SCIENCE AND TECHNOLOGY

Extracorporeal Membrane Oxygenation (ECMO) in the Operating Room

AUDREY STONE

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ABSTRACT

In this review, we discuss the management of patients supported by extracorporeal membrane oxygenation (ECMO) in the operating room. We will review the mechanics of ECMO, indications for veno-arterial (VA) and veno-venous (VV) ECMO, management of patients who are supported by ECMO, and troubleshooting common complications. We will also discuss practical considerations for transporting patients who are supported by ECMO to and from the operating room. ECMO is an established modality to support the heart and lungs with expanding utilization. It can be used as a bridge to organ recovery, organ transplantation and even to temporarily support surgical procedures. The successful management of patients supported by ECMO requires medical expertise as well as vigilance by the entire perioperative team including the anesthesia technician.

HISTORICAL OVERVIEW

The development of modern ECMO has its origins in the early 20th century when the first dialysis machines and cardiopulmonary bypass circuits were being developed. In 1944, Willem Kolff and colleagues, who were pioneers in the field of hemodialysis, noted that blood became oxygenated across a semi-permeable membrane. John Gibbon was a surgeon who utilized membrane oxygenation to build the first cardiopulmonary bypass machines for cardiac surgery in 1953. In 1972, cardiopulmonary bypass was used outside the operating room to support a patient who developed acute respiratory distress syndrome (ARDS) after aortic surgery. Over the next few decades, cardiopulmonary bypass machines were increasingly used to support patients outside the operating room with heart and lung failure. During the recent pandemic, ECMO was used to support thousands of patients with severe pneumonia associated COVID-19 (1).

THE ECMO CIRCUIT

The ECMO circuit uses an inflow cannula to extract blood from the venous system using an external pump and returns the blood into a large artery (VA ECMO) or a large vein (VV ECMO) with outflow cannulas. The ECMO inflow cannula is typically inserted into the femoral or internal jugular veins and functions to drain venous blood into the pump. The most commonly used pumps are centrifugal pumps, which use rotational energy to move blood forward. Blood also flows into an oxygenator where gas exchange occurs. Modern oxygenators use gas-permeable materials like polymethylpentene to facilitate the transfer of oxygen to the blood and carbon dioxide out of the blood. Because carbon dioxide is much more diffusible than oxygen, it is far easier to remove a patient's carbon dioxide than to add oxygen. Increasing the sweep gas flow, or the flow of oxygen through the oxygenator, will remove more carbon dioxide. Because oxygen is less diffusible, the most efficient way to add oxygen to the patient's blood is to increase the fraction of oxygen in the sweep gas (FSO2) and to increase the flow of ECMO through the ECMO circuit, which acts to expose more blood to the oxygenator.

In VA ECMO, blood is returned to the body through a large cannula which is typically inserted in the femoral artery. In VV ECMO, it can be returned into another large vein. VV ECMO can also be accomplished using a single dual-lumen cannula placed in the internal jugular vein, which extracts and returns blood using different lumens. Patients with larger body surface area may require more than one inflow or more than one outflow cannulas as well.

INDICATIONS FOR ECMO AND CANNULATION

VV ECMO is utilized for patients who are experiencing primary respiratory failure that is not amenable to conventional therapies such as mechanical ventilation. Some conditions necessitating VV ECMO include acute respiratory distress syndrome (ARDS), bronchopleural fistula and status asthmaticus. VV ECMO provides the advantage of complete pulmonary support while the patient's lungs are allowed to rest on minimal ventilator settings. VV ECMO is also used in patients with end-stage lung disease awaiting lung transplantation. Since VV ECMO only provides respiratory support, it is not indicated in patients with heart failure. Heart failure patients who also have problems with oxygenation or ventilation should be managed with VA ECMO instead.

VA ECMO is indicated for patients with cardiogenic shock which has not improved with medical management. Common conditions which require VA ECMO include decompensated heart failure, acute myocardial infraction, myocarditis, malignant arrythmias and failure to separate from cardiopulmonary bypass after cardiac surgery. Because VA ECMO requires a cannula to be placed in the arterial system, it is associated with significant morbidity and mortality. Data from the Extracorporeal Life Support Organization (ELSO) registry has consistently reported a survival to hospital discharge of less than 50% for adult patients supported by VA ECMO. In contrast, survival to discharge in VV ECMO patients approaches 60% (1).

A special case of VA ECMO is extracorporeal cardiopulmonary resuscitation (ECPR) which requires transitioning to ECMO in cardiac arrest patients who cannot be resuscitated. While there are few good studies evaluating outcomes with ECPR, patients with a witnessed cardiac arrest who have few comorbidities and a reversible cause of cardiac arrest are more likely to survive.

