Extracorporeal Life Support Organization (ELSO)

Patient Specific Supplements to the ELSO General Guidelines

Introduction

This guideline is a supplement to ELSO's "General Guidelines for all ECLS Cases" which describes prolonged extracorporeal life support (ECLS, ECMO). This supplement addresses specific discussion for categories of patients and follows the same outline as the general guidelines.

This guideline describes prolonged extracorporeal life support (ECLS, ECMO). These guidelines describes useful and safe practice, but these are not necessarily consensus recommendations. These guidelines are not intended as a standard of care, and are revised at regular intervals as new information, devices, medications, and techniques become available.

The background, rationale, and references for these guidelines are found in "ECMO: Extracorporeal Cardiopulmonary Support in Intensive Care (The Red Book)" published by ELSO. These guidelines address technology and patient management during ECLS. 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.

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Neonatal Respiratory ECLS Cases:

I. Patient Condition

A. Indications:

Oxygenation Index: $\frac{\text{Mean airway P x FiO2}}{\text{Post ductal PaO2}} \times 100$

. OI= 20 consider ECLS, OI=40, ECLS indicated

B. Contraindications:

Contraindications for Neonatal Respiratory ECLS are 1.lethal chromosomal disorder, 2.irreversible brain damage, and 3.grade III or greater IVH. Relative contraindications include 1.irreversible organ damage (unless considered for organ transplant), 2. <2 Kg[1], and 3. <34 weeks post-menstrual age because of the increased incidence of increased intracranial hemorrhage.[2] A forth relative contraindication is in patients with disease states with a high probability of a poor prognosis. When there is concern to the appropriateness of ECLS, the specific issues should be discussed with the relevant medical subspecialists prior to cannulation. This allows an in-depth discussion as to the risks of the procedure (including the risk of using valuable resources which could be used for others) vs. the potential benefits. There will, however, be situations where time does not allow for a complete evaluation of the full prognosis. In these cases, discussions should occur shortly after cannulation. If ECLS support is not in the patient's best interest, it should be discontinued.

III. Vascular Access

Vascular access is achieved by cannulation of the neck in neonates with respiratory failure. See General Protocol for blood flow resistance information.

B. Cannulas

Appropriate Cannulas for the Vast Majority of Neonates on ECLS are:

1. VA: Single Lumen Venous (12Fr or 14Fr) + Arterial (8Fr or 10Fr)
2. VV: Double Lumen (12Fr, 14Fr, 15Fr)
3. Cephalad: A cannula can be placed in the proximal IJ for improved drainage and to decrease venous congestion. 8, 10, 12Fr cannulas can usually be placed. The larger cannulas are preferred for improved drainage and decreased stasis.

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[1] Revenis ME, Glass P, Short BL: Mortality and morbidity rates among lower birth weight infants (2000 to 2500 grams) treated with extracorporeal membrane oxygenation. J Pediatr 1992, 121(3):452-458.
[2] Hardart GE, Hardart MK, Arnold JH. Intracranial hemorrhage in premature neonates treated with extracorporeal membrane oxygenation correlates with conceptional age. J Pediatr 2004, 145(2):184-9.

IV. Management during ECLS

A. 2. Oxygenation: Very high PaO2 can occur with high flow VA bypass. In neonates this can cause retrolental fibroplasia, so adjusting flow and/or sweep gas to keep the PaO2 under 100 should be considered.

Critically ill newborns placed on ECLS are often on high doses of inotropes when ECLS is begun. As these drugs are titrated down, resistance falls and systemic pressure falls proportionately. If the systemic perfusion pressure is inadequate (low urine output, poor perfusion, elevated lactate) pressure can be increased by adding blood or low doses of pressor drugs. Systemic vasodilatation requiring pressor drugs is common in patients in septic shock. Although the mean arterial pressure may be low, systemic perfusion may be completely adequate If systemic oxygen delivery is not adequate (venous saturation less than 70%) increase the pump flow until perfusion is adequate. If extra blood volume is required to gain extra flow, it is preferable to transfuse blood or blood products rather than adding more crystalloid solution.

B. 2. Ventilator management: Whether the patient is on either VV. or VA mode, the ventilator should be managed at low settings to allow lung rest. A common mistake is to try to recruit lung volume during the acute inflammatory stage early in ECLS. Typical rest settings for a neonate on ECLS are PIP (15-22), PEEP (5-12), Rate (12-20), It (0.5sec). Using low PEEP may lead to alveolar collapse and increased edema. However, if the PEEP is set too high, venous return and, thus, the hemodynamics may be impaired; particularly when the patient is managed in the VV mode. Rest settings are achieved in some centers with high frequency ventilation.

Air Leak: Neonates with respiratory failure often have persistent air leak prior to ECMO and some patients will develop air leak while on ECMO. In both situations, air leak will usually resolve with decreasing ventilation settings. Ventilator settings should be decreased until no active air leak is visualized. This often means low CPAP settings or even “capping-off” the ETT for some period. Re-expanding the collapsed lung should be done gently over some period of time depending on the severity of the air leak (usually 24-48hrs).

B. 3. Sedation: Neonates on ECLS can usually be successfully managed with light sedation, typically a prn narcotic +/- a benzodiazepine. Paralysis and high dose continuous narcotic infusions should be reserved for the rare ECLS patient such as a newborn with CDH that has significant intestinal distension from swallowed air.

