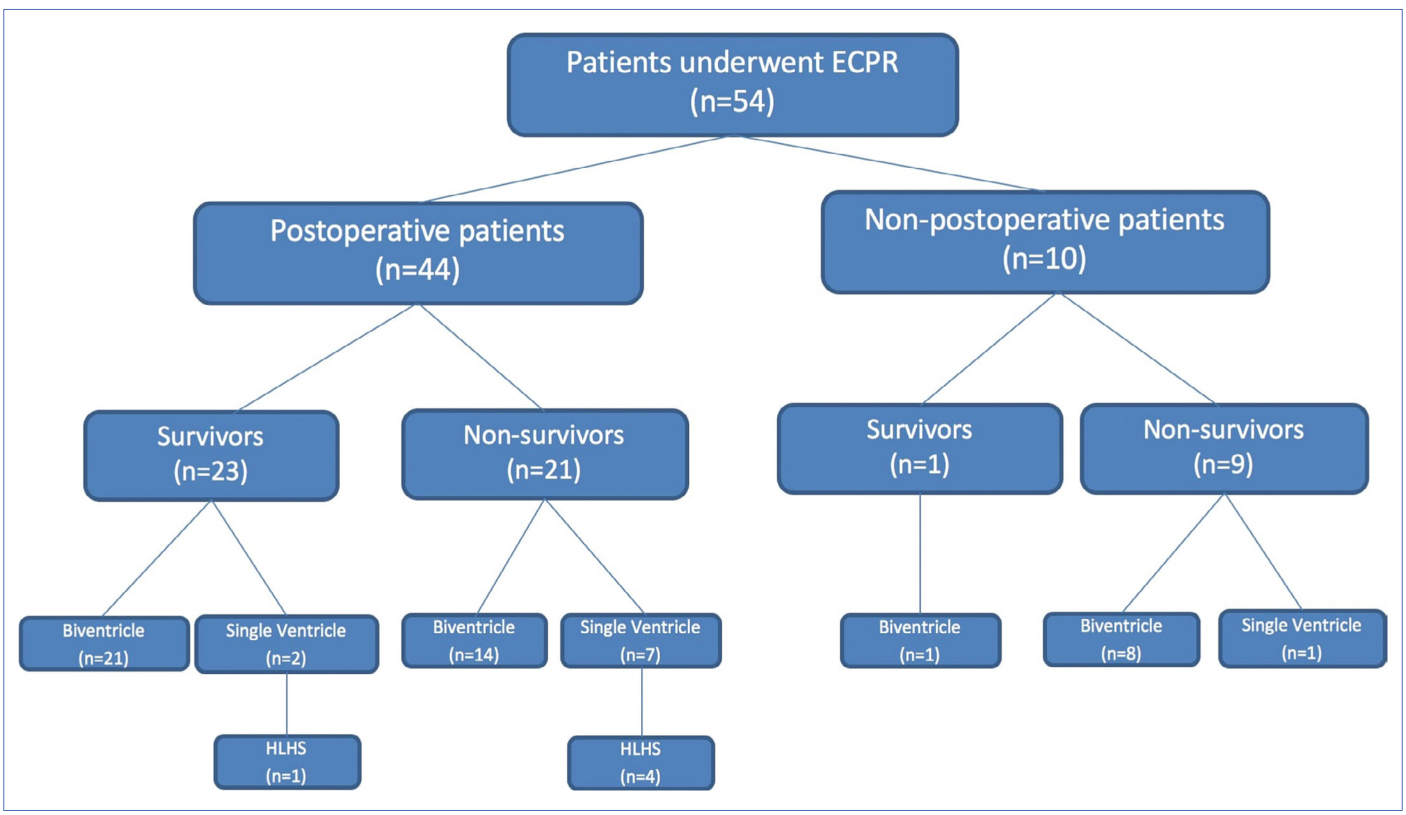

Figure 1. Flow chart of patients' characteristics.

ECPR: Extracorporeal cardiopulmonary resuscitation; HLHS: Hypoplastic left heart syndrome.

