Pediatric Extracorporeal Cardiopulmonary Resuscitation ELSO Guidelines

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Why Consider ECPR for Cardiopulmonary Arrest in Children? Because Conventional CPR may not be Sufficient to Optimize Outcomes in all Pediatric Cardiopulmonary Arrests Situations

Survival rates with good neurologic outcomes following conventional cardiopulmonary resuscitation (CPR) for cardiopulmonary arrest, either in the in-hospital (IH) or out-of-hospital settings, have improved but remain poor in children.[1–3] In general, a longer duration of CPR before the return of circulation is associated with decreased probability of survival,[4,5] worse neurologic[6], and neuropsychologic outcomes among survivors.[7,8]

What is ECPR?

It is the rapid deployment of venoarterial (VA) extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass (CPB) to provide reperfusion with oxygenation and cardiovascular support in the context of cardiopulmonary arrest. In 2018, Extracorporeal Life Support Organization (ELSO) guidelines and Utstein guidelines harmonized their nomenclature and clarified the definition for ECPR.[9] ECPR is defined when ECMO flow is instituted during conventional CPR, delivered with manual or mechanical compressions, or within 20 min of return of spontaneous circulation without ongoing compressions. As such patients cannulated after 20 min of sustained return of spontaneous circulation are classified as receiving VA ECMO, not as ECPR.

The objective of ECMO in patients with cardiopulmonary arrest is to provide circulatory support and gas exchange – both delivery of oxygen and removal of CO_2 and to decrease ischemic reperfusion injury. In this context, ECPR allows ECMO to serve as:

1. a bridge to therapy, intervention, diagnostics, transport, and recovery, or
2. a bridge to organ transplant or replacement with another device, or
3. a bridge to palliative care.

Emergency preservation and resuscitation (EPR) for cardiac arrest from trauma is different from ECPR; EPR involves rapid intra-aortic retrograde flushing of ice-cold preservation solution, venous drainage, and deep hypothermia (<10°C) within minutes; EPR trials are being conducted in trauma arrest.[10]

ECPR Outcomes and the ELSO Registry

The ELSO Registry collects information on children undergoing ECMO cannulation during CPR since 1992. Published survival to hospital discharge in ECPR cases is summarized in Table 1 and spans from 38% in children overall to 42% in children with heart disease. In a study combining a contemporary era (2010–2014) of data in children, with ELSO and the American Heart Association Get With the Guidelines-Resuscitation Registry, the survival to hospital discharge was 31%.[5] In general, survival to hospital discharge for children is higher compared to adults.

Better outcomes for children than in adults may be related to the fact that

1. ECPR is largely offered to children who are in-patients and often are in intensive care unit environments,
2. significantly shorter times between the start of cardiac arrest to return of extracorporeal circulation, and
3. cannulation strategies that more often use neck or central vessels compared to femoral access.

Early neurologic assessment at the time of hospital discharge among survivors suggests that they have good neurologic outcomes.[4] Published longer-term outcomes of children exposed to ECPR are ill-defined and rare.

How to Deploy High-quality ECPR?

High-quality ECPR is a complex intervention and should not be applied in patients as an *ad-hoc* procedure. ECPR is best suited to select populations when delivered by organized systems with predefined guidelines and local protocols.

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Table 1. Studies Reporting Survival to Hospital Discharge in Children with Supported With ECPR and Studies Reporting Longer-term Outcome

Author	Year	Diagnosis	Institution	Total	Survival
del Nido[11]	1992	Cardiac	Pittsburg	11	64%
Dalton[12]	1993	Cardiac	Pittsburg	29	45%
Duncan[13]	1998	Cardiac	Boston	11	54%
Morris[14]	2004	All	Philadelphia	64	33%
Thiagarajan[15]	2007	All	ELSO-R	682	38%
Alsoufi[16]	2007	All	Toronto	80	34%
Chen[17]	2008	All	Taiwan	27	41%
Tajik[18]	2008	All	Meta-analysis*	288	40%
Chan[19]	2008	Cardiac	ELSO-R	492	42%
Kane[20]	2010	Cardiac	Boston	172	51%
Raymond[21]	2010	All	GWTG-R	199	44%
Wolf[22]	2012	Cardiac	Atlanta	150	56%
Lasa[4]	2016	All	GWTG-R	591	40%
Meert[23]	2019	All	THAPCA	147	41%
Bembea[5]	2019	All	ELSO-R and GWTG-R	593	31%
Longer-term outcomes studies with ECPR pediatric patients					
Lequier[24]	2008	Cardiac	Edmonton	9 ECPR (of 39)	At 2 years
Garcia Guerra[25]	2015	All (2000–2010)	Edmonton	55 ECPR	43% at 4.5 years
Kuraim[26]	2018	Cardiac	Edmonton	Some ECPR	variable
Meert[27]	2019	All	THAPCA	147 ECPR	41.5% at 1 year

ELSO-R, Extracorporeal Life Support Organization Registry; GWTG-R, Get With The Guidelines Registry; THAPCA, Therapeutic Hypothermia in Pediatric Cardiac Arrest Trials.