B. 9. Bleeding: See General Protocol. Bleeding into the head or brain parenchyma is the most serious ECLS complication. It can be extensive and fatal. Head ultrasounds should be performed every 24hrs for at least the first 3 days in stable neonates on ECLS and then per institution protocol. If the patient is unstable from a hemodynamic or coagulation standpoint, daily HUS should be considered. If bleeding is detected, the degree of bleeding will guide therapy. For a small bleed, coagulation status should be optimized and repeat HUS should be performed 2 times per day to detect any extension. For extending bleeds, or bleeds that are moderate, measures to optimized cardiorespiratory support should be undertaken and the patient should be weaned from ECMO. For severe intraparenchymal hemorrhage withdrawal of ECLS is indicated because of the poor neurologic prognosis.

B. 10. Procedures: See General Protocol. Unique to neonates is the common reality of CDH repair on ECMO. There remains intra-institutional variation in the ideal timing for CDH repair in ECMO patients. Despite the controversy, CDH repair on ECMO should be performed by a surgeon skilled in procedures on ECMO with special consideration for hemostasis in anticoagulated patients. Some centers routinely add Amicar or another hemostatic agent perioperatively to minimize bleeding.

VI. Head imaging

In addition to serial HUS during the ECMO run, a pre-discharge CT or MRI of the brain should be performed as a more sensitive measure of injury than the bedside HUS.

VII. Expected results (per patient and disease category) and long-term follow-up.

The International Registry reports an 85% ECLS survival and 75% survival to discharge for neonates placed on ECMO for respiratory failure. As these critically ill newborns are at high risk of neurodevelopmental problems, they should be followed and referred for therapy as indicated.

Pediatric Respiratory Cases

I Patient Condition

A. Indications

While no absolute indicators are known, consideration for ECMO is best within the first 7 days of mechanical ventilation at high levels of support

B. Contraindications

1. Recent neurosurgical procedures or intracranial bleeding (within 10 days). Grade II or III intracranial hemorrhage is a general contraindication.

2. Recent surgery or trauma: increased risk of bleeding. While ECMO has been performed successfully in these patients, use of heparinized circuits and/or oxygenators may limit bleeding initially. Care to maintain adequate coagulation factors, platelet counts and use of low ACT’s (160-180) may be helpful.

3. Age and size: pediatric patients are >30 days of age and <18 years of age.

No weight limit although obese patients (especially >100kgs) may require special beds, have high risk of decubiti. May also be more difficult to cannulate.

4. Patients with severe neurologic compromise, genetic abnormalities (not including Trisomy 21).

5. Relative: endstage hepatic failure, renal failure, primary pulmonary hypertension.

C. Specific patient considerations

1. Patients with chronic respiratory failure (BPD, emphysema, cystic fibrosis) may be candidates based on pre-ICU status. Need for bronchodilators, diuretics, oxygen therapy and prognosis for long-term survival should be considered prior to offering ECMO. Cystic fibrosis patients should be eligible for lung transplantation

III Vascular Access

A. Venovenous access with a double lumen catheter placed into the internal right atrium via the internal jugular vein is preferred for pts <10-15 kgs. Catheter placement is best done by direct visualization, using direct cannulation for the semi-Seldinger technique described in the general protocol.

B. Venovenous access may also be performed via 2 separate sites. Usually the right internal jugular vein and the right or left femoral veins are used for access. Percutaneous or the semi-Seldinger technique can be performed. Recirculation is limited if drainage from the femoral site and reinfusion via the R IJ site can obtain enough flow to support the patient.

C. Modified venoarterial approach: Venous access may be obtained by femoral or internal jugular route. A low-lying arterial cannula is placed in the femoral artery (usually 18 cm). Saturation of upper body blood flow (head,heart) can be monitored via venous saturation monitor, pulse oximeter (best placed on right hand or ear), NIRS monitor on forehead, or via arterial blood gas line in right radial. Flow from arterial cannula retrograde up aorta will depend on native cardiac function. Low lying cannula can also be rewired to long (50cm) cannula if cardiac output poor and oxygenation to upper body poor.

D Other: for additional drainage, other venous cannulas can be added into unused femoral or internal jugular sites (while the left IJ has been used, the angle of entry into the heart makes it difficult to get cannula properly placed).

VI Patient and disease-specific protocols

A. Selective CO_2 removal.

For status asthmaticus and other conditions in which blood pCO_2 is very high, reducing the blood pCO_2 gradually to avoid acid base imbalance or cerebral complications. A suggested rate of decreasing arterial pCO_2 is 20 mm/Hg/hr.

When selective CO_2 removal is used to treat permissive hypercarbia and to achieve rest lung settings in ARDS, CO_2 can be normalized at acceptable rest lung settings with low blood flow (20% of cardiac output). If the lung failure is severe this can result in major hypoxemia. If the cardiac output and hemoglobin concentration are normal, arterial saturation as low as 75% is safe and well tolerated. However, increasing extracorporeal blood flow to improve oxygenation is preferable to increasing ventilator pressure or FiO_2 when selective CO_2 removal is used.

B. Support of the tracheobronchial tree:

ECMO may be extremely useful in providing airway support during or following surgical repair of the tracheobronchial tree. It allows adequate carbon dioxide removal and oxygenation at low levels of mechanical ventilator support. Use of ECLS may also eliminate the need for endotracheal intubation and use of mechanical ventilator support altogether. This may enhance the ease of surgical repair and subsequently facilitate healing without concern for rupturing suture lines from applied positive pressure.

C. Mediastinal masses:

ECLS may be applied in conditions where anterior mediastinal masses cause airway compression and high risk of death during endotracheal intubation. Application of ECLS under local anesthesia or light sedation with the patient in the upright position may avoid acute death in situations where loss of negative pressure from spontaneous breathing results in collapse of compressed airways which cannot be reexpanded with routine tracheal intubation.

