Extracorporeal Life Support Organization (ELSO): Guidelines for Neonatal Respiratory Failure

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I. INTRODUCTION

This guideline describes prolonged extracorporeal life support (ECLS), applicable to newborn infants with respiratory failure. These guidelines address technology and patient management during ECMO. Equally important issues such as personnel, training, credentialing, resources, follow-up, reporting, and quality assurance are addressed in other ELSO documents or are center-specific.

II. PATIENT SELECTION, MODES OF SUPPORT, AND TECHNICAL CONSIDERATIONS

Figure 1 lists indications, contraindications, and modes of support for Neonatal ECMO.

A. Cannulation

1. Methods. The decision for VA *versus* VV support for neonatal respiratory ECMO is dependent on the patient, surgeon, and center. Open cut down exposure for VA and VV cannulation and percutaneous VV cannulation are all reasonable options if performed safely with the proper expertise.

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Disclaimer: This guideline describes prolonged extracorporeal life support (ECLS) and extracorporeal membrane oxygenation (ECMO), applicable to Neonatal 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.

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2. Cannulation technique (ELSO Red Book, 5th edition, Ch 12).[1] In most situations, cannula selection occurs after cut down with direct inspection of the vessels. Some surgeons perform bedside ultrasound of the right neck vessels before cannulation to estimate the vessel size and guide selection. Some vasospasm can be expected, so a cannula with a diameter (size in Fr divided by 3.14) that is 80% of the diameter of the vessel can reliably be chosen.

Direct cut down cannulation. Cannulation is usually done in the ICU with full sterile preparation and an OR team. Which vessel to cannulate first depends on surgeon preference? Many prefer to cannulate the artery first as it can be deeper than the vein depending on neck position. Others argue that venous cannula should be inserted first as it is secured at 6–8 cm and the arterial cannula is inserted only 2–3 cm. Furthermore, given that the arterial cannula is clamped while the venous cannula is placed, there is an increased risk of developing an arterial clot, which would be more significant than a venous clot. Direct handling of the vessels is minimized as much as possible to avoid spasm. If the vessels are very small, if there is difficulty with cannulation, or if spasm occurs, then fine stay sutures placed in the proximal edge of the vessel are very helpful. Chest x-ray should be obtained to verify venous cannula tip location in either the right atrium or in the IVC for a bicaval dual-lumen cannula. Echocardiography (ECHO) can also be used to assess position of the cannula tip, particularly during dual-lumen cannula placement. Femoral cannulation is not appropriate for neonates.

Percutaneous cannulation. Some centers have employed percutaneous cannulation techniques for VV ECMO in neonates. This can be accomplished through ultrasound-guided right jugular vein access and gradual dilation of the vessel over a wire using the Seldinger technique. ECHO and/or fluoroscopy should be used to assure safe positioning of the wire during dilation and ultimate placement of the cannula tip to avoid vascular and cardiac injury.

3. Venous drainage. In most cases, there is no need for further venous drainage as suitably sized cannulae will give adequate support. If venous drainage is inadequate, a separate drainage cannula may be required. The cephalic end of the jugular vein is the most common location. If possible, a 10 Fr or 12 Fr arterial cannula with a distal hole should be used for the cephalic drain, as an 8 Fr cannula will likely thrombose.

Some centers routinely place a cephalad venous cannula, but this is an institutional preference and is not normally required. The femoral veins are usually insufficiently sized and should not be accessed in neonates. Central cannulation could be considered for inadequate venous drainage.

B. Pump Selection (ELSO Red Book Ch 5)[1]

There is variation among centers regarding the use of roller *versus* centrifugal pumps for neonates. Roller pumps control flow precisely in infants, but have the risk of circuit rupture. Centrifugal pumps avoid blowout, but are less precise and can cause hemolysis. Many centers have made the transition from roller pumps to centrifugal models, whereas other centers continue to use roller pumps because of the risk for hemolysis with centrifugal pumps. Hemolysis has been associated with neurologic injury, kidney injury, and higher mortality. Rigorous data regarding choice of pump type in neonates are lacking, so pump choice is based on expertise and preference of each center.[2–5]

C. Oxygentor Selection

Rated flow should be over 500 ml/min (see ELSO Red Book Ch 5).[1]

III. MANAGEMENT DURING ECLS

Figure 2 outlines blood flow during neonatal ECMO.

