Update on Anesthesia Management for Explantation of Veno-Arterial Extracorporeal Membrane Oxygenation in Adult Patients

Abstract

The utilization of temporary circulatory support in the form of extracorporeal membrane oxygenation (ECMO) has increased and its indications are expanding. Anesthesiologists may be involved in the care of these patients during the initiation of and weaning off from ECMO, surgical procedures with an ECMO *in situ*, and transfer of patients on ECMO between the operating theater and intensive care unit. This article addresses the anesthetic considerations and management for explant of veno-arterial ECMO in adults.

Keywords: *Adults, anesthesia, Veno-arterial extracorporeal membrane oxygenation, wean*

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Introduction

Veno-arterial extracorporeal membrane oxygenation (VA ECMO) is a temporary mode of therapy to support cardiorespiratory function in cardiogenic shock refractory to conventional treatment. It allows the heart to rest by decreasing myocardial work and cardiac oxygen consumption while maintaining systemic organ perfusion with oxygenated blood.

Cannulation for VA ECMO can be described as either central or peripheral. ECMO components include venous drainage and arterial inflow cannulas, heparin-bonded tubing, centrifugal or roller pump, gas blender, and membrane oxygenator. For central VA ECMO, right atrial blood is drained directly via a long cannula, circulated through an extracorporeal membrane oxygenator for gas exchange, and returned through a long arterial inflow cannula to the ascending aorta. This modality is used when the patient cannot be weaned off cardiopulmonary bypass after cardiac surgery and the chest is left open from sternotomy. More often, peripheral ECMO is favored, even for VA ECMO support post-cardiotomy, as it reduces blood loss from having an open chest cavity. For peripheral VA ECMO, central venous blood is drained through a long cannula introduced either via the femoral vein or the internal jugular vein, with the tip of the cannula positioned at the level of the right atrium and side holes in the vena cava. The arterial return for peripheral VA ECMO configuration is via a cannula inserted directly into the femoral, axillary, or carotid artery. To maintain distal limb perfusion, a short segment of polyethylene terephthalate tube graft (DacronR™) may be sewn end-to-side to the femoral artery to serve as a conduit. Alternatively, a distal perfusion cannula distributing a portion of the arterial return can be inserted, distal to the main entry site of the arterial cannula, to reduce distal limb ischemia. Technological improvements over the last decade have made components in the VA ECMO circuit durable, compact in size, and safer to use.[1]

Depending on the clinical course of the patient's progress, VA ECMO functions as a bridge to recovery or a bridge to decision, either to a different therapeutic modality, such as durable ventricular assist devices or heart transplant, or withdrawal of support. Anesthesiologists may be involved in the care of patients with VA ECMO for various purposes, including weaning off ECMO, noncardiac surgical procedures, and transfer of patients. In this article, cardiopulmonary support during VA ECMO, suitability for weaning, and management to facilitate successful explanation in adults are discussed.

Method

PubMed, Cochrane, and Google Scholar databases were searched from 2008 until

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Access this article online

Website: www.annals.in

DOI: 10.4103/aca.ACA_178_18

Quick Response Code:

2018 without any language restrictions. Web search for unpublished abstracts was also conducted.

The keywords (MeSH terms) included "wean," "venoarterial," "VA," "ECMO," and "adult." Abstracts from more than 53 citations were scrutinized, and included articles were examined for additional references. All study designs were eligible and determined for inclusion as per the following criteria: peer reviewed, VA ECMO related and translated to English if it was originally written in other languages. Unpublished abstracts were also included for review, if relevant, addressing possible publication bias. The total number of articles reviewed was 46. The latest editions of Extracorporeal Life Support Organization (ELSO) guidelines on the subject were also reviewed.

Indications for VA ECMO in Adults

VA ECMO has been employed to bridge adult patients with overt cardiac failure following various causes listed in Table 1. The report from IABP-SHOCK II that the use of intra-aortic counter-pulsation balloon pump (IABP) for cardiogenic shock has not shown benefit over the conventional medical treatment alone,[2,3] and the 2015 American Clinical Expert Consensus Statement[4] supporting the use of other mechanical circulatory support devices over IABP for cardiogenic shock, have further increased the utility of VA ECMO.

