Symposium

Common problems and troubleshooting on ECMO run

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ABSTRACT:
The technological advances in ECMO have changed to enhance safety, accessibility and facilitate its use, contributing to decreased morbidity and improved survival of patients requiring ECMO support. Major advances in ECMO deployment paralleled advances in conventional CPB including cannulas, pumps, oxygenator bubble detectors and heparin bonded circuits which decrease platelet activation, circuit clotting and prolong the circuit life. It is likely that further such advances will diminish complication rates, facilitate more widespread adoption of the technology in middle- and high-income countries, and improve outcomes from refractory heart, lung, and multiorgan failure.

Key words: Pediatric, ECMO, Complications, Thrombosis, Renal complications.

The continued improvement in the clinical management and innovations in the ECMO equipment resulted in wider application in different clinical scenarios. Today it has changed from a “rescue therapy of last resort” to a standard therapy with clear indications and contraindications. There are number of identified complications pertaining to ECMO therapy. These complications could be related to the underlying pathology which led to need of ECMO, or of the ECMO technology itself. Any cause leading to cardiorespiratory failure is associated antecedent injury due to hypoxemia, acidosis and shock. As ECMO is instituted, there are additional complications related because of altered flow dynamics, surgical insertion, circuit tubing, reperfusion injury and anticoagulation. So it is difficult to separate the complications related to ECMO from those related to initial illness(1). As a rule of thumb, the ECMO instituted for pulmonary support ie Venovenous ECMO (VV ECMO) has lesser complications than the ECMO instituted for cardiogenic support - Venoarterial ECMO (VA ECMO).

Common problems

Bleeding and clot formation:
The most common problems of ECMO are bleeding and clot formation in the circuit. There is a very high risk of bleeding on ECMO if any surgical intervention is performed (as minor as putting in a chest tube). Gastrointestinal hemorrhage and oozing from mucosal sites is very commonly seen. Intraventricular hemorrhage is always a dreaded complication throughout the ECMO run. The increased risk of bleeding is multifactorial.1 As the blood flows in the circuit, coagulation factors and platelets are activated and clot formation is triggered. This leads to consumptive coagulopathy resulting in bleeding complications.2 To prevent clotting, heparin which is used for anticoagulation of the circuit anticoagulates the patient too thus increasing the risk of bleeding and hemorrhage.3 The tubing and oxygenator trap platelets, causing thrombocytopenia. A large percentage of circulating platelets have reduced function.2

Most commonly used anticoagulant is unfractionated heparin. Antithrombin III (AT III) acts in concert with heparin to provide anticoagulation so AT III levels needs to be monitored and maintained for the heparin to work as an effective anticoagulant. To regulate the balance between thrombosis and bleeding.3 The institutions monitor anticoagulation in different ways. Activated clotting time (ACT) still remains the predominant diagnostic test utilized to monitor and adjust anticoagulation. Other specific tests including anti-factor Xa level, antithrombin III (AT III) as well as thromboelastograms are used with increasing frequency at many centers. No studies have demonstrated advantages of one test over another either in complications or related to cost of monitoring.

Few centers favor use of alternative anticoagulation agents (direct thrombin inhibitors: Argatroban and Lepirudin or Bivalirudin) especially in cases of suspected heparin induced thrombocytopenia or when long term ECMO use is anticipated. Bivalirudin dose

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adjustments are needed to maintain APTT 1.5-2.5 times baseline values. Some authors prefer to use Argatroban because its half-life is shorter than heparin and a similar ACT target range is effective. Now there are heparin coated ECMO circuit available in some parts of world not yet being universally used.

Our policy is to maintain, patient’s hemoglobin at higher than 8 g/dL. As a result of platelet consumption during ECMO, platelet transfusions are required to maintain platelet counts above 100,000/mcL. ACT should be maintained at 160-180 seconds to avoid bleeding complications. Heparin and blood product administration and factor replacement should be titrated to patient needs. Pediatric programs tend to initiate anticoagulation substantially earlier and aim for higher targets than adult programs because of the lower blood flow rates, larger circuit volumes relative to patient blood volume, and differences in infant coagulation physiology. Pre and post membrane pressures need to be closely monitored as well as frequent inspection of the circuit for any visible clots. Other complications of ECMO include neurologic, cardiovascular, and renal in addition to infections and metabolic problems.