D. Pulmonary embolism

Many patients with primary or secondary ARDS will have small (segmental) pulmonary emboli on contrast CT or angiography. Such emboli do not require any specific treatment aside from the heparinization which accompanies ECLS. When **major or massive pulmonary embolism** is the cause of respiratory/cardiac failure, venoarterial ECLS is very successful management if cannulation and extracorporeal support can be instituted before brain injury occurs. After VA access and successful ECLS is established, document the extent of pulmonary embolism by appropriate imaging studies. Massive pulmonary emboli will usually resolve or move into segmental branches within 48-72 hours of ECLS support. The patient can be weaned from ECLS then from ventilation and managed by pulmonary embolism prophylaxis. Almost all such patients are managed with placement of an inferior vena caval filter. If heart/lung function has not recovered within two days, or if there is a secondary reason to get the patient off ECLS (GI bleeding for example), the patient should undergo pulmonary thrombectomy with cardiopulmonary bypass support. When thrombectomy is done it is usually necessary to continue ECLS for days until lung function is normal.

E. ARDS with secondary lung injury (following shock, trauma, sepsis, etc.)

Once the patient is on ECLS support for stability, adequate repair of secondary organ damage must be performed. If surgical repair of organ injury is required (for example pancreatic resection and drainage for necrotizing pancreatitis, fasciotomy and/or amputation for compartment syndromes and gangrene, excision and drainage of abscesses, etc), these procedures may be adequately performed during ECMO support.

F. Fluid overload

See IV B 4 and 5 in General Guidelines

ECLS offers the opportunity to treat massive fluid overload easily. Adequate renal perfusion through native cardiac output or through VA perfusion can be assured minute to minute with appropriate management. As long as renal perfusion is adequate, pharmacologic diuresis can be instituted and maintained even in septic patients with active capillary leak. Continuous hemofiltration may be added to the circuit if pharmacologic diuresis is inadequate. The hourly fluid balance goal should be set and maintained until normal extracellular fluid volume is reached (no systemic edema, within 5% of "dry" weight). Use of renal replacement therapy to enhance fluid removal and allow adequate nutritional support is often performed. Despite the literature surrounding fluid overload (>10%) as a risk factor for death, review of the ELSO registry also finds that use of renal replacement therapy is also a risk factor for poor outcome. Even if acute renal failure occurs with ECLS, resolution in survivors occurs in >90% of patients without need for long-term dialysis.

G. Post ECLS recovery and management

A patient is weaned off ECLS on non-damaging ventilator settings as described in V. If respiratory function is tenuous the vascular access catheters can be left in place as described in V. Once the patient is off ECLS ventilator weaning continues per unit protocol. There is a tendency to drift into positive fluid balance, more sedation, increasing ventilator settings which should be carefully avoided. Tracheostomy is not often performed in pediatric ECLS but may be indicated if respiratory improvement to allow cessation of mechanical ventilation is prolonged.

Patients who experience severe lung injury from necrotizing pneumonia, or from very high plateau pressures prior to ECLS will have the physiologic syndrome of very high alveolar level dead space. This is characterized by adequate oxygenation on low FiO_2 but CO_2 retention, respiratory acidosis, the need for hyperventilation (either spontaneous or via the ventilator) to maintain $PaCO_2$ under 60, and an emphysematous (honeycomb) appearance on chest x-ray or CT scan. Although this condition has the characteristics of chronic irreversible obstructive lung disease, it may reverse to normal within 1-6 weeks. These conditions heal by contracture eliminating the alveolar level dead space.

H. Lung biopsy

The cause of severe respiratory failure may be unknown when the patient is started on ECLS. Although lung biopsy is the next step in diagnosis, it is potentially dangerous in patients on ECLS with anticoagulation. If pulmonary function rapidly improves during ECLS (the first few days) lung biopsy may be delayed until the patient is off anticoagulation. However, if pulmonary function is not improving after several weeks, the primary diagnosis has not been established by bronchoscopy or other means and the status of lung recovery uncertain, lung biopsy can and should be performed. Lung biopsy is best done by thoracotomy (or thoracoscopy) rather than transbronchially because of the risk of major hemorrhage into the airway with transbronchial biopsy.

I. Rare conditions

ECLS has been used for rare causes of pulmonary failure with variable success. When considering ECLS for a specific diagnosis for the first time in any given center it may be helpful to consult the ELSO registry for the worldwide experience with that condition. Examples are vasculitis, autoimmune lung disease, bronchiolitis, obliterans, Goodpasture syndrome, rare bacterial, fungal or viral infections.

VII Weaning and followup (see general protocol)

Patients should have a thorough neurologic evaluation, including imaging with a CT or MRI scan, done prior to hospital discharge. A followup plan that involves a minimum of yearly patient assessment should also be developed. A minimum level of progress in normal developmental milestones, school performance, required medications and subsequent hospitalizations post-ECMO should be obtained.

Pediatric cardiac cases

I Patient condition

A. Indications

1. Early postoperative cardiac failure in the operating room (unable to come off bypass).

2. In the ICU: the severity defined by pressor and inotropic requirement, metabolic acidosis, decreased urine output for 6 hours.

3. Cardic arrest from any cause: with response to CPR but still unstable and no response to CPR direct massage underway for 5 minutes.

4. Myocardial failure unrelated to operation: myocarditis, myocardiopathy, toxic drug overdose.

B. Contraindications:

1. Age and size: in general any infant considered old and large enough to undergo a cardiac operation is an appropriate candidate for ECLS.

2. Futility: the likelihood of a normal child resulting from the treatment is small

3. CPR ongoing > 5 minutes (see above)

C. Special patient considerations:

1. Untreatable underlying diseases and congenital malformations

2. Consider whether the patient is a candidate for heart transplantation on the first day of ECLS. The answer will set the goals and the time limitations for ECLS or other support systems.

