Extracorporeal Life Support Organization (ELSO): 2020 Pediatric Respiratory ELSO Guideline

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Disclaimer: **This guideline describes prolonged extracorporeal life support (ECLS) and extracorporeal membrane oxygenation (ECMO), applicable to Pediatric respiratory failure. These guidelines describe useful and safe practice, prepared by ELSO and based on extensive experience and are considered consensus guidelines. These guidelines are not intended to define standard of care and are revised at regular intervals as new information, devices, medications, and techniques become available.**

PATIENT SELECTION

Indications (ELSO Red Book, 5th Edition Ch 19)[1]

Extracorporeal membrane oxygenation (ECMO) should be considered in patients in whom a reversible pathology is known or suspected, and in whom providing ECMO poses less risks than not providing extracorporeal support (Table 1).

Decisions should be made on an individual level based on knowledge of the patient's disease, institutional experience, expert consensus, and consultation.

ECMO support should be offered in all patients with acute severe respiratory failure who demonstrate progressive persistent failure despite optimized conventional therapies and maneuvers.[2]

ECMO should be considered when the risk of mortality reaches 50% and is strongly indicated when mortality risk approaches 80% with conventional therapy.[3] Earlier consideration may be indicated to minimize barotrauma and other morbidities from aggressive conventional therapies.

With the advent of lung protective ventilation strategies, the decision to offer ECMO may be made at an individual patient level in patients who have required 2 weeks or more of mechanical ventilation.

Contraindications (ELSO Red Book 5th Edition Ch 19)

Although there are few absolute contraindications, ECMO should not be employed when the patient has an overall poor prognosis or when there is high likelihood of survival with unacceptable disability (Table 2).

MODE OF SUPPORT

Rationale

Choosing between venovenous (V-V) and venoarterial (V-A) support in patient with respiratory failure may be challenging, and decisions should be made according to the support required to assure appropriate hemodynamic function at the time of cannulation.

If the patient requires minimal to modest inotropic/vasopressor support at the time of cannulation, it is always worthwhile to first-attempt V-V ECMO. Sometimes, providing adequate O_2 can improve hemodynamics such that V-A cannulation will not be required.

In some instances, there may initially be some hemodynamic instability warranting V-A ECMO. After initial clinical improvement, and if a long run is predicted given the underlying disease process, the patient may occasionally be converted to V-V ECMO.

Cannulation Variations

There are many ways in which to support a patient who requires ECMO for respiratory support and these vary according to local expertise, equipment availability, and patient properties. Some of the possibilities include:[4]

- V-V support with two site cannulation using single lumen catheters
- (dl)V-V support with one site cannulation using a double-lumen atrial catheter
- (dl)V-V support with one site cannulation and a double-lumen, bicaval catheter
- V-A support—venous drainage and arterial return
- VV-A (venovenous arterial) when an additional drainage cannula is required to support flows
- V-VA (venovenoarterial) where there is additional venous return either through a second venous cannula
- (dl)V-VA (veno-venoarterial) where there is additional venous return via the return limb of a dual-lumen venous cannula

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In ECMO centers that cannot access double-lumen cannulae, single-cannula two-vessel (femoral drainage and internal jugular return) V-V ECMO is appropriate. In small children, this may be more difficult as small femoral vessels may limit cannula size that prove inadequate to provide full ECMO support. On occasion, drainage from the jugular vein and return through the smaller femoral vein may provide better support.

V-V support may be challenging in small children because of body habitus variability resulting in challenges with bicaval catheter placement as one size does not fit all. Additionally, availability of dual lumen catheters is not universal to each ECMO center. As such, in patients where the femoral vessels cannot house cannulae large enough to fully support complete respiratory nor cardiorespiratory failure, V-A cannulation through the neck may be the most appropriate option. However, many centers have reported success in supporting these children with (dl) V-V and two cannulae ECMO techniques, therefore, the type and site of cannulation is a decision made on a case-by-case basis by the ECMO team and those performing the cannulation.

In older pediatric patients who require hemodynamic support, optimal ECMO support can be accomplished by the (dl) V-VA method: *i.e.*, *via* the femoral artery plus a dual lumen venous cannula in the internal jugular, or two-vessel venous cannulation of the internal jugular and femoral vein (V-VA support). This is usually considered in cases of severe refractory sepsis where upon return of myocardial function, the arterial cannula can be removed leaving the patient on V-V ECMO for the rest of the run.