Patient Selection, Context, and Setting

Patient selection is important. In pediatrics, no randomized controlled trial has yet been conducted to compare conventional high-quality CPR to high-quality CPR with ECPR.[28] The current guidelines are informed by consensus guidelines based on:

1. physiology,[29]
2. literature of institutional clinical experiences,[16]
3. voluntary registry-based studies,[4,5,15]
4. secondary analyses of clinical trials,[23]
5. resuscitation guidelines,[30] and
6. clinical and preclinical CPB practices.

For IH cardiopulmonary arrests, it is best to consider first children with and without cardiac disease. In children with cardiac disease, physiologic functional parameters that limit the effectiveness of conventional CPR may be important to consider when adapting resuscitation practices[29]:

1. patients with limited stroke volume with chest compressions,
2. limited effective pulmonary blood flow and oxygenation with compressions, and
3. limited cerebral perfusion.

In these three main groups, if resuscitation measures are provided, ECPR may need to be considered sooner rather than later – if patients are otherwise suitable – given that conventional CPR may have limited effectiveness. In addition, in special cardiac populations, optimal cerebral resuscitation may only be obtained with ECPR cannulation strategies tailored to their individual functional anatomy. Important differences in reperfusion approaches differ in the single ventricle and bi-ventricular physiology are illustrated in Figure 1A–H. Individualized cannulation strategies should be planned in advance.

In children without a primary cardiac disease, data are very limited, and the reported outcomes associated with ECPR are universally worse than in children with cardiac disease. These worse outcomes may be associated with:

1. the primary cause of the event (*e.g.*, cardiopulmonary arrest with prolonged preceding hypoxemia in asphyxia-related events), or
2. the prolonged low flow and hypotension preceding ischemia (*e.g.*, in severe septic shock).

We suggest that institutions establish local protocols that guide their use of conventional CPR with or without ECPR. If institutions opt to deploy protocols that involve ECPR, one of the early steps of this protocol must include decision making by a senior clinician based on physiologic principles. Combining high-quality ECPR with high-quality conventional CPR may be considered if the cardiopulmonary arrest is witnessed and is associated with a reversible condition. Unwitnessed events in all settings have a poor prognosis and should be considered a relative contraindication for ECPR.

Applying extracorporeal resuscitation measures must improve and not interfere with the quality of resuscitation measures. In some patients, early application of extracorporeal measures may be part of a predefined cardiopulmonary arrest care plan where conventional CPR is not expected to be effective.[31] Such examples would include: 1) high-risk anesthesia induction with diseases associated with obstructed pulmonary blood flow from large pulmonary emboli and 2) cases of severe hyperkalemia with new-onset leukemia and tumor lysis syndrome.

Out-of-hospital Pediatric Cardiopulmonary Arrest

In children, there are insufficient data to support the recommendation for the use of ECPR for out-of-hospital cardiopulmonary arrest events, either applied in the field (*e.g.*, trauma or remote retrievals of avalanche or drowning victims) or in the hospital after ongoing conventional CPR during transport. ECMO has been applied in victims of deep hypothermia associated with submersion in water or avalanches to rewarm and