Peripheral VA ECMO has also been increasingly considered as part of advanced life support for cardiac arrest. Extracorporeal resuscitation during cardiopulmonary

Table 1: Indications for adult VA ECMO

As a bridge to decision* or recovery in severe cardiogenic shock or cardiac failure secondary to
- Acute coronary syndrome
- Refractory cardiac arrhythmias
- Severe sepsis
- Drug toxicity
- Myocarditis
- Pulmonary embolism
- Acute anaphylaxis
- Isolated cardiac or major vessel trauma
- Chronic cardiac conditions

Post-surgical
- Graft failure following heart or heart-lung transplant
- Failure to wean following cardiopulmonary bypass

Post cardiac arrest as part of advanced life support
- After 10 min of adequate but unsuccessful advanced life support[5]

Nonconventional uses
- Peripartum cardiac and respiratory failure such as amniotic fluid embolism and peripartum cardiomyopathy[66]

*Implantation of left or bi-ventricular assist devices or heart transplant

resuscitation (ECPR) deploys peripheral VA ECMO to sustain oxygenated circulation until the return of spontaneous circulation.[5,6] According to the Extracorporeal Life Support Organization (ELSO) Registry report for July 2018, approximately 10.5% of the patients who received ECMO support were for ECPR. Of the patients who had peripheral ECMO for ECPR, approximately 16% were neonates, 37% were pediatric patients, and 47% were adults.[7]

Cardiopulmonary Support during VA ECMO

Pump flow

VA ECMO pump flow in adults is regulated to meet physiological targets of mean arterial pressure (MAP) of 50–70 mmHg, arterial saturation of at least 95%, and venous saturation of greater than 70%.[8] Pump flow is kept between 50 and 75 ml/kg/min to achieve a cardiac index of 3 L/min/m^2.[8,9] Although flow is controlled by pump properties (revolutions per minute on a centrifugal peristaltic pump), the actual flow to the patient is further influenced by resistance of drainage cannulas (length and diameter), as well as patient's intravascular volume or preload[10] and systemic vascular resistance.[9]

During VA ECMO, left ventricular (LV) distension can easily occur because of the pressure imbalance across the aortic valve, caused by the high afterload from ECMO inflow, which prevents the failing left ventricle from ejecting blood. Strategies that can be introduced to reduce LV distension include reducing preload (maintaining a negative fluid balance and increasing ECMO flow to drain a larger portion of venous blood into the ECMO circuit) and promoting LV forward flow (reduction of MAP, administration of low dose infusion of inotropic agent, LV pacing, treatment of tachyarrhythmias, and even insertion of IABP or the Impella™).[11] The Impella™ device is a microaxial pump placed percutaneously via a femoral arterial puncture and positioned across the aortic valve. With the inflow portion lying just within the LV cavity and the outflow portion beyond the aortic valve, LV output is augmented.

Gaseous exchange

Gaseous exchange occurs across the membrane oxygenator where carbon dioxide is removed and oxygen is absorbed. The rate of oxygen delivery and carbon dioxide removal is dependent on the set oxygen concentration and gas flow rate in L/min, commonly known as "sweep." It is usually set as 1:1 with counter current blood flow. Higher sweep results in greater carbon dioxide removal. Oxygen delivery capability is additionally related to blood flow, hemoglobin concentration, patient hemoglobin saturation, and ECMO membrane properties.[8] The sweep flow is adjusted to maintain $PaCO_2$ at approximately 40 mmHg.

A small proportion of venous blood not captured by the venous cannula continues to flow through the right ventricle and lungs. However, mechanical ventilatory support settings are usually adjusted to allow lung rest.[12] In assisted ventilation, low respiratory rate with longer inspiratory time, tidal volume of less than 6 mL/kg, low plateau inspiratory pressure (less than 25 cmH_2O), and low FiO_2 (less than 40%) may be applied.[8] Positive end-expiratory pressure (PEEP) can be set at any reasonable level but avoiding inhibition of venous return.[8] If the patient can breathe spontaneously, an elevated continuous positive airway pressure level with timed pressure release may be applied to ease ventilatory efforts.

Respiratory function cannot be fully assessed as gas exchange is maintained by the membrane oxygenator. With return of well-oxygenated blood from peripheral VA ECMO into the femoral artery, mixing of blood occurs invariably between the aortic root and descending aorta. The exact location depends on the native cardiac output and magnitude of retrograde flow. With poor myocardial contractility, retrograde ECMO flow provides good oxygen delivery to the coronary and cerebral circulation. The preferred site of blood gas sampling with femoral artery cannulation is the right radial artery.

