



## Review Article

# Extracorporeal membrane oxygenation: Perioperative clinical practices and the Indian overview

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## ABSTRACT

Extracorporeal membrane oxygenation (ECMO) has emerged as a mechanical circulatory support system with rapid advancements in its technology. It has become an essential tool in the care of adults and children with severe cardiac and pulmonary dysfunction refractory to conventional therapy. The ease of implementation and cost effectiveness makes it highly desirable alternative for bridge to recovery or decision especially in developing countries like India. However complications and challenges related to ECMO, require more rigorously designed studies towards redefining management of patients. Anaesthesiologist being the perioperative physician has an important role in managing patients with ECMO. This review focuses on fundamental principles, technology, indications, management, weaning, transport protocols, complications, future directions as well as Indian scenario with ECMO utilization.

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## 1. Introduction

Extracorporeal membrane oxygenation (ECMO) has become an invaluable tool for managing patients with severe cardiac and respiratory failure who fail to respond to the maximum conventional therapy.<sup>1-3</sup> Extracorporeal membrane oxygenation is a form of extra corporeal cardiopulmonary bypass support system with special oxygenator which supports the diseased heart and or lungs and aids in recovery. However, it should be understood that ECMO is a supportive therapy rather than disease modifying modality. Trained and experienced physicians should be the part of ECMO program in any tertiary health center bearing in mind the cost involved. The remarkable progress in the field of ECMO necessitates a thorough understanding.

India has smaller allocation of financial expenditure towards health care. Malnutrition and infectious diseases are a big burden extracting a larger proportion of our

health care resources. Simultaneously Indians need quality health care with high standard and safety for successful outcome after the illness. More than 16 established centers are providing ECMO support in India. Fourteen centers are already under Extracorporeal Life Support Organization (ELSO) registry performing >600 cases annually.<sup>4</sup> The detail knowledge about the indications, types, mechanism of functioning, setting up of the circuits and management of the problems during ECMO support is required for the efficient perioperative use.

## 2. Materials and Methods

The present review focuses on all the important aspects in the use of ECMO. The review included the pertinent literatures published in the last 15 years in Pub Med and Google Scholar indexed journals. The Indian perspective is also discussed from the clinical experiences, facts and data available in published literatures.

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### 2.1. Definition of ECMO

Extracorporeal membrane oxygenation is by definition a cardiopulmonary support mechanism, wherein the blood is drained from the venous system and circulated outside the body by means of a mechanical pump. During this process, the hemoglobin moieties get fully saturated with oxygen and carbon dioxide generated is flushed out. Once fully saturated, the blood is re-infused back into the circulation. The flow rate of the mechanical pump is the determinant factor for oxygenation whereas the rate of countercurrent gas flow through the oxygenator determines carbon dioxide ( $\text{CO}_2$ ) elimination at the same time.<sup>1</sup>

### 2.2. History and Evolution of ECMO

The earliest understanding can be recollected back to 1944. This was the period when experiments by Kolff and Berk projected that the blood became oxygenated after passing through cellophane chambers of the artificial kidney.<sup>5</sup> However, it was Gibbon who in 1953 for the first time managed to successfully perform open heart surgery using artificial oxygenation and perfusion.<sup>6</sup> In 1965 Rashkind et al were able to reproduce similar results in a neonate with respiratory failure using bubble oxygenator.<sup>7</sup>