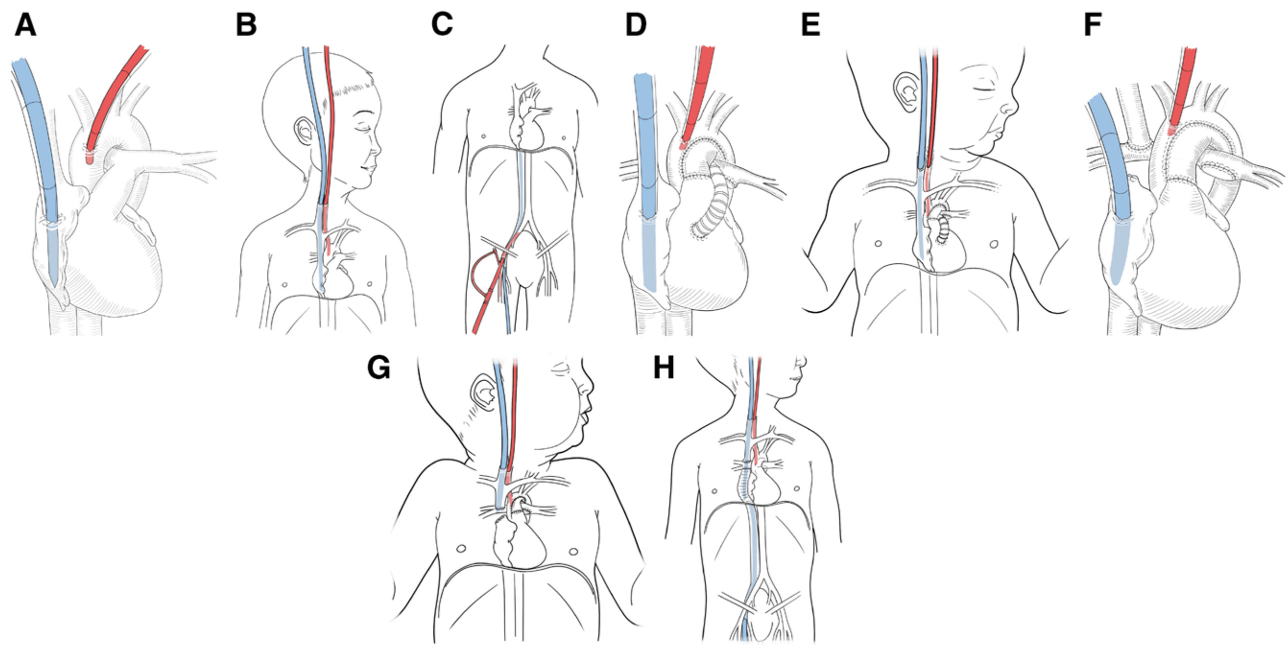

Figure 1. A–H: Cannulation strategies for rapid venous and arterial accesses for ECPR: A, B, and C show strategies for structurally normal hearts or biventricular circulation. A, Central cannulation with venous access in the right atrium and arterial access in the aorta. B, Peripheral cervical cannulation with venous access in the internal jugular vein and arterial access in the common carotid artery. C, Peripheral femoral cannulation with venous access in the femoral vein and arterial access in the femoral artery. Left atrial decompression may need to be considered as an additional intervention in all these approaches. For patients with single-ventricle physiology stage 1 with a shunted or right-ventricle to pulmonary artery conduit physiology, strategies are shown in D and E. D, Stage 1 with central cannulation with venous access in the common atrium and arterial access in the aorta. E, Stage 1 with peripheral cannulation with venous access in the internal jugular vein and arterial access in the common carotid artery. Special care should be taken regarding cannula position in relation to the shunt as it may result in over circulation to the lungs or shunt. For patients with single ventricle physiology Stage 2 with a superior cavopulmonary anastomosis, strategies are shown in F and G. F – Stage 2 with central cannulation with venous access in superior vena cava or in common atrium and arterial access in aorta. G, Stage 2 with peripheral cannulation with venous access with internal jugular vein or femoral vein and arterial access with common carotid artery. If a femoral approach is only used for peripheral cannulation, one must remember that passive venous return must flow through the lungs and mechanical ventilation must be carefully optimized; added venous cannula may be required. For patients with single-ventricle physiology Stage 3 following a Fontan operation, a suggested strategy is shown in H and may be adapted to patient size. H, Peripheral cannulation with venous access in the internal jugular vein and or femoral vein with arterial access in the common carotid artery. Femoral venous cannula may be required depending on patient size and it is important to note that the femoral cannula should be long enough to reach the inferior vena cava drainage site into the Fontan baffle.

resume circulation. In these circumstances, ECPR is a technically attractive indication for ECMO and gradual rewarming; however, the neurologic consequences of indeterminate or prolonged hypoxic-ischemic injury may not be reversible with reperfusion with ECMO. Future evidence may be available from regions and countries with orchestrated emergency medical systems and their registries. Given the absence of clear evidence in favor of ECPR, systems that would opt to offer ECPR for out-of-hospital events should only do this with well-delineated protocols.

Decision and Timing of ECPR

The decision is made if the patient is suited to receive and benefit from extracorporeal resuscitation measures and when the clinician considers (or expects) the cardiopulmonary arrest to be refractory to conventional CPR measures. A lag time of 5–10 min that allows for high-quality CPR to be delivered and obtain spontaneous circulation is usually designed in institutional protocols. ECPR requires additional equipment, people, and resources which explain why a system's launch time is based on the expected time needed to achieve all the steps to get to extracorporeal blood flow. Some organizational benchmarks are <30 min or <40 min for IH events. The decision to launch ECPR and the timing of launching ECPR should be built as separate steps in the institutional protocol.