Anticoagulation Strategy

Patients on VA ECMO are anticoagulated as exposure of patient's blood to the synthetic material of the extracorporeal circuit creates a hypercoagulable state. The degree of anticoagulation is a balance between reducing thrombotic risk while preventing complications related to bleeding. Current ELSO guidelines recommend using unfractionated heparin infusion to maintain activated clotting time (ACT) at 1.5 times normal or between 180 and 220 s,[8,13-17] the activated partial thrombin time (aPTT) maintained at 1.5 to 2 times the baseline value or 60–80 s,[18] and if monitored, the anti-Factor Xa is targeted at 0.3 to 0.7 IU/ml.[13] These targets help guide heparin dosing[13,19] while monitoring for potential bleeding. Viscoelastic tests, such as thromboelastography (TEG) or thromboelastometry (ROTEM), provide comprehensive information on clot formation, strength, and dissolution, and are recommended by the ELSO.[8,20] In patients with heparin-induced thrombocytopenia, where heparin infusions are to be avoided, direct thrombin inhibitors such as argatroban and bivalirudin can be used instead.[13,14,19]

Complications

Bleeding, thrombocytopenia, thrombosis, limb ischemia, and neurological events such as intracranial hemorrhage or stroke are commonly encountered complications in patients requiring VA ECMO support.[21] Major hemorrhage was the most commonly reported complication followed by renal failure requiring renal replacement therapy after institution of VA ECMO for refractory cardiogenic shock post cardiac surgery.[22] Heparin infusion and heparin-coated circuits are known to be the primary causes of bleeding.[23] Thrombocytopenia (defined as platelet count less than 150,000 per microliter) occurs in 20% to 50% of critically ill patients in intensive care units.[24] It is also frequently observed in patients on ECMO support,[14,25] and is attributed to consumption due to activation following contact with the ECMO circuit and heparin-induced thrombocytopenia.[26,27] The degree of platelet reduction is observed to be between 25% and 40%.[28] Platelet count should be maintained above 100,000 to 150,000 per microliter for patients on ECMO.[8,14,19]

Suitability for Weaning Off VA-ECMO

Prematurely withdrawing when the patient is not ready exposes the already compromised heart to stressors from high-dose inotropes, hemodynamic instability, and emergent recannulation and re-initiation of ECMO. On the other hand, delayed withdrawal can unnecessarily prolong the exposure to risks of ECMO-related complications and increase morbidity and mortality.[29]

It is uncommon to attempt weaning in the first 72 h after VA ECMO implantation as the myocardium and other end-organs require time for recovery.[30] In general, patients who can be considered for weaning from VA ECMO demonstrate improving myocardial contractility, reducing inotropic requirements, and decreasing pulmonary capillary wedge pressure and central venous pressure within one week of VA ECMO.[31] Between 31% and 76% of patients can be weaned off VA ECMO depending on the underlying cause of cardiogenic shock.[32-39] Successful weaning means having the ECMO removed and the patient not requiring further mechanical circulatory support in the following 30 days.[40] In cases of drug intoxication, VA ECMO weaning can be attempted earlier.[41-43]

Excellent results have been achieved with VA ECMO support for acute fulminant myocarditis in adult patients, with approximately 72% survival to hospital discharge.[44] Patients who had primary graft failure after cardiac transplant had a 74.3% survival to hospital discharge.[45] Thirty-day survival of approximately 61% can be expected for patients with acute ST-elevation myocardial infarction with profound cardiogenic shock who received primary percutaneous intervention and VA ECMO.[46] Patients who cannot be weaned off cardiopulmonary bypass after cardiac surgery have a lower survival rate of approximately 31%.[47] The most frequent reasons for death are cardiac and multisystem organ failure.