3. Converting to and from cardiopulmonary bypass in the operating room is a special consideration discussed in VI

II Extracorporeal Circuit: general protocol

A heat exchanger will be required for management of these patients.

III Vascular Access

A. All cardiac support requires venoarterial access

B. Chest cannulation is usually used when the patient cannot be weaned from cardiopulmonary bypass in the operating room. The right atrial and aortic catheters are used for ECMO access. The aortic access catheter may be too small for arterial access under prolonged conditions of normothermia and higher flows and hematocrit than during CPB. This will be indicated by high pressures in the blood return line and possibly by hemolysis.

C. Neck cannulation: VA access through the jugular and carotid is used for children < 10 Kg because of the very small size of the femoral vessels in children who are not walking.

D. Femoral vessels: the femoral or iliac vessels are usually large enough to permit appropriate vascular access in children over 10-15 Kg of weight. Both the artery and vein will be occluded by the catheter so provision must be made for profusion of the distal leg. Venous collateral is usually adequate to avoid excessive edema and venous congestion.

IV Management during ECLS

A. Circuit related: General Protocol

7. Traveling to the cath lab or the operating room or the CT scanner is often required for pediatric cardiac cases, so the access tubing and circuit must be planned with that in mind (elevators, battery power, monitors outside of the ICU, etc.).

B. Patient related

1. Hemodynamics: Blood flow is managed to maintain the venous saturation 70-80%.

2. Ventilator: Patients may begin with pulmonary edema but this often clears early in management. The patient can be extubated during most of ECLS run. If the patient remains intubated, the ventilator should be managed at very safe levels (FiO_2 < 40%, plateau pressure < 20 cm/H_2O

9. Anticoagulation and bleeding: Standard anticoagulation is used for all patients, but bleeding is expected if the patient has undergone a recent operation under cardiopulmonary bypass. Whole blood activated clotting time should be maintained at 1.5 times normal for the ACT device. If the ACT is significantly prolonged despite a wide range of heparin dosage, consider the fact that antithrombin 3 levels may be severely decreased. This can be treated empirically with fresh frozen plasma. If intrathoracic bleeding occurs in a patient cannulated through the neck with a closed sternum, there should be a low threshold for opening the chest in the ICU, reexploring the operative sites, evacuating clot, and controlling bleeding as much as possible. Once the chest has been opened (or if the patient is taken directly from the operating room with the chest open) the chest should be left open, suction drains placed and the entire wound covered with a sealed plastic drape adherent to the skin. This will allow direct examination for subsequent bleeding and maintain a very low threshold for reexploration if bleeding persists, particularly if tamponade physiology occurs. The use blood aspiration and return (autotransfusion.) makes special measures for excessive bleeding in open chest patients.

V Weaning

The standard protocol describes weaning under conditions of recovering cardiac and pulmonary function. In these patients, futility relates to whether or not the patient is to be listed for cardiac transplantation. If transplant is possible, then appropriate measurements for matching should be made early in the course and conversion to ventricular assist device considered as soon as patient condition permits. If transplant is not an option, ECLS is used as a bridge to recovery. A ventricular assist device should not be used (under 2007 conditions), and a time limit should be established for recovery of the heart, or discontinuation of ECLS if the heart is not recovered in a defined time (typically 10-14 days).

VI Patient specific issues

A. Patient unable to come off cardiopulmonary bypass in the operating room. Once it is clear that a patient cannot be weaned from CPB despite appropriate pharmacologic measures, the decision to go to the ICU with ECMO support should be made sooner rather than later. The longer the patient is on CPB and high dose pressors the greater the fluid overload, thrombocytopenia, metabolic acidosis, and risk of organ injury. Once the decision for ECLS has been made the patient should be converted to the ECLS circuit and moved to the ICU (without prolonged attempts to stem bleeding in the operating room). The ECLS circuit is attached directly to the intracardiac cannulas after infusing most of the blood in the reservoir into the patient. Once on ECLS, blood in the CPB system should be transferred to blood bags for transfusion in the ICU. The chest is left open with enough suction drains to prevent blood overflow, and the chest is covered with an adhesive plastic drape. The patient will be systemically heparinized with the prolonged ACT. When ACT has reached a level of twice normal a low dose of heparin infusion is done with the goal of maintaining ACT at 1.5 times normal. The bleeding is generally due to thrombocytopenia, thrombocytopathia, and fibrinolysis rather than heparinization per se, so reversing heparin with protamine is rarely helpful. The patient is warmed with the heat exchanger to 37° to enhance coagulation and platelet function. Platelets are transfused to maintain a level greater than 80,000. The use of Amicar and/or aprotinin is indicated. Despite these maneuvers bleeding will persist for several hours, treated by appropriate transfusion of red cells, platelets and fresh frozen plasma. ??? Factor VII should be considered, but only after normothermia is obtained and the other coagulation factors and platelets are as normal as possible (because of the high cost of Factor VII). If mediastinal sheds blood is collected in a sterile fashion it can be reinfused although it is best to wash shed blood and reinfuse only the red cells. 24-48 Hours after CPB the heart has often recovered from myocardial stun and ECLS can be discontinued. If the heart has not recovered within that time the decision regarding possible transplantation should be made, and the remaining course identified as bridge to VAD to transplant or bridge to recovery as discussed in section V.

B. Myocarditis and Myocardiopathy. The prognosis in these conditions is generally good. The threshold for going on ECLS should be quite low because intractable arrhythmias or diastolic arrest can occur without warning. Cannulation is via the neck vessels up to age 2-3, beyond age 3 their neck or femoral vessels can be used.