Resuscitation Measures, Duration, and Quality of CPR

There is no consensus on how conventional CPR should be conducted before cannulating for ECMO. In general, there is a significant decrease in favorable outcomes when blood flow is achieved after 40 min of CPR, but some cases are found in registries where resuscitation measures longer than 60 min or longer have been reported with survival.[4,5] More studies are needed to understand how to maintain high-quality conventional CPR when ECPR preparation, positioning, and cannulation are initiated.[32]

Age and Size

In children, size, and maturity, more than chronological age are considered. Cardiothoracic surgeons are technically able to cannulate neonates and infants less than 2 kg or 3 kg; however, the underlying diseases associated with these

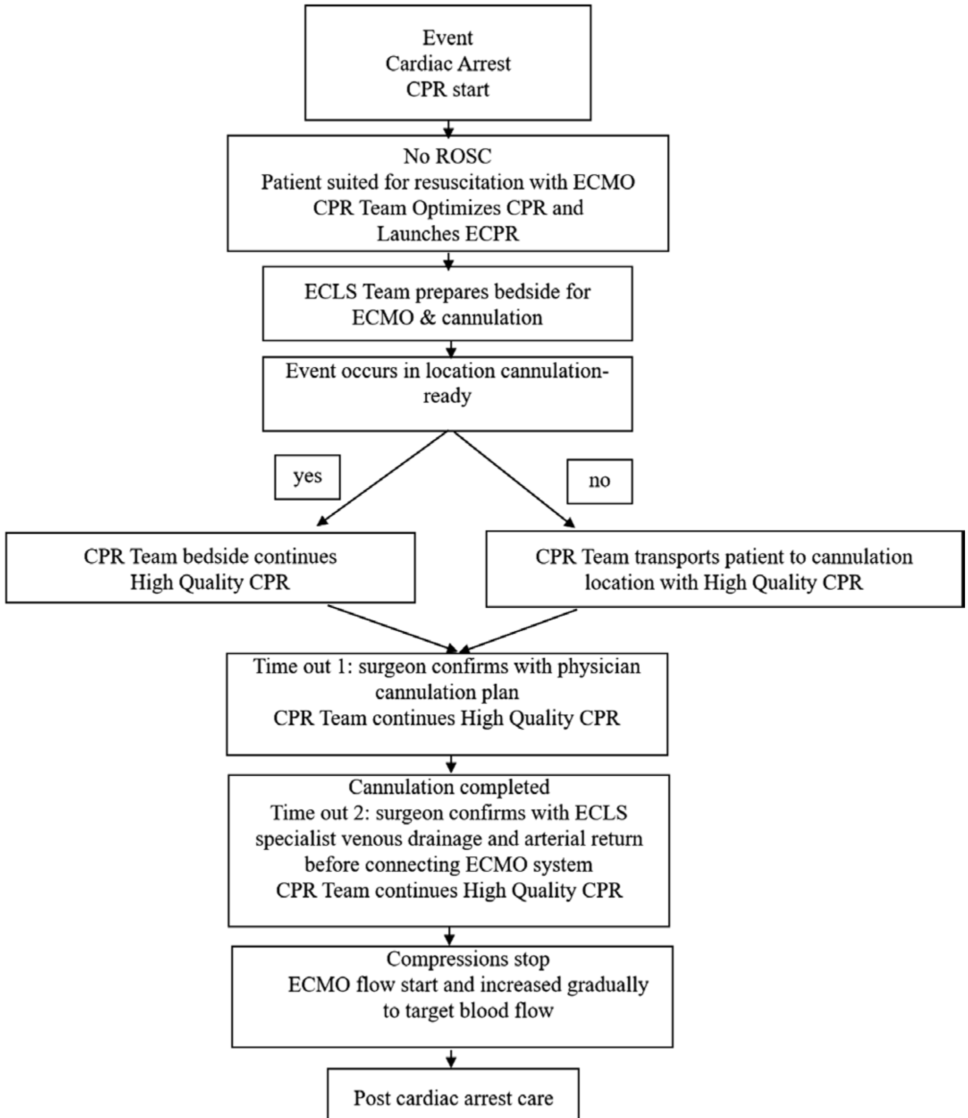

Figure 2. ECPR algorithm.

cardiopulmonary arrest events may not be reversible and the reperfusion injury on the developing organs (brain, heart, bowel, and kidneys) may be significant. Differently, while obesity in adult series has not been associated with adverse outcomes,[33] delivering high-quality resuscitation presents challenges for pediatric teams that may not have adapted resuscitation protocols for 'adult size adolescents'. To provide high-quality ECPR across the weight ranges (2–130 kg) local protocols must include adapting approaches, medications, and equipment. In the context of cardiopulmonary cerebral resuscitation, ECPR and bridging with ECMO, must on balance, add value.