Renal complications:
Renal dysfunction in patients treated with ECMO is mainly due to the altered hemodynamics associated with the baseline disease. Exposure to systemic inflammatory response due to the circuit result in further decrease of renal cortical/medullary blood flow ratio. This is more profound in patients requiring venoarterial ECMO, as the continuous flow generated by the ECMO system may not be sufficient to maintain adequate tissue perfusion and DO2 in peripheral organs such as the kidney. As compared to VA ECMO, specially in hemodynamically stable patients requiring venovenous ECMO, the native pulsatile cardiac output is maintained with minimal repercussions on renal perfusion.

The indications for beginning RRT in ECMO patients are relative, and essentially similar to those for starting RRT in non-ECMO patients. The timing of RRT and the targets for fluid removal need to be adjusted to the overall clinical situation, which is usually complex. Reports in the literature indicate that in pediatric patients, concomitant RRT-ECMO treatment is associated with less fluid overload compared with ECMO alone. Fleming et al reported that treatment of fluid overload has a major role in the decision to initiate RRT in ECMO patients. In particular, fluid overload was the main RRT indication reported for 43% of the patients, while AKI and electrolyte disorders were the indications for 35 and 4% of the patients, respectively.

Neurologic complications:
Neurological complications are highly variable ranging between 4-37% include seizures, Intraventricular hemorrhage (IVH), cerebral infarction and the potential for brain death. It is important to note that even before ECMO is initiated, the patient suffers an insult to the central nervous system secondary to hypoxia and poor perfusion. Cannulation for ECMO alters perfusion and can also contribute to reperfusion injury to the brain. It is therefore difficult to identify whether a neurologic complication is related to the use of ECMO, the antecedent injury suffered before ECMO, or a combination of factors.

According to the ELSO registry the incidence of major neurologic morbidity in cardiac patients as reported to ELSO is highest in neonates, with 7% suffering seizures, 3.5% infarction, and 11% intracranial hemorrhage. Children have slightly lower incidence of seizures and hemorrhage and a slightly higher incidence of infarction. In all age groups those patients who suffer major neurologic complications have a lower hospital survival. In VA ECMO, the right common carotid artery when considered as alternative insertion site, is associated with increased risk of a large watershed cerebral infarction 5-10%.

Cardiovascular complications: Cardiovascular complications include arrhythmias, hypotension, tamponade and cardiac stun. In addition newborns are at risk for maintenance or persistence of a patent ductus arteriosus.

Pulmonary complications: Pulmonary complications include pneumothorax or other airleaks as well as pulmonary hemorrhage and hemotheraces. Pneumothorax are often minimized by the use of rest ventilator settings.

Infectious complications: Infectious complications include culture proven infection and signs of inflammation, such as neutropenia and elevated C-reactive protein that suggest infection. Attachment to an ECMO circuit for an extended period provides a portal for potential infection, but these patients are also intubated and have many catheters and tubes that contribute to infection risk.

Metabolic complications: Metabolic issues include glucose, electrolyte and acid-base abnormalities.
Banked blood may contain high quantities of glucose and citrate, so glucose and calcium imbalances can be problematic. In addition patients may have a high bilirubin level or high plasma free hemoglobin, indicating significant hemolysis secondary to ECMO. ECMO may alter serum concentration of drugs due to increased volume of distribution, and decreased Kidney or liver function.¹⁴

**ECMO troubleshooting**

The important aspect of trouble shooting is to recognize the problem and then treat. The problem can be related to cannulas, tubings, blood pump, oxygentor, cannulation or weaning ECMO.