TRANSPORTING PATIENTS ON ECMO

Patients supported by ECMO often require procedures in the operating room to facilitate necessary procedures or transition from ECMO to recovery, alternative mechanical support or organ transplantation. Transporting these patients to and from the operating rooms requires a team-based approach to enable monitoring and management. In addition to the perioperative team, ELSO recommends that a team member dedicated to monitoring the ECMO circuit – often a perfusionist or ECMO specialist – accompany ECMO patients who are transferred within a hospital (2). Prior to transport, the perioperative team should ensure that adequate battery life is present in all devices including the ECMO console. Adequate oxygen to support both the ECMO oxygenator and the ventilator should be packed for transport. The use of an ICU ventilator is recommended to avoid inconsistent ventilation and atelectasis associated with disconnection of the endotracheal tube from the ventilator (3). Some patients may require transport with a defibrillator, other mechanical circulatory devices, a Nitric Oxide delivery system, and other equipment. During transport, both the ECMO console and vital signs monitor may require attention. Vasoactive medications and fluids may have to be delivered to maintain stability. After reaching the transport destination, meticulous care is necessary to ensure that the equipment is attached to durable oxygen and power sources.

INTRAOPERATIVE MONITORING AND MANAGEMENT

All patients supported by ECMO in the operating room require standard American Society of Anesthesiologist (ASA) monitors. Additionally, these patients will likely have one or more invasive pressure monitors which include arterial lines, central venous lines and pulmonary artery catheters. Frequent laboratory tests are required to assess the patient's hemoglobin, electrolytes and coagulation profile. Transesophageal echocardiography can also be used to evaluate cardiac function, monitor volume status and to guide surgical procedures. Because patients with end-stage lung disease supported by ECMO may not be able to impair the delivery of volatile anesthetics, a total intravenous anesthesia (TIVA) approach or a balanced approach with infusions of propofol, opioids or benzodiazepines may be used. Regardless of the choice of anesthetics, depth of anesthesia monitoring is recommended to ensure that the patient is sufficiently anesthetized for the procedure. Near infrared spectroscopy (NIRS) monitors should also be considered to ensure perfusion to the brain.

Arterial blood gas (ABG) testing on arrival to the operating room and at frequent intervals is necessary to ensure that the combination of the ventilator and ECMO oxygenator are adequately performing gas exchange. Activating clotting time (ACT) is also used to ensure that anticoagulation goals are being met. The ECMO console can serve as an important intra-operative monitor, providing real-time ECMO flow, circuit pressures and some laboratory tests. These laboratory tests can include hemoglobin and right atrial oxygen saturation.

Patients supported by VA ECMO frequently require systemic anticoagulation (often with heparin or bivalirudin) to reduce clot formation in the circuit and arterial embolization of blood clots. Anticoagulation in VV ECMO patients varies by institution with some using systemic anticoagulation, some using subcutaneous heparin as the sole anticoagulant and some using no anticoagulation. While anticoagulation in the ICU is monitored using a range of tests such as the anti–factor Xa assay and chromogenic factor II level, ACT remains the most common point-of-care test to assess anticoagulation in the operating room. The therapeutic target level of ACT for ECMO ranges from 160 to 200 depending on the type of ECMO (VA vs. VV), as well as patient and procedural factors.

TROUBLESHOOTING THE ECMO CIRCUIT

Problems with flow

The flow of blood on ECMO is analogous to cardiac output and is measured in liters per minute. Increasing the pump speed, measured in rotations per minute (rpm), should increase flow. On VA ECMO, higher flow results in a higher augmentation of cardiac output and better oxygen delivery. On VV ECMO, higher flows simply result in better oxygen delivery. In both ECMO configurations, flow is dependent on preload, or the blood draining from the patient and sensitive to afterload, which is the pressure against which the ECMO circuit has to pump. A common scenario in the operating room is low flow associated with very negative venous pressures reported on the ECMO console, suggesting low preload. This can also result in 'chattering' or visible vibration of the inflow portion of the ECMO circuit, which results from suction forces transmitted from the inflow cannula. This problem can be corrected by administering fluids. Kinking or compression of the tubing coming from the ECMO towards the outflow cannula can result in low flows as well, accompanied by elevated arterial pressures reported by the console.