C. ECPR in children. ECLS is a valuable adjunct to CPR if it is instituted early (see I). Although CPR > 5 minutes is a general rule for a contraindication (because of the high likelihood of brain damage), if CPR is done successfully with evidence of good perfusion longer periods of arrest may be considered an indication. This is particularly true in situations like the cath lab where successful CPR can be carried on for an hour or more.

D. Echocardiography. Following ventricular function by echocardiography is an essential adjunct to ECLS management for cardiac failure. During high flow VA ECLS the heart will be relatively empty, so it is necessary to turn the flow down until the atria are appropriately filled in order to evaluate ventricular function. ECHO is the most valuable method to determine the extent of myocardial recovery. In addition ECHO can help to identify the position of intravascular catheter, the status of valve and conduit function, and the presence of clot in the cardiac chambers.

E. Non functioning ventricles, left side venting, inotropes, pulsatility and clots in the heart. If the left ventricle function is inadequate to open the aortic valve, left ventricular diastolic pressure and left atrial pressure will gradually increase during VA support, as the left side of the heart fills with bronchial venous flow, thebesian flow and any blood passing from the right side to the left. This will cause a gradual increase in left atrial pressure. When the left atrial pressure reaches 25-30 pulmonary edema will ensue. This process takes 4-8 hours in most cases. If the left ventricle is not emptying through the aortic valve the left side of the heart must be vented into the venous drainage of the ECLS circuit within a few hours. If the chest is open this can be done simply by placing a catheter in the left atrium directly. If the chest is closed this is best done by creating an atrial septal defect with a balloon septostomy in the cardiac catheterization lab. If a cardiologist experienced in this procedure is not available direct atrial venting should be done by a thoracotomy. To avoid the need for left sided venting it is worthwhile to attempt inotropic drugs to improve left ventricular contractility and vasodilator drugs to decrease systemic vascular resistance. Aside from avoiding left sided pressure, pulmonary edema and the need for venting, maintaining continuous blood flow through both sides of the heart is important to prevent clotting in the pulmonary vessels or myocardial chambers. Even with coagulopathy and systemic heparinization stagnant blood will gradually clot, most commonly in the left atrium and left ventricle. This is detected by echocardiography. If there are clots on the left side of the heart there is a risk of systemic embolism if and when myocardial function returns, creating a management dilemma. The best approach is to realize that native myocardial recovery will not occur. If the patient is a transplant candidate inotropes should be discontinued and a search for a donor emphasized. If there are clots in the heart and the patient is not a potential transplant candidate this is a sign of futility and an indication to discontinue ECLS.

F. Pulsatile flow. For the reasons discussed in E above it is important to maintain left ventricular function which will result in some systemic pulsatile flow (approximately 10 mm/Hg pulse pressure). If the native heart does not provide any pulse pressure, is there any advantage to using a pulsatile pump to maintain pulsatility for systemic organs? The answer is that pulsatility during VA perfusion is not important as long as the total perfusion is adequate (3 L/m^2/min or higher, venous saturation > 75%). In addition to being unnecessary, maintaining pulsatile flow may be deleterious because the arterial infusion catheter is usually quite small, and the intermittent high flow rates during the systolic phase of pulsation may lead to high pressure in the perfusion circuit and hemolysis.

G. Cath Lab trips. Cardiac function can be effectively followed by echocardiography, but there should be a low threshold for repeat cardiac catheterization during ECLS to measure pressures, flows, saturations etc.

VII Expected results

Series in the literature and ELSO registry data.

Adult respiratory failure cases

I Patient Condition

A. Indications

1. In hypoxic respiratory failure due to any cause (primary or secondary) ECLS should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of 80% or greater.
    a. 50% mortality risk can be identified by a PaO2/FiO2 < 150 on FiO2 > 90% and/or Murray score 2-3
    b. 80% mortality risk can be identified by a PaO2/FiO2 < 80 on FiO2 > 90% and Murray score 3-4

2. CO2 retention due to asthma or permissive hypercapnia with a PaCO2 > 80 or inability to achieve safe inflation pressures (Pplat ≤ 30 cm HO) is an indication for ECLS.
3. Severe air leak syndromes

B. Contraindications

There are no absolute contraindications to ECLS, as each patient is considered individually with respect to risks and benefits. There are conditions, however, that are known to be associated with a poor outcome despite ECLS, and can be considered relative contraindications.

1. Mechanical ventilation at high settings (FiO2 > .9, P-plat > 30) for 7 days or more
2. Major pharmacologic immunosuppression (absolute neutrophil count <400/ml3
3. CNS hemorrhage that is recent or expanding

C. Specific patient considerations

1. Age: no specific age contraindication but consider increasing risk with increasing age
2. Weight: over 125 kg can be associated with technical difficulty in cannulation, and the risk of not being able to achieve an adequate blood flow based on patient size.
3. Non fatal co-morbidities may be a relative indication based on the individual case (i.e. diabetes and renal transplant and retinopathy and PVOD complicated by severe pneumonia)
4. Bridging to lung transplant: generally bridging to lung transplant is impractical because of limited donors. Using an implanted membrane lung (in a paracorporeal position) with extubation and ambulation is being evaluated in some transplant centers.

III Vascular access

A. Modes of vascular access

VV is preferred for adult respiratory failure when cardiac function is adequate or mildly depressed. VA is preferred if cardiac function is moderately to severely depressed and cardiac support is also required. Patients with severe respiratory failure and secondary cardiac failure may improve on VV support alone. These patients may be initiated on VV and transitioned to VA or hybrid VVA if cardiac improvement does not occur.