A. Oxygenation

Oxygenation of the tissues is affected by blood flow, hemoglobin, and oxygen saturation. Oxygen delivery should be at least three times oxygen consumption (6 ml O_2/kg/min for neonates). Support is typically initiated with a sweep gas of 100% FiO_2. In VA ECMO, SvO_2 is an excellent indicator of adequate end organ oxygen delivery, with a goal of 65–80%. SvO_2 can be used as a trend in VV ECMO. Because of the negative effects of hyperoxia, if the patient's arterial PaO_2 is found to be over 100 mm Hg, the circuit flow or sweep gas FiO_2 should be adjusted accordingly.

B. CO_2 Clearance

CO_2 clearance is controlled by the sweep gas flow rate. CO_2 transfer across the membrane lung is very efficient and will exceed oxygen transfer. Blood gas values must be assessed soon after initiating flow to avoid hypocarbia. Sweep gas flow rates are initially set equal to blood flow and adjusted to keep the patient's $PaCO_2$ 40–45 mm Hg.

C. Anticoagulation (ELSO Red Bood Ch 7)[1]

Anticoagulation is achieved with heparin or a direct thrombin inhibitor (DTI). In neonates, the most common anticoagulant is heparin, but some centers have started to use DTIs. However, experience with DTIs is limited in this patient population. As with other patient groups, there is no consensus or ELSO recommendation regarding best anticoagulation practice for neonatal respiratory ECMO patients, and there is no ideal choice for anticoagulation.

1. **Table 1** outlines anticoagulation monitoring.
2. Anticoagulants

3. Heparin (unfractionated heparin or UNFH) is given as a bolus (50–100 units/kg) to the patient at the time of cannulation, followed by a continuous infusion. Given that premature infants are at higher risk for IVH, the cannulation bolus dose is often 50 units/kg.

The neonatal ECMO circuit prime is generally anticoagulated with 100 units of heparin per unit of packed red blood cells (PRBCs) for the neonatal circuits with 1⁄4 inch tubing. UNFH infusion rates in neonates on ECMO usually start at 25–30 units/kg/hr. Neonates may require higher doses of UFH due to their low plasma concentrations of ATIII. Note: Heparin-induced Thrombocytopenia (HITT) is extremely rare in neonates.

Direct thrombin inhibitors (DTIs) include **argatroban** and **bivalirudin**. They do not require ATIII for action and unlike heparin, DTIs can inhibit clot-bound thrombin, which may be an advantage. DTI dose is titrated by PTT (1.5–2 times normal) or ACT. It may be difficult to monitor the effect of DTIs on anticoagulation if the patient has an abnormal PTT level before initiating ECMO. Furthermore, the PTT level tends to plateau over time, resulting in potentially unreliable levels.

D. Patient Management (ELSO Red Book Ch 14)[1]

1. Hemodynamics during **VV support**. Patients are dependent on their own cardiac output to maintain hemodynamic status. Appropriate medications and infusions are used to control cardiac output, blood pressure, and vascular resistance. Patients on inotropic support before ECMO will typically wean substantially after being placed on ECMO despite a lack of direct blood pressure support from the ECMO circuit.

During **VA support**, hemodynamics are controlled by the blood flow (pump flow plus native cardiac output) and vascular resistance. Because the pulse pressure is low, the mean systemic arterial pressure will be somewhat lower than normal. In addition, patients placed on ECMO for cardiac support are typically on significant inotropes before ECMO initiation. As these drugs are titrated down, resistance decreases and systemic pressure falls proportionately. If the systemic perfusion pressure is inadequate (low urine output and poor perfusion), pressure can be increased by increasing pump flow, transfusing blood products, and/or titrating vasopressor infusions. Systemic vasodilatation requiring pressors is common in patients in septic shock.

Systemic perfusion is best measured by mixed venous blood saturation (SvO_2). In VV ECMO, the SvO_2 value measured from the ECMO circuit is not accurate due to recirculation. Some centers choose to obtain an accurate measure by turning off the flow for 30 seconds, then measuring SvO_2 over the next 10 seconds. If the patient has a cephalad cannula, some centers may also place a separate saturation probe on the cephalad cannula to continuously monitor cerebral SvO_2. Assuming a SaO_2 more than 95% and a SvO_2 greater than 65% indicates adequate systemic oxygen delivery, even though the pressure may be low. If systemic oxygen delivery is not adequate (SvO_2 less than 65%), pump flow can be increased until perfusion is adequate. If extra blood volume is required to gain extra flow, blood products and crystalloid solution can be considered. In VA ECMO, increasing ECMO flow will result in increased oxygen delivery to the systemic circulation.