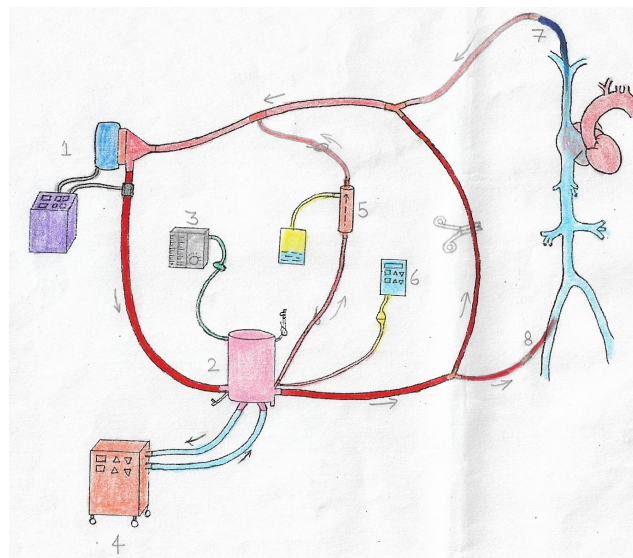
First successful application of ECMO was in 1972 to treat an adult who had developed post traumatic respiratory failure.<sup>8</sup> This was soon followed by the first ever successful trial of ECMO in neonates who were suffering with severe neonatal respiratory distress by Bartlett et al. in 1975.<sup>9</sup> Thus the platform was set for further research.

These earlier studies however failed to show promising results as the patient population studied was limited. Subsequently conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR) trial in 2006 set the standards for the perioperative usage of ECMO.<sup>10</sup> The trial showed improvement in the mortality rate and severe disability 6 months after randomization of patients who were suffering from severe respiratory failure treated with ECMO. The trial was conducted in an expert center with high case turnover.<sup>10</sup>

### 2.3. Cardio-respiratory physiology and ECMO

ECMO can be either veno-arterial (VA) or veno-venous (VV) type based on the underlying pathology to be treated. The VV- ECMO (Figure 1) is mostly instituted for respiratory failure. These patients have impaired gaseous exchange at the alveolar-capillary membrane, leading to hypoxia, hypercarbia and pulmonary vasoconstriction. Here the amount of blood that is removed and returned to the circulation remains essentially equal, thereby maintaining preload. The VV- ECMO improves oxygenation and increases  $\text{CO}_2$  clearance thereby decreasing pulmonary vascular resistance, reducing right ventricle workload and improving performance. This process reduces the intrinsic

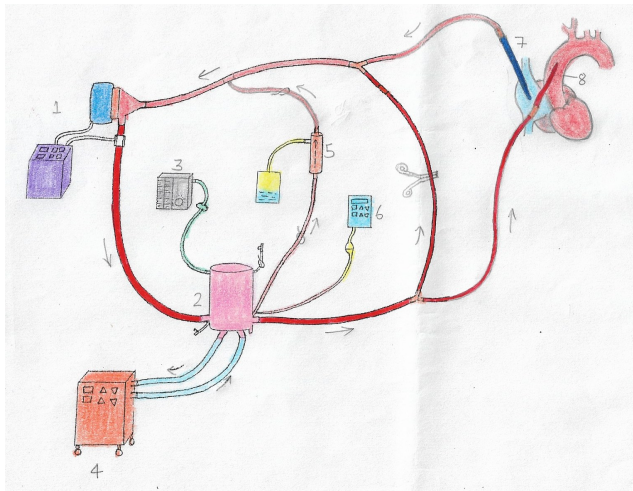
work burden on the diseased lungs especially that caused by the high pressures delivered by mechanical ventilation. The period of rest provided by the extracorporeal gas exchange provides optimal conditions for healing process to occur. It should be emphasized at this point that VV-ECMO does not have direct action on left ventricle (LV) performance. Improvement in LV function can be attributed to improved right ventricle (RV) performance. This can be explained on the basis of ventricular interdependence.



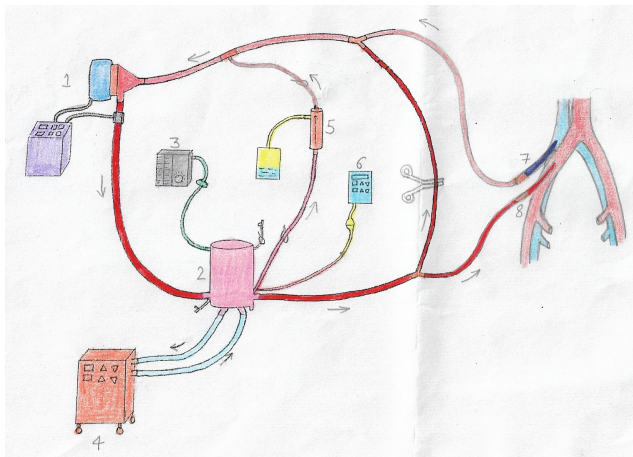
**Fig. 1:** VV ECMO (1= Centrifugal pump, 2= Oxygenator, 3= Gas blender, 4= TCM, 5= Hemofilter, 6= Pressure module, 7= Venous cannula, 8= Arterial cannula)