- In V-VA support, as in femoral V-A ECMO, it is essential to ensure adequate oxygen delivery to the brain and heart. This should be undertaken by monitoring pulse oximetry placed on the right hand (or ear), if possible, near infrared spectroscopy (NIRS) monitor on the forehead, and *via* arterial blood gas analysis from a line in the right radial artery.
- The amount of flow from the femoral arterial cannula retrograde up the aorta in a VV-A approach will depend on native cardiac function. Upon the return of native cardiac function, competition will begin to be observed and the patient will be desaturated above the abdomen (Harlequin syndrome). To minimize differential cyanosis, the approach can be to change the proximal venous drain, which is in the jugular vein to an arterial return cannula making it V-VA. The additional return cannula in the superior vena cava (SVC) will ensure that oxygenated blood perfuses the upper body, notably the cerebral and coronary circulation. Differential cyanosis should be monitored for, with a right radial arterial line and NIRS when possible.

Cannulation (ELSO Red Book 5th Edition Ch 20)

Cannulation may be achieved by direct cut down, percutaneous cannulation or by Semi-Seldinger technique. A bolus of heparin (25–100 U/kg) should be given before cannula placement, even if the patient is coagulopathic or bleeding.

(dl)V-V access may be achieved with a double lumen catheter placed into the right atrium *via* the right internal jugular vein. Cannulation of the left internal jugular vein should only be undertaken with surgical expertise, as it carries a risk of SVC perforation.

The tip of a dual-lumen catheter will vary depending on manufacturer specifics.

Fluoroscopy or echocardiography are highly recommended when placing a bicaval dual-lumen cannula in children. This is to confirm placement of the wire within the inferior vena cava (IVC) and to ensure that it hasn't migrated into the hepatic vein, as it frequently does in young patients. When placing a bicaval dual-lumen catheter, a modified cut down approach might be used as it allows for placement of the needle into the internal jugular vein and to facilitate the placement of the guide wire into the IVC.

There are many considerations and challenges with selecting the appropriate mode, cannula size, and cannulation site in pediatrics. Some additional considerations should be given to the addition of a cephalad venous cannula for venous drainage from the head, the addition of lower limb perfusion cannula for adequate distal perfusion if femoral arterial cannulation is used, as well as the potential for reconstruction of the neck vessels after cannulation (Table 3).

Recirculation can be limited by using the femoral site for drainage and the right internal jugular vein site for reinfusion.

Circuit and Cannulae (see Separate Guideline)

When cannulating a pediatric patient for ECMO, the team should attempt to place the largest venous drainage and largest return cannula possible to be able to achieve adequate maximum flows.

Whenever possible, the team should choose cannulae that will provide complete respiratory support and meet metabolic demands, as monitored by SvO_2 and lactate.

MANAGEMENT DURING ECMO

Circuit Management (see Separate Guideline)

Patient management

A. Blood flow (ELSO Red Book 5th Edition Ch 4): During V-V ECMO, oxygenated blood from the pump is returned to the body where it is mixed with deoxygenated blood from systemic venous return. This results in a systemic arterial saturation of 75%–85%. As native lung function improves, the systemic arterial saturation increases.

During V-A ECMO, the proportion of infused oxygenated blood to native aortic blood is significantly higher, leading to a normal systemic arterial saturation, but the oxygenated blood may not be evenly distributed especially as native cardiac output returns leading to differential hypoxia (Table 4).

B. Gas exchange (ELSO Red Book 5th Edition Ch 4): At the initiation of ECMO, whether it be V-V or V-A, hypercarbia should be corrected slowly to avoid rapid changes in cerebral perfusion (*e.g.,* over 4–8 hours).

Carbon dioxide clearance is dependent on sweep gas flow.

Oxygenation is primarily determined by circuit blood flow rate, total cardiac output, and hemoglobin levels (Table 5).

C. Hemodynamics (ELSO Red Book 5th Edition Chapters 4, 13, and 22):

a. *Venovenous ECMO* V-V ECMO does not provide the patient with direct hemodynamic support, it will however provide improved conditions for ventricular function by providing well-oxygenated coronary artery blood flow. Therefore, vasoactive medications and infusions may be required to optimize cardiac output, blood pressure, and systemic vascular resistance.

SvO_2 may not be a reliable indicator of oxygen delivery due to recirculation in V-V ECMO.