Already Supported by ECLS

In children already on an extracorporeal or paracorporeal devices, occasionally malfunction or disconnection can occur (*e.g.*, while on ECMO, ventricular, or lung-assisted devices). Resuscitation protocols will include planning for cannulation and instructions on using or not using cardiac compressions.[34]

The Team

ECPR requires a well-coordinated team of expert-trained professionals to ensure rapid and successful deployment (*e.g.*, in Tables 2 and 3).

1. Standard resuscitation measures should be initiated by the first group of individuals who focus on high-quality CPR with minimal interruptions before and during ECMO deployment.
2. A team of individuals is dedicated to ECPR who are skilled providers with rapid cannulation and preparation of the ECMO circuit.
3. A team calling system (*e.g.*, team paging system) is used to efficiently mobilize the entire ECPR team and resources necessary.
4. ECPR teams vary in composition across systems and settings. ECPR teams may be available to deploy 24/7; this may not be sustainable for all organizations.
5. ECPR is a low-volume high-risk event: resources required for system and team training and testing, using simulation is useful to maintain the efficiency of the high-performing

Table 2. Tasks and Team Members With Predefined Roles and Responsibilities

Unit Type and Event Location	ICU Cannulation-ready Location	Non-ICU Cannulation-ready Location	Non-ICU Not Cannulation Location
Predefined cannulation locations	Cannulation equipment and footprint approved room	Cannulation equipment and footprint approved: • Image-Guided Laboratory • Cardiac Catheterization Laboratory • Operating Rooms	Cannulation equipment not available and footprint not approved: • Inpatient wards • Out-patient clinics, NICU, Emergency Department, Diagnostic Imaging, and Remote anesthesia locations (*e.g.*, MRI)
Tasks	Members responsible for task		
Start Resuscitation	Bedside clinician (ICU nurse or physician)	Bedside clinician (ICU nurse or physician)	Clinician witness pages Stat Code Blue Team
Stat ECMO Team page	ICU physician faculty or Charge Nurse or delegate	ICU physician faculty or Anesthesia faculty	ICU physician faculty or delegate
Event manager	ICU physician 1	ICU physician	ICU physician
CPR team leader	ICU physician 2	Anesthesia faculty	CCRT or ICU fellow
Conventional High-quality CPR	ICU CPR Team	Anesthesia CPR Team	Intra-hospital transport with ongoing CPR to cannulation-ready location
ECMO vessel cannulation	CVS surgeon 1 (in-house) CVS surgeon 2	CVS surgeon 1 (in-house) CVS surgeon 2	CVS surgeon 1 (in-house) CVS surgeon 2
ECMO circuit	ECMO specialist 1 (in-house) Perfusion specialist 1 or ECMO specialist 2	ECMO specialist 1 (in-house) Perfusion specialist 1 or ECMO specialist 2	ECMO specialist 1 (in-house) Perfusion specialist 1 or ECMO specialist 2
CPR medications	Bedside and medication nurses	Bedside and medication nurses	Bedside and medication nurses
Compressions	2 assigned	2 assigned	2 assigned
Heparin bolus	ICU staff physician and ECMO specialist double checks	ICU staff physician and ECMO specialist double checks	ICU staff physician and ECMO specialist double checks
Resources	Charge or Clinical support nurse	Charge or Clinical support nurse	Charge or Clinical support nurse
Airway	Respiratory therapist once tracheal intubation established	Anesthesia second staff once tracheal intubation established	Respiratory therapist once tracheal intubation established
Documentation and clock time keeper	Documentation nurse or RT	Documentation nurse or RT	Documentation nurse or RT

(1) Institutions may apply different versions of this breakdown based on the location of event and the predefined locations for cannulation.
(2) Electronic Centralized Team Page and Members are trained to go directly to cannulation location indicated on their text page without wasting time calling back (*e.g.*, Surgeons, ECMO Specialist, Perfusion Specialist) and start preparing.

teams.[29] Unless organizations dedicate the means to support this infrastructure, effective CPR and efficient transition to ECPR, will be difficult to maintain.[32] Effective leadership positively impacts both simulated and actual clinical resuscitation events.