Veno-arterial ECMO on the other hand is mainly indicated for treating severe cardiac or cardio-respiratory failure. It is classified into central (Figure 2) and peripheral (Figure 3) VA ECMO. The oxygenated blood will return to the aorta and thereby causes significant reduction in the preload to reduce the left ventricular end diastolic volume (LVEDV) and wall stress of the failing heart. This type of extracorporeal circuit aims at providing partial cardiac support and hence the left ventricle continues to have certain amount of intrinsic activity and generates 20-30% of stroke volume. The rest 70-80% of the cardiac output is produced by the extracorporeal circuit. Thus some cardiac ejections continue to occur, such that venous return to the right heart continues and passes through the pulmonary system.

There are however certain physiological consequences of the VA-ECMO. At the onset, there is negligible resistance to retrograde ECMO return flow. Improved functioning of the heart will increase native antegrade aortic flow. This will prevent the oxygenated blood returning from ECMO circuit to traverse the aortic arch. If the cardiac function improves before the pulmonary function, the left ventricle will be ejecting poorly oxygenated blood from pulmonary circulation into the ascending aorta leading to hypoxemia.



**Fig. 2:** VA ECMO (central type) (1= Centrifugal pump, 2= Oxygenator, 3= Gas blender, 4= TCM, 5= Hemofilter, 6= Pressure module, 7= Venous cannula, 8= Arterial cannula)



**Fig. 3:** VA ECMO (Peripheral type) (1= Centrifugal pump, 2= Oxygenator, 3= Gas blender, 4= TCM, 5= Hemofilter, 6= Pressure module, 7= Venous cannula, 8= Arterial cannula)

This is called as *Harlequin syndrome*.<sup>11</sup> This problem can be overcome by using 2 venous cannulae from SVC and IVC; and aortic or arterial cannula called as veno-veno-arterial (V-VA) ECMO.

#### 2.4. Indication and contraindication of ECMO

Based on the data obtained from the international ELSO registry,<sup>4</sup> institution of ECMO may give promising results and outcome wherein understanding of the pathological processes is clear. The indications of ECMO can be categorized into cardiac, respiratory or combination of the two (Table 1). The contraindications are summarized in Table 2.

**Table 1:** Indications of ECMO

<b>A</b>	<b>Indications for cardiovascular support</b>
	1. Cardiogenic shock/ severe cardiac failure due to- i. Acute coronary syndrome (ACS) ii. Malignant Cardiac Arrhythmias refractory to medical management iii. Severe Sepsis iv. Myocarditis v. Pulmonary embolism vi. Acute anaphylaxis 2. Post orthotopic cardiac transplant: primary graft failure after heart or heart-lung transplantation 3. Post complex congenital and adult cardiac surgery: failure to wean from cardiopulmonary bypass 4. Bridge to heart transplants
<b>B</b>	<b>Indications for respiratory support</b>
	1. Acute respiratory distress syndrome due to- i. Severe pneumonia of varying etiologies ii. Aspiration syndromes iii. Alveolar proteinosis 2. Supporting the diseased lungs or to provide lung rest during acute phase of- i. Airway obstruction ii. Pulmonary contusion iii. Smoke inhalation 3. Lung transplantation- i. Bridge to transplantation ii. Primary graft failure iii. Intraoperative
<b>C</b>	<b>Indications for miscellaneous use</b>
	1. Congenital diaphragmatic hernia 2. Meconium aspiration syndrome

