



Extracorporeal Life Support Organization (ELSO)

Guidelines for Adult Respiratory Failure

Introduction

This adult respiratory failure 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 adult respiratory failure.

This guideline describes prolonged extracorporeal life support (ECLS, ECMO). This guideline 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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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 mortality is 80% or greater.

a. 50% mortality risk is associated with a $\text{PaO}_2/\text{FiO}_2 < 150$ on $\text{FiO}_2 > 90\%$ and/or Murray score 2-3.

b. 80% mortality risk is associated with a $\text{PaO}_2/\text{FiO}_2 < 100$ on $\text{FiO}_2 > 90\%$ and/or Murray score 3-4 despite optimal care for 6 hours or more.

2. CO₂ retention on mechanical ventilation despite high P_{plat} (>30 cm H₂O)

3. Severe air leak syndromes

4. Need for intubation in a patient on lung transplant list

5. Immediate cardiac or respiratory collapse (PE, blocked airway, unresponsive to optimal care)

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 associated with a poor outcome despite ECLS, and can be considered relative contraindications.

1. Mechanical ventilation at high settings ($\text{FiO}_2 > .9$, P-_{plat} > 30) for 7 days or more

2. Major pharmacologic immunosuppression (absolute neutrophil count <400/mm³)

3. CNS hemorrhage that is recent or expanding

4. Non recoverable co morbidity such as major CNS damage or terminal malignancy

5. Age: no specific age contraindication but consider increasing risk with increasing age

II. Vascular access

A: Modes of vascular access

1. **Stable patients:** VV is preferred for adult respiratory failure when cardiac function is adequate or moderately 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. VV access may be by femoral and jugular veins with 2 cannulas or a double lumen cannula via the jugular vein.

2. Selective CO₂ removal: AV access may be considered for selective CO₂ removal in hypercapnic states.

Low flow VV with a pump can be used for selective CO₂ removal when the risk of arterial complication is unacceptable.

3. Unstable patients: If very unstable, **VA access** via IJ or femoral vein and fem artery is preferred. VAV may be used for concomitant heart and lung failure to supplement upper body oxygenation. If cardiac function recovers before lung function, access can be converted to VV.

B: Cannulas

1. Modes: Percutaneous access is possible in most adult patients. Ultrasound and fluoroscopy can facilitate cannulation. In the absence of imaging, the placement of conventional IV catheters first to verify position by pressure measurement can be followed by the placement of larger cannulas over a wire.

2. Cannulas: A large double lumen cannula, or two large (23-31 Fr) venous cannulas are required: IVC via femoral vein for drainage and right atrial via the jugular or opposite femoral for blood return.

For selective venovenous CO₂ removal 15 Fr double lumen cannulae will deliver adequate blood flow for total CO₂ removal.

For arteriovenous CO₂ removal, a 10 to 12 Fr arterial and 14 to 16 Fr venous cannulae provide adequate flow for total CO₂ removal.

III. Management during ECLS

A: Circuit related Management

1. Blood flow: Flow: 50-80 cc/drykg/min. Max initially, then lowest flow to maintain SaO₂>80-85% at rest vent settings.

Calculate DO₂/VO₂ frequently: Circuit DO₂ (flow x outlet-inlet O₂content) plus pt lung DO₂, =total DO₂, related to VO₂ (3cc/kg/min.)

Goal: DO₂:VO₂ >3 (Corresponds to SvO₂ 25-30% less than SaO₂)

2. Oxygenation: In the absence of lung function, VV access can supply all metabolic oxygen requirements. The arterial saturation is usually 80-85%, but may be 75-80% (PaO₂ 45-55). The lower recirculation with the three cannula or double lumen VV 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 adequate to maintain

DO₂ three times VO₂. 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 FiO₂ above rest settings during VV support.

3. CO₂ removal: Patient PaCO₂ is controlled by the sweep gas flow. When the circuit and blood flow are planned for oxygenation, CO₂ removal can be excessive, and the sweep gas flow is titrated to maintain PaCO₂ at 40 mmHg (usually 1:1 to blood flow). For selective CO₂ removal blood flow can be as low as 1L/min and sweep gas can be up to 15L/min, titrated to maintain PaCO₂ at 40 mmHg.

4. Anticoagulation: Heparin bolus before cannulation, and heparin infusion to maintain ACT 180-200 seconds or PTT 40-50 seconds.

B: Patient related Management

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 direct 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.

2. Ventilator management: Patients are on high FiO₂ and ventilator settings during cannulation. The goal of ventilator management on ECLS is to use FiO₂ <0.4, and nondamaging “rest settings (P_{plat}<25)” In many patients the lung may proceed to total consolidation before recovery occurs, but this might be avoided by maintaining some inflation pressure as high pressures are decreased, and by supplying nitrogen to prevent adsorption atelectasis. Each patient is different, but a general algorithm for ventilator management is:

a) First 24 hours: moderate to heavy sedation.

Pressure controlled ventilation at 25/15, I:E 2:1, rate 5, FiO₂ 50% ,FiN₂ 50% If initial PaCO₂>50, increase sweep slowly to bring PaCO₂ down slowly, 10-20 mmHg/hour

b) After 24-48 hours: (Stable hemodynamics off pressors, fluid balance underway, sepsis Rx underway) moderate to minimal sedation.

Pressure controlled vent at 20/10. I:E 2:1, rate 5 plus spontaneous breaths, FiO₂ .2-.4, FiN₂ 60-80%. (rest settings)

c) After 48 hours Minimal to no sedation.