Equipment Considerations for ECPR

1. ECPR systems require equipment that is stored "ready" for rapid mobilization. Pre-assembled dry or wet prime circuits that can be turned on and connected with predefined gas and power sources (or tanks and battery).
2. Systems may use either centrifugal or roller pumps. Centrifugal pumps are generally more compact and have improved mobility compared to roller pump systems.
3. ECPR systems include a heat exchanger. Heat exchangers are used to providing temperature-targeted management (TTM).

Priming Solutions for ECPR

No evidence supports one priming method above another. Some prime their circuits with crystalloid solutions (*e.g.*, Lactated Ringers or Plasmalyte) whereas others use red cell or whole blood. Delays in ECMO deployment while awaiting the availability of blood for priming is not current practice. Institutional protocols should be set in advance based on blood bank operations.

Oxygenation and CO_2 Removal With ECPR

There is no published evidence to guide membrane gas management during ECPR deployment. ECPR practice has been adopted from CPB clinical practice. For the IH setting, some centers use blended gases on their standard ECMO circuits (O_2 and air) and will titrate FsO_2 and attempt to minimize hyperoxia as it may worsen ischemia-related reperfusion injury.

There is no published evidence to guide CO_2 management in ECPR. Removal of CO_2 is extrapolated from the neonatal respiratory ECMO, anesthesia, and CPB literature.[35] Early measurement of arterial blood gases on initiation helps to avoid hypocapnia and hypercapnia which alter cerebral blood flow and may influence neurologic outcome. For centers who provide ECPR in patients <3 kg, flow gas meters that permit low flow settings are needed to avoid inadvertent hypocapnia from rapid decarboxylation easily achieved with contemporary membranes.

Vascular Access and Cannulation

Cannulation for ECPR must be achieved rapidly, peripherally, or centrally. Target pump blood flow is set by estimating the cardiac output indexed with the patient size and by the physiologic need based on the underlying disease. During cardiac compressions, peripheral cannulation is associated with less frequent interruptions compared with central cannulation; however, no evidence exists to support one approach over the other.

Table 3. Roles and Responsibilities for ECPR Cannulation Location in ICU Example*.

ICU Physician 1 (ICU or CCRT ICU-Trained Fellow)	
	Code Team Leader focused on high-quality CPR
	Calls ICU Faculty if not bedside
ICU Physician 2 (ICU Faculty)	
	Event Manager
	Launches E-CPR team page weight and cannulation location information
	Orders patient heparin bolus and double-checks dose with ECMO specialist
	Explains to guardians the circumstances of the event and provides informed consent
	Facilitates team "Hot debrief" after patient stabilized on ECMO target flows
Registered Nurse (RN) 1	
	Charge/clinical support nurse
	Assigns roles
	Brings defibrillator and resuscitation cart
	Enforces crowd control
	Ensures all equipment is available
RN 2	
	Assistant to cannulating surgeons
	Ensures patient is in proper position with CPR board under patient
	Provide sutures, dressings, and other necessary surgical supplies (*e.g.*, cautery)
Cardiothoracic Surgeons 1 and 2 (Fellow and Faculty)	
	Places roll under neck or hips to optimize vessel cannulation approach
	Opens all sterile ECMO trays
	Assigns CPR compressors with sterile gloves (2 people)
	Prepares surgical sites for cannulation
ECMO Specialist/Perfusion Specialist (2 people)	
	Call blood bank and requests blood products
	Assemble ECMO circuit, cannula, and activated clotting time machines
	Prepare ECMO circuit for initiation
	Assist surgeons with selecting cannula and connectors based on blood flow estimated based on weight and cardiac index desired
	Add medications and albumin to circuit only when cannulas are being inserted
	Double checks heparin patient bolus (50U/kg) dose with ICU physician faculty
	Blood primes circuit when indicated and if time to cannulation allows it
Respiratory Therapist (RT) 1	
	Responsible for airway and ventilator
	Continuous end tidal CO_2
	Prepares equipment for intubation if patient not yet intubated
	Runs arterial blood gas samples
Bedside RN 1	
	Ensures bedside set up complete
	Connects medication delivery vascular access line to patient
	Administers medications and fluids to patient
	Communicates clearly to Recorder person what and when medications are given
	Draws patient blood samples
	Completes electronic medical record documentation (vitals, medications, fluids)
Medication RN 1 and RN 2	
	Prepare medications and fluids
	Label and double checks all medications and fluids
Recorder 1 (RN or RT)	
	Positions self to oversee resuscitation, read monitor, hear ordering physician and confirm that medications and fluids have been administered by Bedside RN, using stool if necessary
	Keeps track of time of events
	Completes documentation of resuscitation and ensures record is signed
Social worker	
	Supports family

*Cannulations in the operating room or in the catheterization laboratory involve some adaptation to this general list.