In the case of **VV ECMO**, flow changes are less straightforward, as recirculation (newly oxygenated blood just delivered into the patient and taken back into the drainage lumen) can occur. Recirculation is dependent on cannula position, patient volume status (right atrial dimensions), native cardiac function,

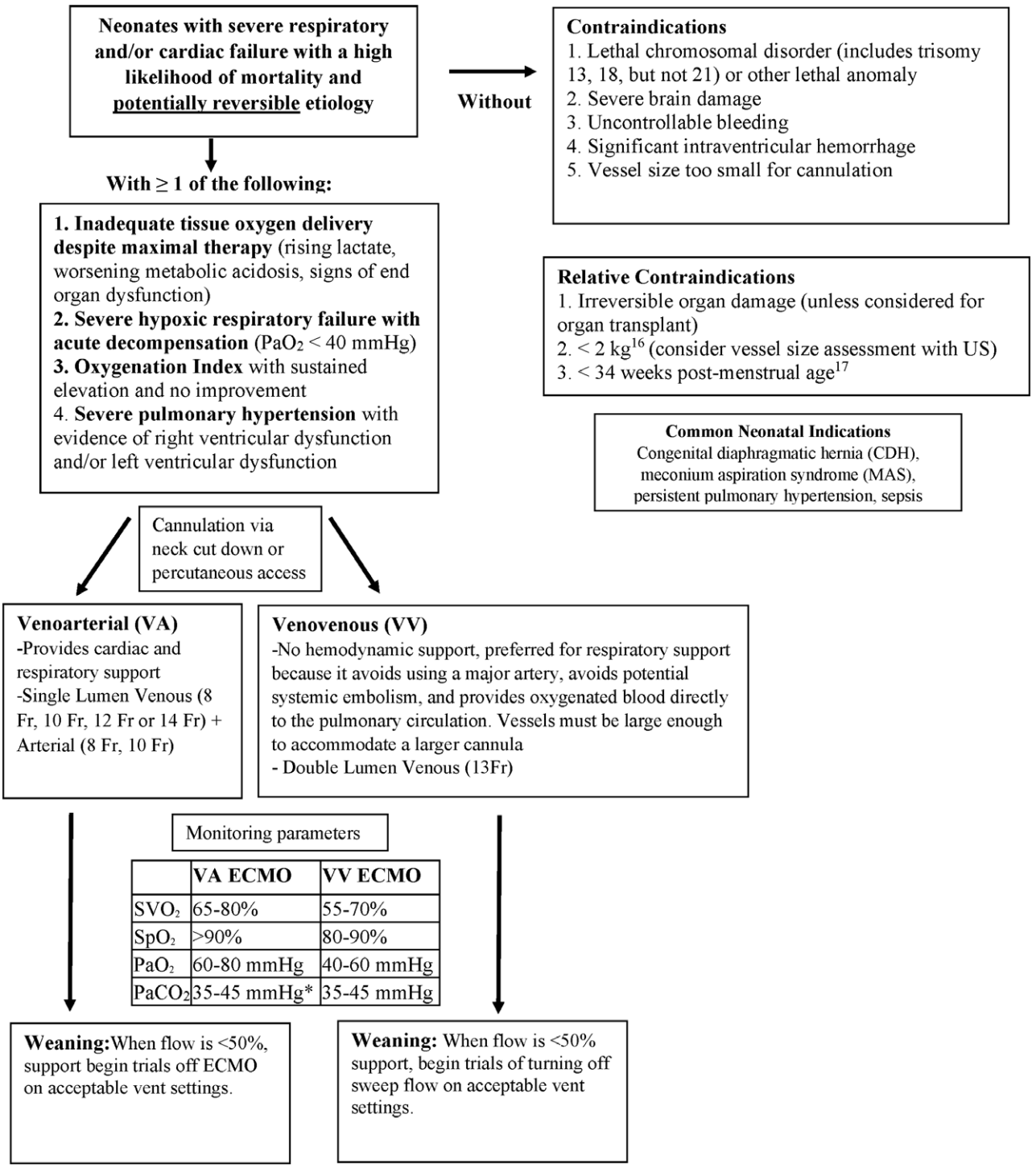

Figure 1. Indications, contraindications, and modes of support.

and flow rates, and it should be considered whether increasing ECMO flow does not result in a higher patient saturation. Elevated circuit flow may worsen the phenomenon of recirculation and is evidenced by decreased peripheral SpO_2 and increased SVO_2. In this scenario, a CXR or echocardiogram should be obtained to evaluate the cannula position. Potential treatments for recirculation include sedation, patient repositioning, cannula adjustment, volume administration, and decreasing circuit flow.

2. Ventilator management (Red Book Ch 14)[1] Figure 3 shows ventilator management and gas exchange while on neonatal ECMO.