(A) **The issues related to cannula can be:**

1. Blood/fibrin clots – usually present where the tubing connects to the cannula when low flows and not properly anti-coagulated – Anticoagulation is increased and titrated , clots are monitored and if increase may have to replace connection

2. Un-tie-banded tubing connection with cannula – Tubing not inserted all the way in to cannula connector.
   To avoid catastrophic disconnection insert tubing well and secure.

3. Recirculation - In Veno-venous ECMO with Femoral vein – internal juglar vein cannulation, recirculation of ECMO blood flow can occur if ECMO blood flow is too high or if tips of cannulas are to close to each other. It is suspected when high mixed venous oxygen saturation are high (> 90’s) with low patient SaO₂.¹⁵
   To address this situation first ECMO blood flows are decreased however if not rectified then tips of the cannulas are repositioned.

4. Dual lumen cannulas (Avalon) used for veno-venous ECMO via the Internal juglar vein needs to be placed in a such away that the drainage lumen (distal tip of the cannula ) lying below the diaphragm (in the IVC) and the infusion lumen (proximal opening) in the SVC or SVC/right atrium junction, orienting the ECMO flow towards the tricuspid valve.¹⁶
   a. If not positioned correctly mixing may occur reflected as high preoxygenator saturation and low patient saturation.
   b. If cannula not inserted all the way, blood flow towards the innominate vein, left side congestion , brain death may ensue.

   c. When signs of right ventricle dysfunction manifest we should consider switching to VA ECMO.

(B) **The tubing on a ECMO circuit** will almost never give any problems, the caution is not to have too short or too long tubes.

(C) **Blood Pump** – Centrifugal pumps are widely used on ECMO circuits. In the setting of stable RPM, a drop in flow in a circuit with a centrifugal pump may be caused by decreased Preload or excessive afterload.¹⁵ The issues related to access head are:

1. Flow fluctuations in the access pump – This is when the venous access is unable to maintain a constant flow rate. Problem is usually with the venous access line or poor venous pressure.
   a. Venous access line – kinked cannula, Poor canula tip position , Kicking line syndrome
      i. Kicking line syndrome - venous access line keeps wiggling randomly, like a fire hose. The reason this happens is the vein collapses intermittently around the access cannula tip, causing the intra cannula pressure to briefly become very negative (which causes the atmospheric pressure to forcefully straighten the tube).¹⁵
   b. Decrease venous pressure-Poor Intravascular volume, Increase intrathoracic / intraabdominal pressure.
   c. The high suction at the cannula tip will shred more red cells. Generally an access pressure in excess of 250 mmHg will give rise to hemolysis.

**Management of access issues**

**Troubleshooting the circuit**

- First things first: check the cannula. Is it kinked?
- Patient repositioning may be helpful (or more harmful, if you kink the cannula)
- The oxygenator and pump head should be inspected for clots, as these may be contributing to haemolysis.

**Trouble shooting the patient**
• Some fluid resuscitation may be helpful (as it refills the central venous spaces, hopefully giving the venous access pump more pumpable substrate).
• One should think about abdominal compartment syndrome or some other reason as to why the big central vein where the cannula is might be under filled.

**Giving up**
• The pump RPM might need to be turned down.
• Ultimately the cannula may need to be repositioned or an additional cannula may be required if access problems continue. A second cannula frequently puts an end to the access problems.

2. Hand crank should always be available in case of a console malfunction – back up ECMO cart/console should always be available by bedside

3. Flow sensor issue (continuous alarming) – notify ICU team – fully support patient (ventilator, pressors) – Replace gel on sensor and restore blood flow

**(D) Oxygenator:** is the component of ECMO where majority of circuit related problems are seen

1. Increase Pre Oxygenator pressure and decrease post oxygenator pressure
   Cause: clot formation
   Management: Assess clotting whether it is getting worse over time or not and also Oxygen function is assessed by looking at the post oxygenator blood gas.