Recirculation occurs when oxygenated blood returns directly to the ECMO circuit and not to the patient. This results in proportionally less oxygenated blood circulating to the patient. It is increased by higher circuit flow and lower cardiac output. Type and placement of cannulae affect recirculation as well. Recirculation may be higher in atrial double lumen or two-site single cannulation techniques.

Hypertension occurs frequently with V-V ECMO and may be seen due to the diversion of venous blood into the ECMO circuit resulting in low cardiac filling pressures.

In the event of a **cardiac arrest** during a V-V ECMO run, compressions should be initiated when possible, as per Pediatric Advanced Life Support (PALS) algorithms. Vasoactive support should be initiated early. The V-V circuit should continue running during the resuscitation to support gas exchange in lungs that will most likely not be adequately supported by conventional mechanical ventilation or bagging. Cardiopulmonary resuscitation, although necessary, puts the patient at risk for cannula displacement, vessel rupture, and air entrainment into the circuit. The priorities during a cardiac arrest while on V-V ECMO are: (1) appropriate resuscitation of the patient and (2) initiation of V-A ECMO support as soon as possible.

b. Venoarterial ECMO V-A ECMO provides hemodynamic support, and the amount of support depends on flow provided by the size of the cannulae native cardiac output and systemic vascular resistance.

Although the pulse pressure and mean arterial pressure may be lower than usual, systemic perfusion is usually adequate. Inotropes and vasopressors should be weaned in V-A ECMO if possible as the perfusion improves with ECMO support.

End-organ oxygen delivery is best assessed by mixed venous blood saturation, lactate, urine output, NIRS, and peripheral perfusion in V-A ECMO. Increasing pump flows may help achieve better perfusion and oxygen delivery in V-A ECMO, however, this may be at the expense of increased hemolysis.

If systemic oxygen delivery is inadequate, the pump flow should be increased based on the size of the cannula until perfusion is adequate. Extra blood or crystalloid to optimize cardiac preload and/or oxygen carrying capacity may be required to achieve end organ oxygen delivery.

In V-A ECMO, the loss of pulsatile flow may incur an increase in renin and angiotensin. Hypertension may also reflect fluid overload, pain, or agitation. Systemic vasodilators, diuretics, or sedation may all be used to treat hypertension depending on the etiology.

D. Ventilator management (ELSO Red Book 5th Edition Chapters 21 and 22): Regardless whether V-V or V-A ECMO is employed for primary respiratory failure, the goal should be lung rest *via* reduction of barotrauma/volutrauma and minimization of oxygen toxicity.

Typical rest settings should include low-normal peak inspiratory pressure (<25) and fraction of inspired oxygen <50%. Positive end-expiratory pressure should be between 5 and 15 cm H_2O and titrated to lung recruitment and distention of large airways to promote secretion clearance, whereas the patient remains unable to self-recruit. Low or no respiratory rates may be needed.

The use of lung recruitment maneuvers is controversial.[5]

Spontaneous breathing should be allowed, as this enhances recovery and lung rehabilitation.[5] However, strong spontaneous breathing can produce high transpulmonary pressures and result in patient self-inflicted lung injury (P-SILI).[6] Adjusting sweep as flow to improve ventilation may help.

Sweep gas should be adjusted to maintain the blood $PaCO_2$ at 40–45 mm Hg, or permissively higher in patients with chronic lung disease.[7]

If a pneumothorax develops, the ventilator settings can be further reduced at the risk of incurring atelectasis. Consideration should be given to manage the patient with CPAP only or no positive pressure. Due to the risk of bleeding, the decision to place a chest tube for a pneumothorax should be considered carefully by senior clinicians, with hemodynamic compromise being the only absolute indication for placement.

iNO may be considered in patients with severe right heart failure and pulmonary hypertension, to promote forward flow and ventilation/perfusion matching, although it is not typically needed during V-V ECMO runs. Positive end-expiratory pressure on ventilator rest settings should be optimized to minimize right heart strain and prostaglandins may be considered to maintain ductal patency in neonates.

Extubation while on ECMO is an option to consider as it allows for decreased sedation, improved neurologic assessments, and increased rehabilitation. However, this must be carefully considered in young children in whom it may be difficult to adequately clear secretions and in whom wakefulness must be weighed against the risk of cannula kinking and dislodgement.