3. Fluid management: blood volume and fluid balance The ECMO circuit for neonates is primed with red blood cells, which will equilibrate with the native blood volume during the first several minutes. The goal of fluid management is to return the extracellular fluid volume to normal (dry weight). During the acute inflammatory stage early in ECLS, capillary leak may occur

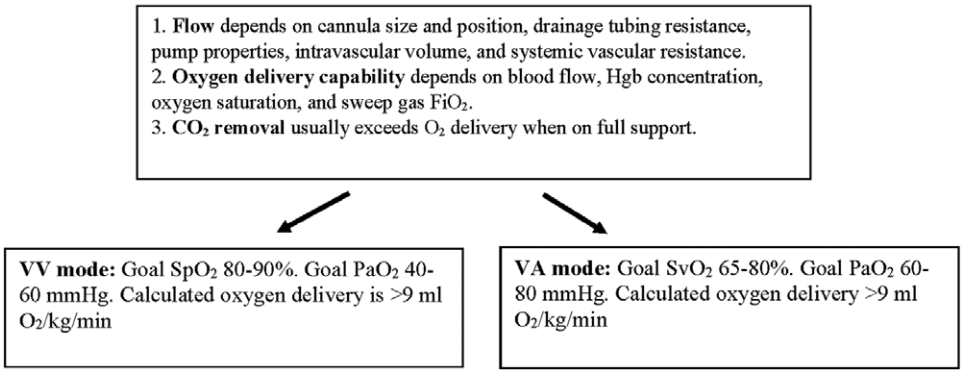

Figure 2. Blood flow for neonatal ECMO.

and is exacerbated by excessive crystalloid infusion. When the patient is hemodynamically stable (typically 24–48 hours), ultrafitration, continuous renal replacement therapy (CRRT), and/or diuretics may be used to manage fluid status. Diuretics are often delivered as an infusion to avoid anticoagulation instability. If the diuretic response is not sufficient, SCUF (slow continuous ultrafiltration) or CRRT can be used to remove fluid. If renal failure occurs for any reason, it may be treated with CRRT.

4. Sedation Minimal sedation is the overall goal. Neonates are initially managed on intermittent dosing of narcotics, but most will require continuous infusions. Given concern for adverse neurologic effects, benzodiazepine use should be minimized. Dexmedetomidine may be considered as a sedation adjunct. Muscle relaxants are given during cannulation, decannulation, and circuit changes because of the risk of air embolism. Some institutions hold sedation and analgesia for a neurologic examination (a daily drug holiday).

5. Nutrition management Neonates may have significant catabolism and weight loss while on ECMO, but they are not typically fully enterally fed. Trophic feeds should be encouraged and advanced slowly as tolerated. Parenteral nutrition should be started within 24 hours of ECMO with a goal of providing approximately 80–120 kcal/kg/day. Some centers choose to pursue fluid restriction to limit fluid overload, so

Table 1. Anticoagulation Monitoring

Unit of Measurement	Definition	Normal Range/Goal	Factors Affecting Levels
Activated clotting time (ACT)	Time (in seconds) in which whole blood clots in response to a fibrin activating reagent	Different upper limits of normal (120–140 seconds for most systems). Goal ACT levels are usually 1.5 times normal for the ACT measurement system	Heparin, coagulation factors, platelet level, infection, and temperature
Partial thromboplastin time (PTT)	Time in seconds in which plasma clots in response to a fibrin activation reagent	Normal range is age-related, and neonates have higher values. Goal is 1.5 times normal	Heparin, coagulation factors, and AT3 levels. If FVIII is elevated, PTT can underestimate anticoagulation
Anti-Xa assay in plasma	Measures the anticoagulant effect of the heparin-AT3 complex or the heparin concentration, depending on the assay	Anti-Xa levels of 0.3-0.7 IU/mL are recommended. Neonates have decreased concentration of clotting factors and decreased thrombin levels	Hyperlipidemia, hemolysis, and hyperbilirubinemia. Some laboratories add exogenous ATIII to anti-Xa assays, which can impact results, especially in neonates who have low endogenous AT III levels
Thromboelastography (TEG)	Measures the time for whole blood to form a clot, the density/strength of the clot, and clot lysis over 30 minutes	Measured with and without heparin effect	May be useful to distinguish between an underlying coagulopathy, surgical bleeding, and bleeding from heparin effect
Antithrombin (AT3)	Inhibits coagulation when combined with heparin	Normal range is 80–120% of control. Low plasma concentrations (~60% of adult values) are physiologically normal in neonates. Low AT3 levels can be treated by giving fresh frozen plasma or recombinant AT3	Low AT3 leads to heparin resistance and thrombosis
Thrombocytopenia	Low platelet count (<150,000) is common during ECMO due to binding on circuit surfaces	50,000–100,000 depending on ECMO center preference	
Fibrinogen	Soluble protein in plasma, from which fibrin is produced by the enzyme thrombin	Maintained >100 mg/dL routine and >150 mg/dL in bleeding patient by transfusion of fresh frozen plasma or cryoprecipitate	Can become depleted in the presence of circuit clots