2. Both Pre/Post oxygenator pressures decrease
   Cause: Pump flow, kink anywhere before the oxygenator
   Management – To make sure that ECMO flow is not decreased, and there is no kink anywhere near preoxygenator

3. Both Pre/Post oxygenator pressure increase
   Cause: elevated systemic vascular resistance, obstruction anywhere post oxygenator like clot formation, kink
   Management: Mechanical obstruction needs to be taken care off like kink or clot, however if there is increase systemic vascular resistance adding vasodilator may help.

4. Low Post Oxygenator PaO2
   Cause: Oxygenator malfunction, clot formation, very low mixed venous oxygen saturation
   Management: Check Pre oxygenator PaO2, Evaluate oxygenator performance the a decision need to be taken to change the oxygenator or not

**(E) Cannulation:** a variety of complications can occur during cannulation, including vessel perforation with hemorrhage, arterial dissection, distal ischemia, and incorrect location (e.g., venous cannula within the artery) or development of pseudoaneurysm at the site of insertion. These complications are rare <5%.

1. Distal limb ischemia – can be managed by by inserting an additional arterial cannula distal to the femoral artery cannula to perfuse the distal extremity at the time of ECMO insertion. Alternatively, a cannula can be inserted into the posterior tibial artery for retrograde flow to the extremity.

2. Cardiac thrombus- occurs secondary to retrograde blood flow in the ascending aorta whenever peripheral cannulation through the femoral artery and vein are used for VA ECMO. Stasis of the blood can occur if left ventricular output is not maintained, which may result in cardiac thrombosis.

3. Coronary or cerebral hypoxia: during VA ECMO, fully saturated blood infused peripherally into the femoral artery from the ECMO circuit will preferentially perfuse the lower extremities and the abdominal viscera. Blood ejected from the heart will selectively perfuse the heart, brain, and upper extremities. In the setting of poor lung function with good myocardial function. One may circulate poorly oxygenated blood in these areas resulting in cardiac and cerebral hypoxia. This phenomenon is also known as upper body hypoxemia, North-south syndrome and Harlequin syndrome.

   a. It can be fixed by adjusting the ventilator settings.
   b. By increasing the VA ECMO flows.
   c. By switching the arterial outflow cannulation from femoral artery to the axillary or carotid artery.
   d. A VA-V ECMO circuit can also be created
where a portion of oxygenated blood from the arterial outflow cannula is diverted by the right internal jugular vein in the right heart.

4. Cardiac shunt – During VA ECMO with femoral artery cannulation, the retrograde flow of the ECLS pump can overwhelm a failing left ventricle (LV). A poorly functioning LV becomes a conduit for retrograde flow and fluid backs up into the LA. Increased LV pressure will allow retrograde flow into the pulmonary veins resulting in pulmonary hemorrhage. There is no convenient management therapy.17
   
a. Inotropic support can be instituted or escalated to increase the contractility of the myocardium.
   
b. In addition afterload reduction with vasodilator or Intra-aortic balloon pump (IABP) may be implemented. An IABP bring the added benefit of improving coronary perfusion during diastole.
   
c. Venting the left atrium or ventricle – To access the LV apex with a cannula, and connect that cannula to the venous access lines of the ECMO circuit, allowing the ECMO pump to decompress the left ventricle.
   
d. Atrial septostomy - with the intention of allowing left-sided blood to mingle with the right side, thus equalising the pressures between the cardiac chambers.18

Conclusion:
Knowledge and appreciation of the circuit, cannulae, and the physiology of gas exchange with ECMO are necessary to ensure lung rest, efficiency of oxygenation, and ventilation as well as troubleshooting problems. Anticoagulation is a major concern with ECMO, and the evidence is evolving with respect to diagnostic testing and use of anticoagulants. Clinical management of the patient includes comprehensive critical care addressing sedation and neurologic issues, ensuring lung recruitment, diuresis, early enteral nutrition, treatment and surveillance of infections, and multisystem organ support. Risks, complications, and long-term outcomes and resources need to be considered and weighed in before widespread application. Ethical challenges are a reality and a multidisciplinary approach that should be adopted for every case in consideration.

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