Table 2. Risk factors for mortality

Risk factor	Survivors (n=24)		Non-survivors (n=30)		p
	n	%	n	%	
Male gender	14	51.9	13	48.1	0.27
Lactate before ECMO, mmol/L	12.85±3.81		14.85±5.62		0.205
	12.6 (IQR, 8.8–16)		14.4 (IQR,12–20)		
Duration of ECMO, days	5 (IQR, 3–7)		7 (IQR, 3–9)		0.2
Postoperative	23	52.3	21	47.7	**0.015**
Non-postoperative	1	10	9	90	
Biventricular physiology	22	50	22	50	0.083
Single-ventricle physiology	2	20	8	80	
CA at ICU	23	51.1	22	48.9	**0.029**
CA at non-ICU	1	11.1	8	88.9	
Open chest cannulation	22	45.8	26	54.2	0.561
Peripheral cannulation	2	33.3	4	66.7	

ECMO: Extracorporeal membrane oxygenation; IQR: Interquartile range; CA: Cardiac arrest; ICU: Intensive care unit.

CA outside the ICU. Twenty-three of the survivors (95.8%) experienced CA in the ICU, and 1 of the survivors (4.2%) experienced CA in non-ICU locations.

There was a statistically significant difference between survival rates according to CA localization in ICU (51.1%) and non-ICU patients (11.1%), with the survival rate being significantly higher in ICU cardiac arrest patients (p=0.029) (Table 2).

Forty-eight patients (88.8%) underwent open chest cannulation, 4 patients (7.5%) underwent neck cannulation, and the remaining 2 patients (3.7%) underwent groin cannulation. Among survivors, 22 patients underwent open chest cannulation, 1 patient underwent neck cannulation, and 1 patient underwent groin cannulation. While 42 of 44 postoperative patients (95.4%) underwent open chest cannulation, 6 of 10 non-postoperative patients (60%) underwent open chest cannulation.

Five patients (9.2%) underwent reoperation during ECMO support. Two patients underwent shunt revision/replacement operation, 1 patient underwent mitral valve repair, 1 patient underwent pulmonary artery banding, and the last patient underwent atrial septum fenestration operation. Two (40%) of these 5 patients survived.

The median duration of ECMO support was 5 days (IQR, 2–8 days) in the cohort. The median duration of ECMO support was 5 days (IQR, 3–7 days) for survivors and 7 days (IQR, 3–9 days) for non-survivors. The median duration of ICU and hospital stay after the surgery was 24 days (IQR, 10–34) and 29 days (IQR, 10–44), respectively.

Among the 24 survivors, 17 patients (70.8%) were discharged from the hospital without any neurological sequelae. Four patients underwent tracheostomy due to major neurological sequelae and were discharged from the hospital with home ventilation support. The remaining 3 patients were discharged with a physical therapy rehabilitation program after receiving antiepileptic treatment for seizure disorder. The survival rate without neurological sequelae among all patients was 31.4% (17/54).

Discussion

In recent years, ECPR applications using ECMO as rescue therapy in pediatric CA have become increasingly common. This study presents our experience with 54 pediatric cardiac patients who underwent ECPR. Our primary goal in the management of pediatric cardiac patients experiencing CA is to rapidly perform ECPR if ROSC after CCPR is not possible. In our study, we report that the overall survival rate to hospital discharge was 44.4%, and the survival rate without neurological sequelae was 31.4%.

Survival rates after ECPR vary in recent reports. Wolf et al.[14] reported an overall survival rate of 56% in their study of 90 pediatric cardiac patients who underwent ECPR. In the ELSO 2023 reports, the survival rate in pediatric patients was announced as 41%, and the survival rate in neonatal patients was announced as 42%.[15] However, these results include all cardiac and non-cardiac pediatric patients, and survival was reported to be higher in cardiac patients.[15]

Our overall survival rate (44.4%) is similar to ELSO reports. In our study, all patients were cardiac patients, and the survival rate in neonates (4/17) was 23.5%, while the survival rate in the other pediatric population (20/37) was 54%. We think that the low survival rate in newborn patients may be due to the complex surgeries that they have undergone, such as the Norwood procedure or transposition surgery with coronary anomalies.