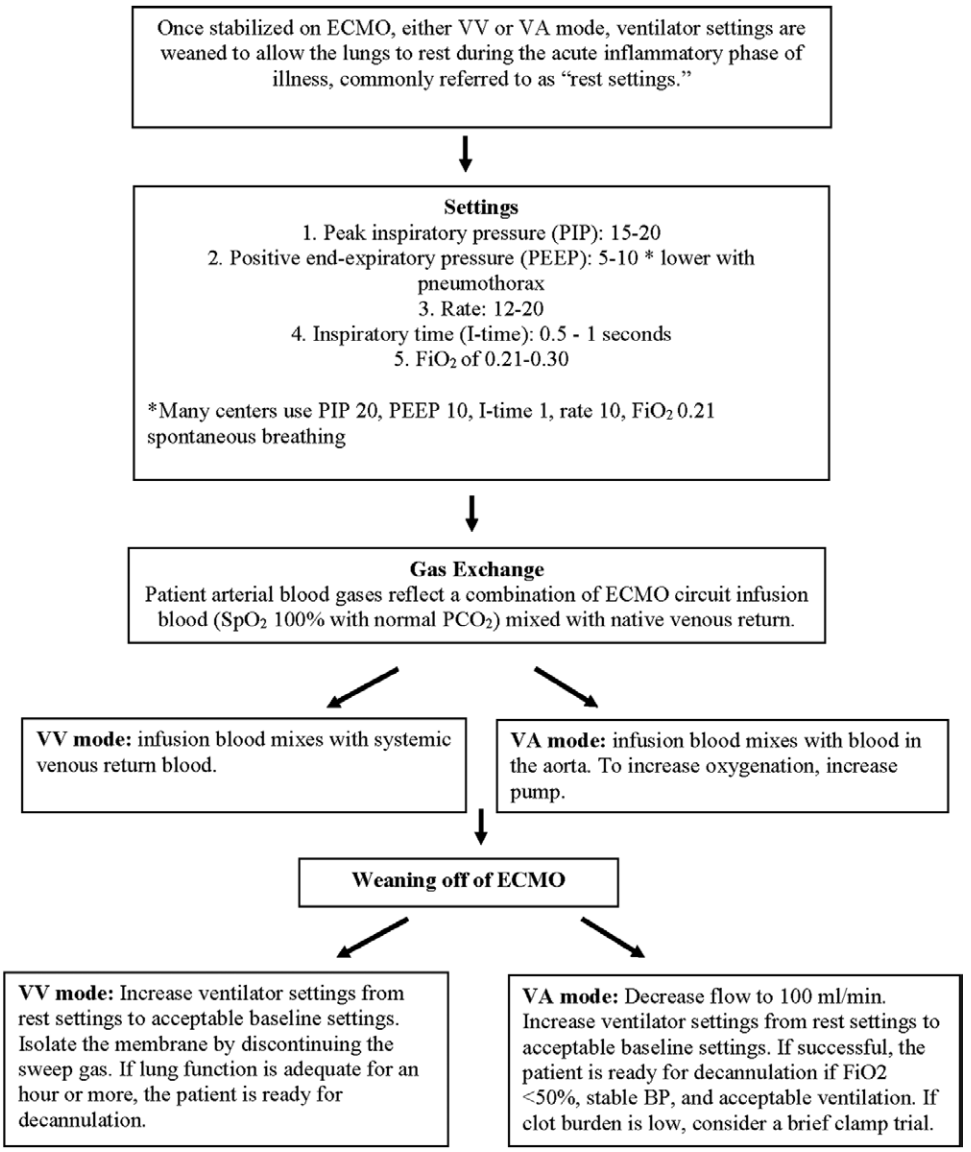

Figure 3. Ventilator management on ECMO.

calorie intake should be maximized in light of fluid restrictions. Alternatively, early initiation of CRRT to control fluid balance has been shown to improve protein delivery.[6] Some institutions run lipids through a peripheral intravenous line to avoid lipid precipitation and thrombosis in the circuit.