AV access may be considered for selective CO_2 removal in hypercapnic states. It has the potential complications of arterial access but is a much simpler circuit. Low flow VV with a pump can be used for selective CO_2 removal when the risk arterial complication is unacceptable .

Hybrid VVA can provide partial cardiac support as well as respiratory support, and is an option when cardiac function is depressed and does not improve with improved oxygenation following VV support.

B. Cannulas

Percutaneous access is possible in more than 90% of adult patients. Ultrasound and fluoroscopy can facilitate cannulation. In the absence of imaging, the placement of conventional IV catheters first to verify position can be followed by the placement of larger cannulas over a wire. A large double lumen cannula, or two large (23-26 Fr) venous cannulas are required: IVC via femoral vein for drainage and right atrial via the jugular or opposite femoral for blood return. The three cannula technique (short drainage cannulas in the jugular and femoral, and a long return cannula in the opposite femoral can result in low recirculation and higher saturations. Large double lumen cannulas are available for adults to allow VV with single catheter access.

For selective venovenous CO_2 removal 15 Fr double lumen cannulae (Origen) will deliver adequate blood flow for total CO_2 removal. [This may have higher recirculation due to the two drainage sites]. For arteriovenous CO2 removal, a 10 to 12 Fr arterial and 14 to 16 venous cannulae provide adequate flow for total CO2 removal.

IV Management during ECLS

A. Circuit related

2. **Oxygenation**: in the absence of lung function, VV access can supply all metabolic oxygen requirements, but the arterial saturation is usually 80-85%, but may be 75-80% (PaO_2 45-55). The lower recirculation with the three cannula approach results in arterial saturations of 85% to 92%. This is ample oxyhemoglobin saturation for normal systemic oxygen delivery as long as the cardiac output and hemoglobin concentration are normal. However the ICU staff may be uncomfortable with arterial saturation under 90, and education regarding oxygen delivery is important. Avoid the temptation to turn up the ventilator settings or FiO_2 above rest settings during VV support.

B. Patient related

1. Hemodynamics: On VA support, SvO2 can be used to guide hemodynamic management as discussed in the general guidelines. On VV support there is no hemodynamic support provided by the extracorporeal circuit. The patient should be managed with inotropes, vasodilators, blood volume replacement etc. as if the patient were not on extracorporeal support. Echocardiography is an excellent tool to assess hemodynamic function and help guide management during VV ECLS, as it is not practical to measure SvO2.

2. Ventilator management

Key aspects to consider:

- The lungs are not used for gas exchange during ECLS, so avoid aggressive recruitment maneuvers, high levels of PEEP, or high inflation pressures.
- There is no evidence that an “open lung” approach results in better pulmonary recovery than more conservative approaches.
- Rapid respiratory rates produces added mechanical stress

Reasonable initial ventilator settings during ECLS could be decelerating flow (pressure control), a respiratory frequency of 4 to 5 per minute, modest PEEP (e.g. 10 cm H20), and low inflation pressure (e.g. 10 cm H20 above PEEP, or a PIP of 20 cm H20. Once patients stabilize and sedation can be lightened, spontaneous ventilation with pressure support ventilation can be considered.

Bronchoscopy and airway lavage are facilitated by extracorporeal support and should be used as indicated. Lighter sedation and supported ventilation may allow mobilization of distal secretions and may reduce the need for bronchoscopy.

2a. Management of air leaks: Chest tube placement is frequently accompanied by bleeding complications, so a conservative approach is often taken to pneumothoraces. **A small pneumothorax** (estimated 50% or less with no hemodynamic compromise and no enlargement over time) is best managed by waiting for absorption with no specific treatment. **A symptomatic pneumothorax** (> 50%, enlarging, or causing hemodynamic compromise) should be treated by external drainage, although a small tube should be used with appropriate preparation (see section IV:9). **Massive air leak** or bronchopleural fistula (less than half of the inspired volume comes out as expired volume) can be managed by ECLS, in fact it is sometimes a specific indication for ECLS. As in any bronchopleural fistula, the first objective is to evacuate the pleural space so that the lung contacts the chest wall, leading to adhesions with closure of the visceral pleura. During ECLS this can almost always be managed by a single chest tube placed on high continuous suction (20-50 cm/H^2O), then limiting inspiratory pressure and volume. In some cases, it may be necessary to manage the airway by continuous positive airway pressure at 10, 5 or even 0 cm/H^2O for hours or days. When the air leak has sealed, airway pressure is gradually added until conventional rest settings are reached. Recruitment of the totally atelectatic lung may take one or more days.

Bronchopleural fistula with a massive air leak **directly from a bronchus or the trachea** (after lung resection or trauma for example) should be managed initially as outlined above, but direct endoscopic or thoracotomy closure is often required.

VI Patient and disease-specific protocols

A. Selective CO_2 removal

For status asthmaticus and other conditions in which blood pCO_2 is very high, reduce the blood pCO_2 gradually to avoid acid base imbalance or cerebral complications. A suggested rate of decreasing arterial pCO_2 is 20 mm/Hg/hr.

When selective CO_2 removal is used to treat permissive hypercarbia and to achieve rest lung settings in ARDS, CO_2 can be normalized at acceptable rest lung settings with low blood flow (20% of cardiac output). If the lung failure is severe this can result in major hypoxemia. If the cardiac output and hemoglobin concentration are normal, arterial saturation as low as 75% is safe and well tolerated. However, increasing extracorporeal blood flow to improve oxygenation is preferable to increasing ventilator pressure or FiO_2 when selective CO_2 removal is used. This is not an option with arteriovenous CO2 removal, however.