ECMO flow rate is usually optimized daily by weaning to the lowest flow which can provide adequate support at minimal vasoactive medication doses and ventilator settings. If pulsatile arterial waveform is observed for at least 24 h, generally a trial of weaning can be conducted. With close monitoring of the patient's MAP, the ECMO flow rate can

be progressively reduced step-wise by 0.5 L/min every 3 to 5 min until 1.5 L/min[12,48] or step-wise to 50% then 25% of full flow.[31] This step-wise reduction strategy is stopped when the MAP decreases to less than 60 mmHg, following which the ECMO flow should be returned to the baseline. If the MAP can be maintained above 60 mmHg with ECMO flow rates at 25% of full flow, it suggests that native heart function may be adequate to allow weaning off ECMO. The extracorporeal circuit may be clamped for a trial period of 30 min to 4 h.[31] Anticoagulation is maintained during this trial, and the circuit is periodically unclamped to avoid blood stagnation.[8]

Transthoracic or transesophageal echocardiography (TEE) imaging provides pertinent information on the patients' cardiac function. Signs of cardiac recovery on echocardiography include improved ventricular contractility and consistent opening of the aortic valve.[49] The baseline and subsequent echocardiographic measurements during step-wise reduction of ECMO flow should include evaluation of LV ejection fraction (EF), LV outflow tract velocity time integral (LVOT VTI), aortic VTI, and peak systolic velocity (S' wave) at the lateral mitral annulus on tissue Doppler imaging. At minimal ECMO support, echocardiographic indices predictive of successful weaning include LVEF of between 20% and 25%, LVOT VTI and aortic VTI greater than 12 cm, S' wave velocity at the lateral annulus of the mitral valve greater than 6 cm/s, no worsening of ventricular dilatation or mitral or tricuspid regurgitation, and no cardiac tamponade.[12,49-51] While on ECMO, the pressure gradient between the right atrium and ventricle is reduced due to reduced preload, and the assessments of tricuspid regurgitation and right ventricular (RV) systolic pressure are inaccurate. Hence, during the process of weaning from ECMO support, TEE imaging should also focus on the RV function.

"Pump Controlled Retrograde Trial Off" (PCRTO) has been used for neonate and adult VA ECMO weaning.[52,53] In PCRTO, pump speed is gradually reduced until circuit flow becomes retrograde, with the pump acting as a resistor to prevent precipitous decrease in systemic vascular resistance. Retrograde flow provides adequate RV filling to allow assessment of RV function. The sweep gas is also turned off during this process, so the patient's gas exchange can be assessed.

Recovery of myocardial function pushes the mixing point of blood pumped from the left ventricle and blood from the ECMO more distally along the aorta. The native cardiac output now perfuses the coronary and cerebral circulations, and with good pulmonary gas exchange, the coronary arteries, the innominate, and the right carotid artery receive well-oxygenated blood. However, in the presence of atelectasis and shunting, poorly oxygenated blood would be delivered to the coronary and cerebral circulations while fully oxygenated blood perfuses the distal two-thirds of the body.[9] As mentioned earlier, the preferred site of blood gas sampling would be the right radial artery.

Patients on VA ECMO can be considered for weaning even if renal function has not fully recovered. Recovery from acute renal injury following cardiogenic shock can take up to four weeks after improvement of cardiac output.[54,55] The presence of renal and liver impairment will influence the choice of drugs, drug dosing regimen, and volume administration. Volume overload can be managed by diuretic or hemofiltration.[30]

Preparation for Explantation of ECMO Support

A multidisciplinary approach is essential for the perioperative management of the patient. As early as feasible, the cardiothoracic surgeon should conduct a team brief for the anesthesiologists, perfusionists, and operating theater nursing staff involved in the procedure to ensure that all are uniformly informed about the patient and surgical plan. Components discussed in the team brief are listed in Table 2. Explantation of central VA ECMO should be conducted in the cardiothoracic theatre. While peripheral VA ECMO may be explanted by the bedside, access to percutaneous cannulation sites is better and sterility can be maintained during the procedure if performed in the operating theatre.[56] Having a shared mental model within the team benefits the patient by coordinating care, minimizing delays,[57] and improving team performance in provision of clinical care.

Anesthesia Considerations for Explantation of VA ECMO

Preoperative assessment

While on VA ECMO, patients may be pacing-dependent or have pacing *in situ* via either transvenous or epicardial leads.[20,58] Relevant information for the anesthesiologists includes mode and rate of pacing, intrinsic rhythm, output,

Table 2: Components of preoperative team brief
Patient-related
• Indication for VA ECMO
• Patient comorbidities and concomitant pathology
• Current ECMO parameters
• Echocardiography findings
• Degree of anticoagulation
Intraoperative plans and concerns
• Operative plan
• Strategy for weaning
• When weaning should be aborted and patient returned to full support
• Coagulation strategy until successful weaning
• Ventilatory strategy and concerns
• Equipment required

and sensing threshold. Being familiar with the use of the pacemaker is important as adjustments may have to be made after weaning off ECMO.