6. Temperature The desired blood temperature within an ECMO circuit matches the normal average body temperature (typically 37°C). This temperature is a set point on the water bath of the heat exchanger. If there is a concern for hypoxic ischemic encephalopathy (HIE) and there is a desire to maintain mild hypothermia (33–34°C) during the first 24–72 hours, it is possible to decrease the water bath temperature. Case series show an increased risk of intracranial hemorrhage (ICH) for HIE patients on ECMO, but available evidence suggests this is from the ischemic injury combined with heparinization and not clearly worsened by hypothermia.[7] Thus, many centers perform standard of care cooling for these patients. However, there is no benefit in initiating cooling after starting ECMO support if the patient has not been cooled pre-ECMO in a setting where HIE is a concern.[8] Hyperthermia (from fever or inflammation) may be masked due to the water bath set point. Therefore, it is advantageous to closely assess for infection using laboratory values (WBC, CBC shifts, acidosis, and blood cultures) to avoid hypermetabolism and recognize potential infection.

7. Infection and antibiotics There is no standard policy regarding prophylactic antibiotics or surveillance blood cultures during ECMO support. There is, however, no data to support prophylactic antibiotic use in neonatal ECMO, and antibiotics should be reserved for suspected or proven infection. Bacteremia during ECMO may be related to bacterial growth on a component of the circuit, but is usually related to another source in the patient. Unlike suspected "line sepsis" in the usual critically ill patient, it is often not possible to change ECMO cannulas. Changing the circuit should be considered if cultures remain positive while on antibiotics, although there are limited data on this practice.

8. Procedures Procedures on ECMO require special consideration for hemostasis in anticoagulated patients. The heparin

infusion is often decreased, platelet levels are increased to >80–100,000/mm^3, and fibrinogen to >150 mg/dL. Surgical procedures on ECMO may also benefit from an antifibrinolytic therapy, that is, aminocaproic acid (amicar). Anticoagulation may be discontinued 1 hour before and during invasive procedures and restarted after the risk of rebleeding has decreased. If bleeding persists post-procedure despite decreased heparin and product replacement, it is reasonable to stop anticoagulation until the bleeding stops. This may stop the bleeding, but may also result in clotting in the circuit. Therefore, active surveillance of the circuit is important, particularly in neonatal circuits with relatively low flow.

9. Neuroimaging Head ultrasound (HUS) is an essential neuroimaging technique in neonates. A common HUS imaging protocol includes obtaining a baseline pre-ECMO ultrasound followed by a daily monitoring HUS for the first 3–5 days of cannulation, the period during which the incidence of ICH is highest.[9,10] HUS is then done at variable intervals for the duration of the ECMO run. Additional ultrasounds should be obtained based upon clinical indications, such as new onset seizures, sudden drop in hemoglobin, or other clinical concerns.

Head computed tomography (HCT) has been used for follow-up of abnormal ultrasounds for emergent evaluation that would impact immediate survival or continued ECMO candidacy. However, head CT is not sensitive or specific for gray and white matter injury.

Magnetic resonance imaging (MRI) is the gold standard for detection of intracranial injury and pathology, in particular stroke and white matter injury. MRI cannot logistically be performed on ECMO. However, MRI with contrast can be done after ECMO support or before discharge. Some centers report improved visualization of the white matter with 1 mm cuts.

10. Neuromonitoring Electroencephalogram (EEG or aEEG). Critically ill infants are at high risk for seizures, and the majority of seizures tend to be electrographic only.[11,12] The incidence of seizures for neonates on ECMO varies between 5% and 30%. Treating seizures is typically accomplished in a multidisciplinary approach using antiepileptics at the direction of the Neurology service. Please refer to the Neuromonitoring guideline for additional information.

IV. COMPLICATIONS OF NEONATAL ECMO (ELSO Red Book Ch 17)[1]

Management of Common Complications (**Table 2**)

A. Air in the Circuit Requires Immediate Response, Especially on VA ECMO

1. Stop the blood pump and clamp the arterial (infusion) line.
2. If possible, restart blood flow through a bridge line to shunt the air to the venous portion of the circuit.
3. Examine the circuit for air and identify the source of air introduction.
4. Remove any residual air and repair or replace the source of the entrainment. Potential causes should be examined from the venous cannula and progress through the entire circuit, looking for loose tubing connections, stopcocks and/or air in infusion lines preoxygenator.
5. Much of this type of air intrusion is trapped by the oxygenator. Once visible air is extracted from the circuit, circulate