B. Pulmonary embolism

Many patients with primary or secondary ARDS will have small (segmental) pulmonary emboli on contrast CT or angiography. Such emboli do not require any specific treatment aside from the heparinization which accompanies ECLS. When **major or massive pulmonary embolism** is the cause of respiratory/cardiac failure, venoarterial ECLS is very successful management if cannulation and extracorporeal support can be instituted before brain injury occurs. After VA access and successful ECLS is established, document the extent of pulmonary embolism by appropriate imaging studies. Massive pulmonary emboli will usually resolve or move into segmental branches within 48-72 hours of ECLS support. The patient can be weaned from ECLS then from ventilation and managed by pulmonary embolism prophylaxis. Almost all such patients are managed with placement of an inferior vena caval filter. If heart/lung function has not recovered within two days, or if there is a secondary reason to get the patient off ECLS (GI bleeding for example), the patient should undergo pulmonary thrombectomy with cardiopulmonary bypass support. When thrombectomy is done it is usually necessary to continue ECLS for days until lung function is normal.

C. ARDS from secondary lung injury (following shock, trauma, sepsis, etc.)

Once the patient is on ECLS support there is a temptation to be less aggressive treating the primary problem, however this is generally a mistake. The threshold for operations should be lower rather than higher despite ECLS and anticoagulation (for example pancreatic resection and drainage for necrotizing pancreatitis, fasciotomy and/or amputation for compartment syndromes and gangrene, excision and drainage of abscesses, etc.).

D. Fluid overload

See IV B 4 and 5

ECLS offers the opportunity to treat massive fluid overload easily. Adequate renal perfusion through native cardiac output or through VA perfusion can be assured minute to minute with appropriate management. As long as renal perfusion is adequate pharmacologic diuresis can be instituted and maintained even in septic patients with active capillary leak. Continuous hemofiltration can and should be added to the circuit if pharmacologic diuresis is inadequate. The hourly fluid balance goal should be set (typically -100 to 300 cc/hr for adults) and maintained until normal extracellular fluid volume is reacher (no systemic edema, within 5% of “dry” weight). Although normal renal function can usually be maintained, the life threatening condition is respiratory failure. Even if acute renal failure follows ECLS, it will resolve to normal renal function within six months in 90% of cases.

E. Post ECLS recovery and management

A patient is weaned off ECLS on lung-protective ventilator settings as described in V. If respiratory function is tenuous the vascular access catheters can be left in place as described in V. Once the patient is off ECLS ventilator weaning continues per unit protocol. There is a tendency to drift into positive fluid balance, more sedation, increasing ventilator settings which should be carefully avoided. If tracheostomy was not done during ECLS it should be done as soon as anticoagulation is reversed in most cases. (This eliminates sedation and problems of ventilator weaning from management considerations.)

Patients who experience severe lung injury from necrotizing pneumonia, or from very high plateau pressures prior to ECLS will have the physiologic syndrome of very high alveolar level dead space. This is characterized by adequate oxygenation on low FiO_2 but CO_2 retention, respiratory acidosis, the need for hyperventilation (either spontaneous or via the ventilator) to maintain $PaCO_2$ under 60, and an emphysematous (honeycomb) appearance on chest x-ray or CT scan. This condition has the characteristics of chronic irreversible obstructive lung disease, however this condition almost always reverses to normal within 1-6 weeks. It is analogous to the condition of alveolar level dead space CO_2 retention that occurs in children with severe staphylococcal pneumonia leaving large bullae at the alveolar level. These conditions heal by contracture eliminating the alveolar level dead space.

F. Lung biopsy

The cause of severe respiratory failure may be unknown when the patient is started on ECLS. Although lung biopsy is the next step in diagnosis, it is potentially dangerous in patients on ECLS with anticoagulation. If pulmonary function rapidly improves during ECLS (the first few days) lung biopsy may be delayed until the patient is off anticoagulation. However, if pulmonary function is not improving and the primary diagnosis is not known, lung biopsy can and should be done within the first week on ECLS. Lung biopsy is best done by thoracotomy (or thoracoscopy) rather than transbronchially because of the risk of major hemorrhage into the airway with transbronchial biopsy. As with any thoracotomy during ECLS, it is best to leave the chest open covered by an adhesive plastic drape, with definitive closure after ECLS.

G. Rare conditions

ECLS has been used for rare causes of pulmonary failure with variable success. When considering ECLS for a specific diagnosis for the first time in any given center it may be helpful to consult the ELSO registry for the worldwide experience with that condition. Examples are vasculitis, autoimmune lung disease, bronchiolitis, obliterans, Goodpasture syndrome, rare bacterial, fungal or viral infections.

VII Expected results:

The CESAR trial in the UK: ECMO protocol, 63% healthy survival at 6 months. Control 47%

Adult Cardiac Cases

I. Patient condition

A. Indication for ECMO in adult cardiac failure is cardiogenic shock:

Inadequate tissue perfusion manifested as hypotension and low cardiac output despite adequate intravascular volume.

Shock persists despite volume administration, inotropes and vasoconstrictors, and intraaortic balloon counterpulsation if appropriate.

Typical causes: Acute myocardial infarction, Myocarditis, Peripartum Cardiomyopathy, Decompensated chronic heart failure, Post cardiotomy shock.

Septic Shock is an indication in some centersa.