PCV as above or CPAP20 plus spontaneous breathing. Trach or extubate within 3-5 days

d) CO₂ clearance mode: If the primary goal is CO₂ clearance (asthma, COPD exacerbation, avoiding high P in ARDS, Bronchopulmonary fistula, weaning from severe ARDS)

VV access, DLC via IJ preferred. Cannula can be smaller size, but should allow 1 L/min flow. Recirculation is acceptable. Use a full size oxygenator. Consider adding a post-pre shunt to allow 2-3L/min flow through the oxygenator to avoid clotting.

Regulate patient return flow with Hoffman clamp and flow meter to .5-1.5 L/Min to maintain PaCO₂ 40.

e) Recruiting trials: None until significant aeration on CXR and > 100cc/ min tidal volume.

After aeration, Cilley test. (increase FiO₂ to 1.0 with no other changes . Positive test is rapid increase to SaO₂ 100%) If positive Cilley test, start recruitment: CPAP with spontaneous breathing at 25cm H₂O. OR PSV at 25/10 rate 5, I:E 3:1 , 10 min/hr. then return to rest settings. Readjust flow if recruitment is successful. No airway Pplat >25.

3: Sedation. See general guidelines

4: Blood volume. See general guidelines

5: Temperature. See general guidelines

6: Renal and nutrition. See general guidelines

7: Infection and Antibiotics. See general guidelines

8: Positioning and Activity Management:

After 24-48 hours, sitting several hours/ day. Prone positioning if there is posterior consolidation with some open lung anteriorly. Be careful not to dislodge cannulas. Exercise in bed. Progress to sitting bedside, standing, walking as tolerated.

Increase flow and sweep during activity to maintain goal SaO₂ and PaCO₂.

9: Bleeding. For bleeding, 1. Decrease heparin to ACT 180 sec, D/C heparin if still bleeding 2. Platelet transfusion 3.FFP for factors, VWF replacement. 4. Check d dimers, If present anti fibrinolytics, Change circuit? 5. Local control, reop as needed with a low threshold. See general guidelines for alternatives

10. Procedures. See general guidelines

IV: Weaning: Trials off, Futility

A: Weaning. Decrease flow in steps to 1L/min at sweep 100% OR decrease flow to 2L/min then decrease sweep FiO₂ to maintain SaO₂ > 95%.

When SaO₂ stable on these settings, on VV, trial off by clamping sweep on vent rest settings PSV or CPAP 20 cm H₂O. If SaO₂ >95 and PaCO₂ <50 x 60 mins, come off.

If PaCO₂ >50 stay on at low flow, go to selective CO₂ clearance mode.

B: Trial Off. See general guidelines.

C: Decannulation. See general guidelines.

D: Futility. See general guidelines.

V: Patient and disease specific protocols:

A: Bronchoscopy and airway lavage are facilitated by extracorporeal support and should be used as indicated. Lighter sedation, prone positioning, and chest PT may allow mobilization of distal secretions and may reduce the need for bronchoscopy.

B: Management of air leaks: Chest tube placement is frequently accompanied by bleeding complications and need for thoracotomy, 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) can be 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 can 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/H₂O), 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/H₂O for hours or days leading to total atelectasis. 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.

C: Selective CO2 removal

For status asthmaticus and other conditions in which blood PaCO₂ is very high, reduce the blood pCO₂ gradually to avoid acid base imbalance or cerebral complications. A suggested rate of decreasing arterial pCO₂ is 20 mmHg/hr. When selective CO₂ removal is used to treat permissive hypercarbia and to achieve rest lung settings in ARDS, CO₂ 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 adequate, 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 FiO₂ when selective CO₂ removal is used. This is not an option with arteriovenous CO₂ removal. . In choosing the cannulation approach in such patients it is important not to undersize the cannula so that the maximum flow is less than the required flow to facilitate oxygenation.

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. Heparinization is required for the circuit, and adding thrombolytic drugs to speed up clot lysis often results in extensive spontaneous bleeding, so it is best to avoid lytics. 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.

E: 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.).

F: Fluid overload

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 reached (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.

G. 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 to facilitate ventilator weaning and minimize pharyngeal airway contamination and pneumonia. 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 FiO₂ but CO₂ retention, respiratory acidosis, the need for hyperventilation (either spontaneous or via the ventilator) to maintain PaCO₂ 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 reverts to normal within 1-6 weeks. It is analogous to the condition of alveolar level dead space CO₂ 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.

Post ECMO: Be careful! 10% of post ECMO pts die in hospital Stay in the home ICU until off vent x 24 hours. Avoid return to sedation and more ventilation. Scan for DVT within 48 hours of coming off ECMO. Consider IVC filter if there are signs of DVT.

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 and the primary diagnosis is not known, lung biopsy can and should be done within the first week on ECLS as early biopsy increases diagnostic yield allowing introduction of specific therapy early. 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.

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.

VI: Expected results:

The CESAR trial in the UK compared patients randomized to conventional care versus protocolized care including ECMO if needed. Healthy survival at 6 months was 63% in the ECMO protocol versus 47% in the conventional care group. Peek GJ, Mugford M, Tiruvoipati R, et al; for the CESAR trial collaboration. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomized controlled trial. *Lancet* 2009 Sep 15

A matched pairs study of ECMO in H1N1 influenza patients in the UK showed 76% survival in the ECMO protocol group versus 45% survival in the matched pairs control group. (*Noah, JAMA. 2011;306(15):1659-1668*)