Problems with oxygenation and carbon dioxide removal

Hypoxemia on ECMO may be difficult to detect using conventional pulse oximetry, as some patients who are supported with VA ECMO and have poor native heart function will not have any arterial pulsatility. Frequent arterial blood gas sampling may be necessary to ensure that these patients are adequately oxygenated. Cerebral oximetry using NIRS may provide an early warning sign that perfusion or oxygenation in the brain may be inadequate. In patients who are hypoxemic, the FSO2 and ECMO blood flow should be increased until the oxygenation goals are met.

Hypercarbia is rare on ECMO because of the efficiency of the oxygenator in removing carbon dioxide. In patients without severe lung disease, carbon dioxide removal may be performed both by the lungs on the ventilator and the ECMO oxygenator. However, it is preferable to use the oxygenator rather than the lungs to allow for lung-protective ventilation at low pressures and volumes. In patients with elevated carbon dioxide levels, the sweep gas flow on ECMO can be increased to remove additional carbon dioxide.

WEANING FROM ECMO AND DECANNULATION

Patients are frequently weaned from VA ECMO in the operating room because it allows the surgical team to repair the artery used for ECMO cannulation and evaluate heart function using intraoperative echocardiography. Patients supported by VV ECMO can frequently be decannulated at bedside in the ICU. VV ECMO patients are decannulated when there is evidence of good lung function. This often requires a PaO2/FiO2 ratio of at least 200 and a normal carbon dioxide level when the ECMO sweep gas is turned off.

Patients supported by VA ECMO can be decannulated when their native heart function improves or when they transition to a durable mechanical support device such as a left ventricular assist device (LVAD) or undergo heart transplantation. The process of weaning a patient from VA ECMO involves gradual reduction of ECMO blood flow while evaluating the native heart function using echocardiography and invasive pressures. A recovered heart will accept additional preload as the ECMO blood flows are weaned and pump that preload forward resulting in a normal blood pressure and low left (PA catheter) and right (CVP)-sided filling pressures.

CONCLUSION

ECMO is an established technology for providing cardiac and/or pulmonary support and its use has increased significantly in the last several decades. It is common for patients supported by ECMO to undergo cannulation and decannulation in the operating room and also undergo necessary procedures. The ECMO circuit, which consists of the pump, oxygenator, cannulas and tubing have important functions and require monitoring throughout the perioperative period. The transport of ECMO patients within the hospital is a complex logistical task which requires special equipment and expertise. Patients supported by ECMO require additional monitors in the operating room to monitor oxygenation and perfusion. Volatile anesthetics may not be effective in patients with end-stage lung disease and these patients will require alternative anesthetic techniques and depth of anesthesia monitoring. Problems with flow and gas exchange occur frequently and require vigilance and prompt management. The increasing frequency of patients supported by ECMO requires the perioperative team, including the anesthesia technician, to be familiar with ECMO equipment, patient management and potential complications.

Works Cited

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To test your knowledge on this issue's article, provide correct answers to the following questions on the form below. Follow the instructions carefully.

1. Which type of mechanical circulatory support device is best used to support patients with end-stage lung disease?
A) VA-ECMO
B) Impella
C) VV-ECMO
D) LVAD

2. Which of the following should be increased to reduce the patient's carbon dioxide level?
A) ECMO blood flow
B) Fraction of inspired oxygen (FiO2)
C) ECMO sweep gas flow
D) Anticoagulation target

3. Which of the following is an acceptable Activated Clotting Time (ACT) target for a patient supported by VA ECMO?
A) 480
B) 300
C) 180
D) 100

4. Which of the following reflects a patient's oxygen level while supported by ECMO?
A) pulse oximetry
B) cerebral oximetry
C) PaO2
D) all of the above

5. Which of the following is a complication of ECMO?
A) hypoxemia
B) hypercarbia
C) bleeding
D) all of the above

6. Which of the following should be used to ensure that a patient supported by ECMO is getting adequate anesthesia?
A) Depth of anesthesia monitor
B) Cerebral oximetry
C) Near Infrared Spectroscopy
D) Pulse oximetry

7. Which of the following is used to describe the process of placing a patient undergoing unsuccessful CPR on ECMO?
A) LVAD
B) Impella
C) VV-ECMO
D) ECPR

8. Which of the following need to be monitored while transporting a patient on ECMO?
A) ECMO console
B) Transesophageal echocardiography
C) Transthoracic echocardiography
D) Near infrared spectroscopy

9. A patient who is supported by ECMO experiences chatter or vibration of the ECMO inflow lines during a surgical procedure. What should be done?
A) Increase ECMO flow
B) Infuse normal saline
C) Increase sweep gas flow
D) Obtain activated clotting time (ACT)

10. True or False: ECMO was used to support patients during the COVID-19 pandemic.
A) True
B) False

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