Table 2. Complications of Neonatal ECMO

Hemolysis	Bleeding	Clotting
Hemolysis: **free hemoglobin in the blood plasma in concentrations exceeding > 50 mg/dl (normal <10 mg/dl).**	**Bleeding** at the ECMO cannula site, surgical site bleeding, and CNS hemorrhage rates have shown an increased frequency since 2000.	**Clots** in the circuit (oxygenator, bridge, bladder, hemofilter, or other) are the most common mechanical complications. More common with respiratory than cardiac ECMO runs.
Suspect **hemolysis if the urine is dark and urinalysis shows large blood, but no red cells.**	**Bleeding into the head or brain parenchyma** is the most serious ECMO complication. It can be extensive and fatal. **See management below.**	**Detection** requires careful visual examination of the circuit using a strong light source.
Verify **hemolysis with an elevated plasma hemoglobin level. There may also be increased conjugated bilirubin, anemia, and increased haptoglobin.**	**Bleeding post chest tube placement** is a common complication even if all appropriate steps are taken during tube placement. It may occur early or after several days. **See management below.**	**Clots are dark** (red, brown, black) non-moving areas seen on the circuit, typically in areas of alterations in flow (reservoir, oxygenator, and connectors). Small preoxygenator clots may not require intervention other than continuing observation and monitoring.
Higher plasma hemoglobin **can be caused by negative pressure generated by centrifugal pumps, partial circuit or component thrombosis, malocclusion of the roller pump, high shear stresses related to turbulent flow, and chattering of the venous lines.**	**Mucous membranes:** bleeding from the nasopharynx, mouth, trachea, rectum, or bladder commonly occurs with patient care. Patients should not have rectal temperatures, rectal suppositories, or receive intramuscular medications. Bladder catheterizations should be avoided if possible.	**Light-colored thrombi** (white, cream) consisting of platelets and fibrin, are often observed in areas of turbulent flow such as at tubing/connector ends. Typically, no intervention is required unless a significant change is observed in color, size, or mobility causing concern for dislodgement.
Hemolysis **results in increased free circulating hemoglobin that causes nephrotoxicity, increased vascular resistance, increased thrombin generation, platelet dysfunction, and clotting disorders.**	**GI bleeding** can occur from gastritis from sump placement/local irritation. Acid suppression medication is often adequate, although gastric lavage with saline may be indicated to evaluate for ongoing bleeding. Topical agents such as Carafate and Mylanta should be avoided due to an unacceptably high aluminum content.	**Intervention** ranges from isolated component changes *vs.* consideration to change the entire circuit.

Table 3. Neonatal Considerations

Condition	Considerations	ECMO Survival
PPHN (Persistent Pulmonary Hypertension of the Newborn)	**PPHN** may be secondary to **MAS, sepsis, and pneumonia.** In this setting, the vasculature is vasoconstricted, but normally formed. In other cases, the lung parenchyma may be normal or hypoplastic, with the pulmonary vasculature remodeled. This can be seen in **premature closure of the ductus, CDH, omphalocele and gastroschisis,** and **exposure to certain maternal medications**, *i.e.*, SSRIs, aspirin, indomethacin. This can also be part of genetic syndromes, such as **alveolar capillary dysplasia, surfactant protein B or ABCA3 deficiency, and Fryns syndrome**. It is common to see severe hypoxemia in the setting of relatively normal ventilation.	73%[14]
Meconium aspiration (MAS)	**Meconium** can reduce the antibacterial activity of the amniotic fluid and **increase the risk of perinatal infection**. Aspiration can also **induce hypoxia** secondary to airway obstruction, surfactant dysfunction, chemical pneumonitis, and pulmonary hypertension. VV ECMO is most commonly used.	92%[14]
Neonatal sepsis/ pneumonia	The most common organisms are group B beta hemolytic streptococcus (**GBS) or gram-negative organisms.**	45% sepsis, 60% pneumonia[14]
Cardiac Diagnoses	**Congenital heart disease, myocarditis, cardiomyopathy, intractable arrhythmias** with hemodynamic compromise, **pulmonary hypertension**, and **unique ventricular circulation** can all be indications for neonatal ECMO. Cardiac diagnoses discussed in a separate guideline.	35–45%[24]
PPHN associated with Hypoxic ischemic encephalopathy (HIE)	Patients with **HIE** are **at risk for abnormal pulmonary vasorelaxation and pulmonary hypertension**. Whole body cooling (WBC) is standard of care for these infants, but the effect of cooling in patients with HIE who also require ECMO is not definitively known.	80%[20]
Prematurity	**Premature infants are at increased risk of ECMO related morbidity and mortality**. Historically, <34 weeks gestational age was a contraindication to ECMO. However, newer studies have shown that although the rates of survival and cerebral infarction are worse at 29–33 weeks gestational age, the differences are modest and clinically acceptable.[16,17]	~50%[16,17]
Trisomy 21	Neonates with **trisomy 21 (T21)** deserve special mention, as they are **over-represented in cases of severe pulmonary hypertension and the need for ECMO**. 2.3% of neonates with T21 admitted to children's hospitals receive ECMO, and this is especially common in those with concomitant cardiac diagnoses.[18]	50–66%[18,21]
Congenital diaphragmatic hernia (CDH)	Infants born with **CDH often have life threatening cardiorespiratory failure in the first weeks of life** and account for the most common indication for neonatal ECMO utilization. Survival may improve with cardiopulmonary support as pulmonary vascular reactivity and pulmonary hypertension will often improve over the first few weeks of life. Clinical management is complex and presents unique challenges including approach and timing of surgical repair and management of pulmonary hypertension in the presence of persistent fetal shunts. Refer to the CDH guidelines for further information.	~50%[14]
Gastrointestinal Diagnoses	Patients with **omphalocele and gastroschisis can develop PPHN related to lung hypoplasia**.	51% gastroschisis, 18% omphalocele[19]
Renal Disease	**Urinary obstruction** (*e.g.*, posterior urethral valves), renal dysplasia, and vesicoureteral reflux	42%[22]
ECPR	Extracorporeal cardiopulmonary resuscitation (ECPR) is the initiation of ECMO, including cannula placement, during ongoing CPR, so that the ECMO flow itself becomes part of the resuscitation. By necessity, patients are placed on VA ECMO. More common in cardiac patients.	40–50%[14]
EXIT to ECMO	EXIT (ex utero intrapartum treatment) may be performed for prenatally diagnosed cases of pulmonary hypoplasia (CDH, thoracic masses) with immediate placement of cannulae and initiation of ECMO support before the cord is clamped and the infant is separated from placental bypass. The conceptual advantage is avoidance of clinical instability, hypoxia, and acidosis that occur and may worsen pulmonary hypertension.	~64%[23]