Peripheral Cannulations

These are done either with an open surgical or a percutaneous technique or using a hybrid approach. The selection of anatomical sites is determined by the size of the vessel wanted for drainage and for return of blood. The right neck is the fastest anatomical site to cannulate in most children less than 20–40 kg (with normal anatomy) using the internal jugular vein as drainage and common carotid artery for the return. Femoral veins and arteries are to be used in older children and adult size adolescents. Neck cannulation may be associated with reduced mortality.[19] There is no data to inform which cannulation approach provides the best cardiopulmonary cerebral reperfusion.

Central Cannulation

Are used in patients who have undergone a recent sternotomy for cardiothoracic surgery. In these cases, the right atrium and aorta are cannulated directly. In these patients, the time interval necessary to achieve cannulation and target blood flows is usually faster.

Individualization Based on Patient's Physiology

Children with congenital heart disease may need their cannulation strategy individualized to optimize ECMO flow of cerebral and cardiac circulations. Suggestions of cannulation strategies for special circulations are illustrated for key anatomical situations in Figure 1A–H, and these include patients with single ventricle physiology, before and after stage I surgery, and then for Stage II, and after stage II.[36] Children who need a higher cardiac index may require larger cannulas or central cannulations (*e.g.*, septic shock physiology or calcium channel blocker-related toxidromes).

Vascular Patency

In children who have had vessels accessed previously, vessel integrity may be compromised or even ligated. Documentation of anticipatory vascular strategy planning in the event of a cardiopulmonary arrest is best suited to these patients as it prevents delays in connection to ECMO. This approach is similar to establishing airway plans for patients with known difficult airways.

Other Equipment

Sterile ready to use disposable equipment is necessary for ECPR. Carts that contain a wide range of cannulas and connectors that can be mobilized to the site of cannulation are useful. Sterile packs, suturing, preparation solutions, or surgical instruments for cannulation should also be readily available at the bedside. The individuals responsible for cannulations and supporting the procedure must be familiar with the carts and equipment to facilitate the prompt execution of efficient procedures.

Medications

Institutions should deliver heparin boluses before surgical cannulation based on local ECMO protocols. Antibiotic prophylaxis delivery is also similar to local ECMO cannulation protocols (which may be different for peripheral or open chest cannulation). If vascular access is not available during CPR measures, cannulation may begin before heparin or antibiotics are delivered. Intravascular heparin should be delivered as soon as possible to the patient. The intra-osseous route may be used as an alternative; however, there is no reported evidence on this practice.

Location of Cannulation

The patient, equipment, and team members involved in ECPR require a large amount of space. Either for IH or out-of-hospital initiations, most organizations use a space map to organize team members and equipment around the bed that anticipates the requirements of cannulation (*e.g.*, location of the cannulation and the ECMO machine and cart).

1. Each system should designate locations suitable and predefined for cannulation (*e.g.*, ICU or catheterization laboratory) and have a protocol to transport the patient to these locations with ongoing CPR.
2. Transporting a patient while undergoing active CPR is complex and may compromise the quality of CPR; however, completing cannulation and initiating proper post-cardiac arrest care (PCAC), should be orchestrated in the environment that will optimize patient outcomes.
3. Predefining the minimal size, footprint, and features of the location necessary to accommodate the proper performance of the team and the equipment (*e.g.*, ICU *vs* post-anesthesia area *vs* diagnostic imaging area) is necessary.

ECPR Protocols

Organizations committed to providing ECPR have a local written protocol, a list of roles, responsibilities, ordered tasks, individual, or shared checklists, a process flow diagram, in place to enhance performance and minimize disruptive variability. Multiple tasks are accomplished simultaneously by different groups of individuals (see Tables 2 and 3).

1. Protocols include general patient selection and launch criteria, location of cannulation if not in the location of the cardiac arrest, instructions for transport, and CPR measures.
2. ECPR protocol should specify the role responsible for the completion of tasks and the order of completion.
3. A flow diagram or algorithm may contain key steps and "time-out" pauses to verify safety checks.
4. A target duration of time between event start time and time to attain full ECMO flows is important to preset; an individual must be responsible for documentation and timekeeping during the resuscitation and cannulation.
5. Each institution should protocolize the options of "stay and play" to cannulate at the location of the arrest event or "pack up and CPR on the go" to transport to the cannulation location.