E. Fluid management (ELSO Red Book 5th Edition Ch 22): The ultimate goal of management is to target dry weight.

Once hemodynamic stability is achieved, diuretics may be instituted, with the addition of hemofiltration if needed. If the patient has significant acute kidney injury, continuous hemofiltration may be added to the extracorporeal circuit to maintain fluid and electrolyte balance.

Early renal support with hemofiltration may aid in providing optimal nutritional and metabolic support, whilst ensuring fluid overload is avoided or reversed.

F. Sedation (ELSO Red Book 5th Edition Ch 22): The patient should be adequately sedated during cannulation and for the first 12 to 24 hours to avoid air embolism, minimize the metabolic rate, ensure cannulation sites are secure, and to reduce risk of cannula site bleeding.

It is rarely necessary to paralyze the patient except during cannula placement, or to achieve adequate venous drainage while other measures are enacted to enhance this.

Because sedation during V-V ECMO is often needed to tolerate endotracheal intubation, conversion to tracheostomy may be considered to minimize sedation and immobilization especially if a prolonged ECMO run is anticipated.

Sedation should be titrated to the patient's level of anxiety, discomfort and eventually, it should be titrated such that the patient is able to perform self-recruitment and interact synchronously with the ventilator.

Table 1. Common Conditions Requiring ECMO (*ELSO Red Book*, 5th Edition, Chapters 18 and 19)

Conditions for Respiratory ECLS:
Acute respiratory distress syndrome
Viral or bacterial pneumonia
Aspiration pneumonia
Status asthmaticus
Mediastinal masses
Pulmonary hemorrhage
Severe air leak
Bridge to transplant
Perioperative support to airway surgery
Temporary lung nonfunction (*e.g.*, extensive bronchoalveolar lavage)

ECMO, extracorporeal membrane oxygenation; ECLS, extracorporeal life support.

Sedation and analgesia should be held long enough to safely perform a neurologic exam daily, if possible.

Minimizing sedation will increase mobilization, promote spontaneous ventilation for pulmonary recruitment and lung recovery, and decrease withdrawal.[8,9]

G. Nutrition (ELSO Red Book 5th Edition Ch 22): Enteral feeding should be promoted to reduce the need for total parenteral nutrition.

Daily caloric goals should approximate those for critical illness.

Even if the gut is nonfunctional, the team should promote bowel health with an effective laxative regimen. A significant complication that is often the harbinger of impending clinical decline is gastrointestinal bleeding and feeding intolerance.

H. Infection (ELSO Red Book 5th Edition Ch 22): Routine circuit cultures and prophylactic antibiotics are not indicated, beyond treating an underlying infection.

The patient will be unable to mount a fever during ECMO due to circuit temperature control, therefore a high index of suspicion must be maintained.

I. Neurology (ELSO Red Book 5th Edition Chapters 14 and 22 and Neuromonitoring Guidelines): Routine head ultrasounds should be performed in neonates at ECMO initiation, and then daily or second-daily thereafter.

Daily neurologic assessments should be performed in patients while on ECMO. If there are any concerns for bleeding or infarct, computed tomography is indicated.

NIRS and EEG may also be used to monitor neurologic function, particularly in sedated patients.

J. Anticoagulation (ELSO Red Book 5th Edition Ch 7 and Anticoagulation Guidelines): Most children require a general algorithm with a customized approach for titration of heparin or direct thrombin inhibitors. Anticoagulation management, especially in neonates, can be challenging due to developmental differences in hemostasis, low pump flows, and high transfusion requirements.

Table 2. Relative Contraindications, Conditions With Poor Prognosis (*ELSO Red Book*, 5th Edition, Chapter 19)

Conditions rendering patient unlikely to benefit from ECLS:
Large intracranial bleed with mass effect or need for neurosurgical intervention
Hypoxic cardiac arrest without adequate CPR
Irreversible underlying cardiac or lung pathology (and not a transplant candidate)
Pulmonary hypertension and chronic lung disease
Chronic multiorgan dysfunction
Incurable malignancy
Allogenic bone marrow recipients with pulmonary infiltrates
Conditions with worse prognosis in respiratory ECLS:
Hepatic or renal failure
Pertussis infection in infants
Fungal pneumonia
Immunodeficiency
Relative contraindications:
Vessel anomalies or having previously been clipped or ligated for prior ECMO
Localized site infection

ECMO, extracorporeal membrane oxygenation; ECLS, extracorporeal life support; CPR, cardiopulmonary resuscitation.