Ventilatory settings and latest arterial blood gas analysis should be reviewed. Peak airway pressures on the ventilator reflect to an extent the dynamic compliance of the lung and chest wall. This may be an estimate of lung function, albeit a nonideal surrogate. Chest radiographs should be reviewed to exclude pleural effusion and consolidation. If the cardiac function is adequate, the usual causes of hypoxemia after separation from ECMO support include atelectasis as well as interstitial and alveolar edema.[59] A bed-side lung ultrasound can be performed as part of preoperative evaluation of lung function to exclude features of atelectasis, volume overload, and consolidation.

Vascular access for invasive hemodynamic monitoring, such as arterial and central venous catheters, should be visually inspected, and infusion ports on central venous catheters should be identified. Suitable sites for additional intravenous access for volume replacement in an event of bleeding during decannulation should be ascertained. Hemoglobin concentration or hematocrit level, platelet count, and liver function should be reviewed. In addition, it is important to ensure that the ACT is within the targeted range, and acid-base and electrolyte imbalances have been corrected. Because of the ongoing heparinization, bleeding from cannula sites is a concern during ECMO explant. Blood should be grouped and matched.

Transfer of patient to the operating theatre

Before transferring the patient to the operating theatre, it is necessary to prepare the theatre for the explant procedure and ensure that the receiving staff are ready. With the patient being dependent on mechanical ventilation, the proper function of the transport ventilator should be checked, and portable oxygen cylinder should have an adequate oxygen supply for the duration of transfer. Portable patient monitoring should be set-up, and the number of infusions rationalized if possible. The rate of infusions for inotropic agent, drugs for sedation and analgesia, and heparin, as well as the antibiotic dosing regimen should be reviewed and continued during transfer.[8] Emergency airway equipment should be immediately available. The surgeon, anesthesiologist, perfusionist, and intensive care nurse should transport the patient together. The hand crank for the ECMO pump should be available if the transport battery fails during transfer. If the patient requires IABP, the slave cable for external source of electrocardiography (ECG) should be available for use during explantation of central ECMO.

Intraoperative conduct of anesthesia and monitoring

It is best to continue with the ventilator settings from the intensive care unit and adjust the ventilatory settings for lung recruitment, if atelectasis is a concern. In addition to standard monitors and invasive monitoring, temperature should be monitored. Heated water bath humidifier and convection blanket may be applied to maintain normothermia and minimize core-peripheral temperature gradient as hypothermia worsens coagulopathy. Urine output continues to be a surrogate indicator of renal perfusion. Regular arterial blood sampling for point-of-care testing should be performed to assess blood gases, acid-base balance, and to check adequacy of serum potassium, calcium, and hemoglobin concentrations. Electrolytes and acid-base derangements can precipitate arrhythmias.

Either general anesthesia or monitored anesthetic care in conjunction with local anesthesia can be employed, depending on whether the patient has central or peripheral ECMO. For explantation of peripheral ECMO, monitored anesthetic care is appropriate. With central ECMO, general anesthesia with systemic opioids are usually administered. Local anesthetic agents such as bupivacaine may be administered at peripheral cannula sites to provide analgesia for the removal of cannulas and closure of vessels and wounds. Neuromuscular blocking agents are generally not required. The depth of analgesia and anesthesia should be titrated to physiological and autonomic responses. Depth of anesthesia monitors such as bispectral index (BIS) can be considered.

Anticoagulation should be maintained during the weaning process to prevent thrombus formation within the extracorporeal circuit. The ACT should be monitored at regular intervals and additional heparin should be administered to maintain ACT between 180 and 220 s.[15-17] For explantation of central ECMO support, tranexamic acid can be considered.[60]

During weaning of VA ECMO, TEE aids the assessment of native cardiac function in real time as the flows are reduced. Information on both ventricular function, presence of RV dilation, or dysfunction guides ventilatory strategy and volume therapy. As the patient is anticoagulated, insertion of the transesophageal probe should be gentle and probe manoeuvres within the esophagus kept to a minimum to reduce the risk of bleeding.

Supporting cardiovascular function and systemic perfusion

As ECMO flows are reduced, the inotrope and vasopressor infusion rates as well as volume administration should be guided by hemodynamic response. Causes of hypotension after separation from ECMO may relate to physiological components contributing to cardiac output, such as heart rate and rhythm, contractility, preload and afterload; or the development of acidemia, especially after the removal of peripheral cannulas and re-establishment of lower limb perfusion.