The patient's postoperative or non-postoperative status may affect survival after ECPR. Wolf et al.[14] showed that survival rates were significantly higher in non-postoperative patients (46.8% vs. 76.9%, p=0.01). They stated that this result is largely due to the higher survival rate of patients with cardiomyopathy in the non-postoperative group.

In contrast, in our study, survival rates were found to be significantly higher in the postoperative group than the non-postoperative group (52.2% vs. 10%, p=0.015). We believe that in our study, most of the patients (70%) in the non-postoperative group experienced arrest in a non-ICU location, and this affected survival after ECPR.

In our study, survival was significantly lower in patients who experienced arrest in non-ICU locations than in those who experienced arrest in the ICU (11.1% vs. 51.1%, p=0.029).

The functional ventricle type of the patients, whether biventricular or single ventricle, may also be important for survival. Wolf et al.[14] reported that biventricular physiology had better survival rates than single-ventricle patients (69.3% vs. 39%, p<0.02).

In our study, although the survival rates of biventricular patients were better than those of single-ventricle patients, no statistically significant difference was detected (50% vs. 20%, p=0.08). We think that the lack of statistically significant results may be related to the limited number of single-ventricle patients in our study.

Another critical issue in pediatric ECPR is the cannulation site. Increased CPR interruptions during ECMO cannulation have been associated with worse outcomes, and it has been noted that open chest cannulation may also have more frequent interruptions during ECPR.[13,16] However, it was also stated that open chest cannulation may be easier, especially for patients in the early postoperative period.[13] Wolf et al.[14] reported that 60% of survivors underwent open chest cannulation, but there was no significant difference in survival by cannulation site. In our study, 22 of 24 survivors (91.6%) underwent open chest cannulation. Similar to the literature, no significant difference was found between open chest cannulation and peripheral cannulation, although the rate was high (p=0.56).

Neurological damage is well documented as a major complication of ECMO in general and ECPR more specifically.[17] Long-term follow-up of the patient's functional status is very important, especially from a neurological perspective. Our study is limited in this respect. According to ELSO reports, 84% of surviving patients were discharged without the need for neurological rehabilitation.[15] In a meta-analysis, the rate of discharge without neurological sequelae after ECPR was reported as 30%.[12] In our study, 70.8% of surviving patients were discharged without the need for neurological rehabilitation. The survival rate without neurological sequelae was 31.4%.

Although very high lactate levels before ECPR have been found to be associated with adverse outcomes, a clear threshold value has not been established.[18,19] Wolf et al. reported that surviving patients had lower pre-ECPR lactate levels than non-survivors, although this difference was not statistically significant. In our study, it was found that lactate levels before ECPR were lower in survivors, although not statistically significant, and this finding is consistent with literature information (12.85±3.81 vs. 14.85±5.62, p=0.2).

The retrospective nature of the single-center study with a limited number of patients are the main limitations of the study. Studies with multiple centers, more patients, and long-term neurological outcomes are needed to show the outcomes of ECPR.

Conclusion

In conclusion, ECPR is a vital application of ECMO in pediatric cardiac patients. The use of ECPR is expected to significantly increase the rate of hospital discharge after CA. Outcomes may be better in patients who experienced arrest in the ICU and in postoperative patients due to the possibility of faster intervention. Patients with biventricular physiology incline to have better clinical results than patients with single-ventricle. Outcomes in HLHS patients were similarly poor to those in other single-ventricle patients (20% survival).

Disclosures

Ethics Committee Approval: The study was approved by The Dr. Siyami Ersek Thoracic Cardiovascular Surgery Training and Research Hospital Ethics Committee (no: E-28001928-604.01-261748337, date: 06/12/2024).

Authorship Contributions: Concept – M.Ç.; Design – M.Ç.; Supervision – M.Ç., E.H.Y.; Materials – E.H.Y.; Data collection &/or processing – M.Ç., E.H.Y.; Analysis and/or interpretation – M.Ç., E.H.Y.; Literature search – M.Ç., E.H.Y.; Writing – M.Ç., E.H.Y.; Critical review – M.Ç., E.H.Y.

Informed Consent: Written informed consent was obtained from all patients.

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