Once these are defined, internal process measures help review the efficacy of each ECPR performance. These serve to detect vulnerable areas in the algorithm (*e.g.*, decision making *vs* cannulation procedure *vs* priming) and understand delays that prolong time-to-cannulation. Prolonged times to attaining blood flow are associated with worse outcomes. For in-hospital cardiopulmonary arrests, some organizations aim to have processes in place to achieve target flows within 30 min or 40 min either by the return of extracorporeal circulation or spontaneous circulation. Understanding the process lag times and the intervals required to launch the ECPR team members and have them arrive at bedside (approximately 5 min), conduct the cannulation (approximately 15–20 min) while providing high-quality CPR, and preparing the circuit, helps the event manager during the procedure to direct care (ECPR launch decision and request by the 7th minute of CPR). These benchmarks are used for performance review, and for team and system training: these are never used as clock times to stop resuscitation measures.

Postcardiac Arrest Care following ECPR

PCAC in patients who receive ECPR begins immediately after the return of circulation and gas exchange has been established. The priority is to reach target ECMO flows to optimize end-organ perfusion and oxygen delivery.

1. Establish adequate ECMO flow by improved clinical perfusion and neurologic function, follow improvement and resolution of laboratory markers of ischemia (*e.g.*, metabolic acidosis or lactate), and restoration of urine output.
2. Wean inotropic support as much as tolerated to avoid increased left ventricular afterload.
3. TTM and potentially maintain patients with hypothermia (33–34°C) for 24–48 hours, post-arrest to optimize neurologic outcomes though no comparative evidence of improved survival.[37] TTM should not interfere with established ECMO care plans. Hyperthermia should be avoided. TTM defined by a responsible physician based on patient factors or institutional protocols need to be established. Random central or core temperature would not be an acceptable approach. Following cannulation, temperature management is ordered, including target temperature.

Diagnostic or Therapeutic Procedures

These include radiologic imaging and interventional cardiac catheterization. These should, be planned and safely undertaken without delay.

1. Left atrial (LA) decompression: Adequate coronary perfusion is a key target. Following cardiopulmonary arrest, heart and lungs will suffer from ischemia-reperfusion and children with signs of LA hypertension and pulmonary edema/hemorrhage may require emergent left ventricle decompression. This can be achieved directly in children with central cannulation or the catheterization laboratory by creating a communication between the right and left atria.
2. Risk of neurologic injury is greater with ECPR patients compared to ECMO patients. Neurologic assessment may include awakening with clinical assessment,

neuro-monitoring (cerebral oximetry, continuous EEG), neuroimaging [computed tomography (CT) or head ultrasound], and consultation with a neurologist. Neurologic assessment for future prognostication is beyond the scope of this chapter but is an integral part of ECPR PCAC.

Ethics and Informed Consent

Because of the rapid nature of ECPR deployment obtaining informed consent for ECPR may be impractical. Key points to remember:

1. In high-volume centers (cardiac, transplant, and surgical) information is given and consent secured at the time of the anesthesia or surgical consent which is often before a cardiopulmonary arrest event.
2. In organizations where ECPR is offered, oversight for informed consent processes is best aligned with approaches used for conventional CPR.
3. Patients eligible for ECMO or who may have consented to ECMO may not be suited for ECPR nor consent for ECPR. Patient variables and physiology related to cardiopulmonary arrest set elective ECMO and ECPR apart. These subtle differences are explained to guardians of children with complex conditions (*e.g.*, patients with severe pulmonary hypertension before a cardiac catheterization laboratory study) or listed for solid organ transplantation (*e.g.* heart or lung).
4. In unexpected ECPR events, parents or guardians (or surrogate decision-makers) should be informed soon after stable vital signs have been achieved.
5. Conversation around ECPR is best conducted on a frequent regular basis, which allows guardians to be aware of the changes in condition and prognostic information. These conversations about the child's status should include:
   a. Potential reasons for the anticipated cardiopulmonary arrest event,
   b. The time-limited purpose for extracorporeal support based on institutional bridging options,
   c. The care plan that involves the possibilities of survival, survival with morbidities, and of death,
   d. The prognostic information is based on patient-relevant data that may be available.

Key Elements Required to Improve Outcomes in ECPR

1. Patient selection.
2. Team organization.
3. High-quality CPR.
4. Measure and benchmark patient and process metrics.
5. Apply simulation for individuals and team practice.

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