Continuous monitoring of heart function and LV filling with TEE can guide the management of the cause of hypotension

as well as monitor the response to treatment. In addition to evaluation of LV function, RV size and contractility should be monitored. During weaning from ECMO support, if RV dilation is observed in the presence of reduced LV filling, the management should include ensuring normocapnia through ventilatory means, as well as correction of acidosis and pharmacotherapy (nitroglycerin or milrinone infusion) to reduce pulmonary vascular resistance.[9]

Acidosis and electrolyte abnormalities (particularly potassium, calcium, and magnesium) should be corrected as these may trigger arrythmias and impair myocardial contractility. Arrhythmias should be treated immediately to restore sinus rhythm. Measures to improve intracellular and extracellular acidosis should be considered when pH is less than 7.1.[61] The use of sodium bicarbonate or tris (hydroxymethyl) aminomethane (THAM) solution may be considered. However, sodium bicarbonate has not been shown to improve mortality,[62] while causing side-effects such as hypokalemia, hypocalcemia (ionized), prolongation of the QTc interval, and hypercapnia.[63]

If hypotension and acidosis become refractory to management, the patient should be returned to full ECMO support immediately until the issues are identified and treated. It is unlikely for weaning to be successful if metabolic acidosis worsens and cannot be effectively corrected. Other causes of metabolic acidosis to consider include organ ischemia secondary to hypoperfusion such as ischemic bowel.

Should vasoplegia be suspected, vasopressor doses should be adjusted for support accordingly. Volume therapy should be judicious to avoid volume overload and impaired lung function.

Supporting lung function and oxygen delivery

Desaturation may be observed during weaning and after separation from ECMO support. Respiratory acidosis and hypercarbia resulting from hypoventilation can be rectified by adjusting ventilatory settings. Lung recruitment maneuvres to reduce atelectasis and intrapulmonary shunting includes controlled manual inflation of the lungs and increasing PEEP during mechanical ventilation. Loop diuretic therapy may be initiated if interstitial and alveolar edema are the likely reasons for hypoxemia. Treatment should be targeted to the suspected pathology.

Successful weaning

Should the weaning be successful, circuit tubings are clamped and cut, femoral venous and arterial cannulas are flushed with heparinzed saline, and intravenous heparin infusion are ceased. If it is certain that there is no further need for ECMO support, cannulas can be removed and vascular sites closed surgically after heparin infusion has been stopped for at least 30 to 60 min.[8] Access cannulas may be left in place for 24 h or longer[8] in case the patient

requires ECMO support again. In general, bleeding from cannulation sites can easily be controlled by surgical hemostasis. A Valsalva maneuvre might be requested when removing venous cannula to prevent venous air embolism from air entrainment. Protamine may be administered to correct heparinization after vascular closure. The anesthesiologist must be observant in estimating blood loss, especially in the rare event of accidental vascular injury during decannulation and closure of cannulation sites.

Postoperative care

The patient is usually kept intubated and lightly sedated after weaning from ECMO and decannulation. Transport of the patient back to the intensive care unit after the procedure should also follow the same principles as mentioned before.

Postoperative handover is an important process to ensure continuity of care and prevent adverse events and postoperative treatment delays.[57,64] Information communicated in the handover should include perioperative anesthetic and surgical issues, as well as the expected postoperative clinical trajectory. The implementation of a standardized handover template as opposed to unstructured handovers has been shown to provide the best scenario for optimal information sharing.[65]

Conclusion

VA ECMO is increasingly being utilized for cardiac support in various causes of cardiogenic shock and cardiac arrest. Noncardiothoracic anesthetists may find themselves managing such patients for weaning and explant of ECMO, either at the bedside or in the operating theater. Understanding of the basic working mechanism of VA ECMO and the anesthestic considerations for weaning and explantation of ECMO will aid the anesthesiologist in the clinical management of such cases. A multidisciplinary effort involving cardiothoracic surgeons, perfusionists, cardiologists, intensivists, anesthesiologists, and nurses is required in the care of these patients. Most current recommendations surrounding this topic is derived from expert consensus, and more research is needed in this field.

Financial support and sponsorship

Conflicts of interest

There are no conflicts of interest.

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