Guidelines on relative survival without ECMO:
IABP score postcardiotomy(Hausmann H Circ 2002)
Samuels score postcardiotomy (Samuels LE J Cardiac Surg 1999)
Options for temporary circulatory support
Surgical temporary VAD: Abiomed, Levitronix
Percutaneous VAD:TandemHeart, Impella

ECMO: Advantages: Biventricular support, bedside immediate application, oxygenation, Biventricular failure, Refractory malignant arrythmias, Heart failure with severe pulmonary failure
ECMO is a bridge to…
Recovery: Acute MI after revascularization, Myocarditis, Postcardiotomy
Transplant: Unrevascularizable acute MI, Chronic heart failure
Implantable circulatory support: VAD, TAH

B. Contraindications to ECMO

Absolute: Unrecoverable heart and not a candidate for transplant or VAD, Advanced age,Chronic organ dysfunction (emphysema, cirrhosis, renal failure), Compliance (financial, cognitive, psychiatric, or social limitations), Prolonged CPR without adequate tissue perfusion.

Relative: Contraindication for anticoagulation, Advanced age, Obesity.

III. Vascular Access

Postcardiotomy:
Intrathoracic cannulae: ensure site hemostasis, Patch chest open for frequent exploration.
Non-postcardiotomy: Percutaneous femoral artery and vein, Typically most rapid access, 15-21 Fr arterial, 21-28 Fr venous (advance to right atrium if possible).
Percutaneous jugular vein, 21-28 Fr to right atrium, Common carotid via surgical exploration, 10-15% watershed cerebral infarction with carotid ligation, 8-10 mm end to side polyester graft
Femoral arterial cannulation associated with ipsilateral leg ischemia, Percutaneous distal cannulation of superficial femoral artery (may require ultrasound or fluoroscopic guidance), Surgical exploration of superficial femoral artery, Surgical exploration of posterior tibial artery 8Fr retrograde cannula

IV. Management

Maintain left ventricular ejection
Avoid left ventricular distension: Promote recovery Avoid pulmonary edema/hemorrhage, Avoid intracardiac/aortic root thrombosis
Continue inotropes: Minimize vasoconstrictors, Avoid unnecessary flow, Liberal use of intraaortic balloon pump, Frequent assessment by echocardiography, Ventricular distension
Refractory left ventricular distension: Mean PA pressures >30, Nonpulsatile arterial line tracing, Aortic valve does not open, Decompress left ventricle, Open chest postcardiotomy, Insert LV vent, Closed chest cannulation, Transeptal left atrial decompression
Cerebral hypoxia: Femoral arterial ECMO infusion with severe respiratory failure, Hypoxia to coronaries, brain and right upper extremity, PaO2 measured in femoral artery or left radial artery may be elevated, Measure saturations in right hand, Arterial line preferably in right radial artery, Adjust ventilator to maintain adequate oxygenation, May require maximum ECMO flow

V. Weaning

Bridge to recovery (postcardiotomy, acute MI, myocarditis)
Expect early signs of recovery within one week of support
With evidence of improved aortic pulsatility and contraction on echocardiography, optimize inotropes and reduce flow to 50%, then 25% of adequate cardiac output. Use echo to visualize ventricular function and major valvular pathology.
Clamp circuit and allow recirculation for trial period of 30 minutes to 4 hours. Flush cannulae with heparinized saline continuously or flash from the circuit every 10 minutes to avoid cannula thrombosis. If hemodynamics and oxygen delivery are adequate on less then maximum inotropic infusions, consider decannulation.

Bridge to VAD: Transition to VAD when end organs resuscitated, Neurologically intact, Restoration of renal hepatic function, Pulmonary edema resolved, Ideally within one week

VII. Expected results:

40% survival to discharge (may be less with postcardiotomy)

ECPR Cases

I. Patient Condition:

A Indications

AHA guidelines for CPR recommends consideration of ECMO to aid cardiopulmonary resuscitation in patients who have an easily reversible event, have had excellent CPR.

Contraindications: All contraindications to ECMO use (such as Gestational age < 34 weeks) should apply to ECPR patients.

DNR orders

Futility: Unsuccessful CPR (no return of spontaneous circulation) for 5-30 minutes. ECPR ma be indicated on prolonged CPR if good perfusion and metabolic support is documented.

III Vascular Access

C. Cannulation Site

Thoracic (for cardiac patients with recent sternotomy) or Peripheral vessel should be at discretion of the surgical team. Percutaneous cannulation of vessels for ECPR is only recommended if access to the vessels exists prior to CPR, and should only be performed providers who are skilled with vascular access. Percutaneous cannulation can be performed in patients >15 kgs. Placement in specialized areas such the cardiac catheterization (or interventional radiology) laboratory where the placement of these catheters can be directly observed is ideal but non mandatory.

IV: Management during ECLS

1. Initiation of ECMO Flow: Once cannulation is achieved ECMO circuit management should continue as for all other ECMO uses. Because ECPR required rapid cannulation and ECMO access, correct connection of the arterial and venous cannulae to the corresponding limbs should be checked using a "Time-Out' system prior to ECMO flow.
2. Patient Management on ECMO: CNS protection during and after CPR is critical. Therapies known to improve survival and CNS outcomes after CPR such as:

    Total body hypothermia should be included. Cooling should be achieved by applying ice to the head during CPR and for 48 – 72 hours after ECMO cannulation.
    Neurological exams should be performed following discontinuation of neuromuscular blocking agents after hemodynamic stability is achieved in collaboration with the neurologist.
3. Management of Left Atrial Hypertension: Evaluation for LA hypertension should be undertaken soon after the patient is placed on ECMO and LA decompression should be considered if left atrial pressure is thought to be elevated.
4. Diagnosis Procedures including: ECHO or cardiac catheterization or other imaging or laboratory test should be undertaken when the patient if has stable

ECMO flows and perfusion, to evaluate the cause of cardiac arrest if once cannot be determined immediately

V. Weaning

Weaning of ECMO should be undertaken when cardio-respiratory recovery has occurred and per institution's ECMO guidelines. . Long-term follow-up programs based in Neurology and Developmental pediatrics should be established.