flow through the bridge, examine the circuit reaccumulation, and resume support when corrected.

B. Bleeding into the Head or Brain Parenchyma

1. **Stable neonates**: Head ultrasounds (HUS) should be performed every 24 hours for at least the first 3–5 days and then per institution protocol.
2. **HUS shows bleed**: CT scan may provide additional information on severity and progression of hemorrhage.
3. **For a small bleed**: coagulation status will need to be optimized and HUS repeated frequently to detect any extension.
4. **For extending bleeds or bleeds that are moderate:** measures to optimize cardiorespiratory support should be undertaken to allow the patient to be weaned from ECMO.
5. **For severe intraparenchymal hemorrhage**: withdrawal of ECLS may be indicated.

C. Bleeding Post Chest Tube Placement

1. Accumulated blood should be evacuated by a posterior tube, as evacuation quantifies the rate of bleeding and decreases the risk of a hemothorax and later clot.
2. A CT scan may be indicated to determine if the tube is in the lung parenchyma. If it is, then the tube should be removed, but thoracotomy will probably be needed to control the bleeding and air leak.
3. If less invasive measures do not stop the bleeding, thoracotomy is indicated to find and control the source.

V. WEANING OFF ECLS AND DECANNULATION

Figure 3 outlines ventilator management and weaning off of ECMO.

A. Decannulation

Cannulas placed by direct cutdown are removed by direct cutdown. The cannulas are removed, and the vessels are often ligated. Neck vessel reconstruction at the time of decannulation is done at the discretion of particular surgeons and centers, but there is no consensus on its utility.[13] A percutaneously placed cannula is easily removed, and hemostasis is obtained by holding pressure over the area until the skin is sutured. No further pressure will be required once the skin is closed. Long-term patency of these vessels can be expected.

B. Stopping Support for Futility (Nonreversibility)

ECMO should be stopped if the disease process is nonreversible. This could include severe brain injury, diagnosis of an irreversible process, or organ failure with no possibility of transplant. During the consent process before placing a patient on ECMO, it should be made clear that continuation of ECMO will be reassessed frequently and that ECMO may be discontinued if the patient has not shown any improvement in a reasonable amount of time. The definition of a reasonable amount of time is patient and diagnosis dependent.

VI: EXPECTED RESULTS

The overall survival to hospital discharge is 73% for patients treated with ECMO for neonatal respiratory disease. The overall survival rate to decannulation from ECMO support is slightly higher at 83%. The average ECMO run times have increased during the last 15 years to slightly more than 200 hours per ECMO run, as compared with approximately 150 hours in the 1990s.[14] Longer ECMO runs and lower survival suggests that ECMO is being increasingly utilized as a therapy for more critically ill patients with more associated comorbidities.[15]

VII: NEONATAL CONSIDERATIONS

Table 3 outlines Neonatal Considerations for ECMO.

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