Table 3. Cannulation Complications

Cannulation complications:
Cannula malposition
Bleeding
Vessel damage
Adjacent organ injury
Air embolism
Right atrial injury
Pericardial effusion

Table 4. Blood Flow Rate

	Oxygen Delivery	ECMO Blood Flow Rate
Neonates	6 ml/kg/min	100–150 ml/kg/min
Children	4-5 ml/kg/min	80–120 ml/kg/min

ECMO, extracorporeal membrane oxygenation.

WEANING OFF ECMO

Weaning V-V ECMO (ELSO Red Book 5th Edition Ch 24)

Improving compliance and radiographic appearance of the lungs are indications of recovery. Additionally, improvement in oxygenation and ventilation may be observed without changes to the circuit or ventilator.

When management is carried out using lowest blood flow to provide adequate support and low ventilator settings, weaning will occur naturally as patient improves. A trial off may be indicated sooner, in circumstances such as uncontrolled bleeding.

Although weaning, it is imperative not to oversedate the patient because of dyspnea. Providers must distinguish dyspnea and tachypnea without distress in an unbothered patient versus dyspnea with distress. The removal or depression of respiratory drive may hinder the ability to wean off ECMO

Table 5. Ventilation and Oxygenation

Factors that Determine Ventilation	Factors that Determine Oxygenation
Sweep gas flow rate	Membrane integrity (presence of clots)
Membrane properties and surface area	Blood flow rate
Inlet PCO_2	Membrane properties and surface area O_2 concentration

support. The provider may have to tolerate higher than normal range CO_2 given residual chronic lung disease while weaning, and the sweep gas may have to be adjusted to allow for higher CO_2 before the wean. During decannulation, some patients may not tolerate muscle paralysis as it may cause inadvertent hypercarbia and failure to wean off ECMO.

Trial off (ELSO Red Book 5th Edition Chapters 16 and 34)

When trialing off V-V support, adjust the ventilator to acceptable settings to test gas exchange independent of ECMO support. Maintain blood flow and anticoagulation, stop the sweep gas, and cap off the oxygenator.

Patient arterial blood gases, oxygen saturation, end-tidal CO_2, and clinical exam should be assessed for tolerance.

If lung function is adequate at safe ventilator settings for an hour or more, the patient may be ready for decannulation.

The patient may remain on the circuit without sweep gas or oxygen for up to 24–48 hours to ensure that the wean is tolerated in patients whose ability to maintain native gas exchange is questioned. It should be noted that this practice should be limited to few patients with very questionable trials off ECMO.

If there is no uncertainty about the need for further ECLS, it is best to remove the cannulae after the trial off has successfully finished.

Stopping ECMO for Nonrecovery, Nonbridging to Transplant (ELSO Red Book 5th Edition Ch 70)

ECMO should be discontinued when there is no hope for healthy survival (severe brain damage, no lung recovery, and no hope of organ transplant), as decided by the multidisciplinary team caring for the patient.

This possibility of stopping should be explained to the family when consent for ECMO is obtained. A reasonable deadline for organ recovery or replacement should be set early in the course.

For lung failure, patients may be supported for a prolonged period (days to months) awaiting recovery. The management of these patients often requires consultation with other ECMO centers that have had similar experiences.

Follow up (ELSO Red Book 5th Edition Chapters 19 and 22 and Neuromonitoring guidelines)

All ECMO survivors should be followed up regularly. Follow up with appropriate specialists is indicated for survivors who demonstrate chronic lung disease or significant kidney injury.

Neurodevelopmental abnormalities have been described in up to 50% of ECMO survivors.

Patients should have a thorough neurologic evaluation. Survivors require a follow-up plan that consists of regular patient assessments and should be screened for issues with behavior and school performance. They should be followed by a Pediatric Neurologist if they have any evidence of neurological abnormalities at discharge.[10]

Decannulation (ELSO Red Book 5th Edition Ch 12)

Decannulation should be performed by the surgical team that placed the cannulae, who may decide to reconstruct the vessels, while others may opt to ligate.

When removing a venous cannula, air can enter the venous blood through the side holes if the patient is breathing spontaneously. This is prevented by administering short-term pharmacological paralysis or by performing a Valsalva maneuver on the ventilator.

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