**Table 2:** Contraindications of ECMO

<b>A</b>	<b>Absolute contraindications</b>
	1. Severe cardiac failure such that patient is not a candidate for transplant or mechanical circulatory assist devices 2. Disseminated malignancy 3. Unwitnessed cardiac arrest 4. Known severe brain injury 5. Prolonged CPR without adequate tissue perfusion 6. Acute aortic dissection 7. Severe aortic regurgitation (AR) 8. Severe chronic organ dysfunction (emphysema, cirrhosis, renal failure) 9. Peripheral vascular disease for VA ECMO 10. Cardiogenic failure due to severe chronic pulmonary hypertension
<b>B</b>	<b>Relative contraindications</b>
	1. Advanced age 2. Obesity 3. Patient with anticoagulation 4. High pressure or high FiO <sub>2</sub> IPPV > 1 week for VV ECMO

**Table 3:** Checklist at the initiation of ECMO

1	ACT > 200seconds
2	Oxygen line is connected to the oxygenator
3	Gas flow started $\geq 5$ -6L/min
4	Sterile loop is opened and handed to cannulating surgeon
5	Circuit is cut between two clamps allowing sufficient length on the access line and return line to prevent any tension on the circuit
6	Ensure no air in circuit
7	VV ECMO- target flows must provide adequate arterial oxygenation
8	VA ECMO- target flows must provide adequate oxygen delivery
9	Routine patient and circuit arterial blood gases to be performed
10	Step down on ventilator settings

**Table 4:** Monitoring patient on ECMO

1.	Pump flow rate- Blood flow rate should be 60- 150 ml/kg/min It should be started slowly 20 ml/kg/min in order to reduce chances cardiac stunning
2.	Haemodynamic observations MAP- 70-100 mmHg in adults, 40-60 mmHg for neonates and small child. Pre pump pressure- up to -20 mmHg is acceptable. Delta pressure- it is the difference between pre and post oxygenator pressure it is strictly maintained as recommended in order preventing excessive haemolysis. It should be less than 300 mmHg
3.	Evidence of hypovolaemia in the form of fluctuating flow rates and 'shaking' of ECMO tubes
4.	Neurological status
5.	Coagulation profile- ACT, APTT
6.	Arterial blood gas analysis- electrolytes, lactate, hematocrit
7.	Temperature- Core and peripheral
8.	Urine output
9.	Chest X-Ray

### 2.5. Technique for assembling ECMO

The VV ECMO circuit is connected in series to the heart and lungs. When we are using a single venous cannula, the access cannula extracts blood from the vena cava or right atrium, circulates through the extracorporeal circuit and returns the blood to right atrium via the return cannula. In two venous cannula systems in VV ECMO (Figure 1), drainage occurs usually via the cannula placed in the common femoral vein and infusion of oxygenated blood continues through the right internal jugular or other femoral vein. The positioning of the cannula should also be taken into consideration in all the scenarios. Ideally the cannula tip, when using one venous cannula, should rest in the infra-diaphragmatic part of IVC. The proximal opening should be positioned in the superior vena cava (SVC) or SVC-RA junction, thus directing the opening towards the

tricuspid valve. Blood flow is set at 3-6L/min for acceptable oxygenation. Oxygen flow rates are set at twice the value.

The circuit of VA-ECMO is assembled in parallel to heart and lungs. The cannulation is either central or peripheral type (Figures 2 and 3). The access cannula extracts venous blood from the large central veins or right atrium and after oxygenation in the membrane oxygenator; the pump returns the blood to a major artery. Central cannulation is performed at ascending aorta whereas femoral, axillary or carotid arteries are used during peripheral cannulation<sup>12,13</sup> Central cannulation is preferred approach in post- cardiectomy ECMO. The flow rates may vary from low flows of 2-3L/min to as high as 4-6L/min. This determines whether partial assistance to native circulation will suffice or is there a demand to totally replace the patient's cardiac output. Ideal site for cannula placement is in ascending aorta just above aortic valve. However we should avoid cannulating the same side of groin for arterial and venous access, as this may carry the risk of venous congestion due to femoral venous compression by the adjacent arterial cannula. As discussed previously, ECMO circuit is designed in such a manner that it can provide partial support as in asthma to total support in failing heart. The flow rates corrected to body surface area (BSA) are 3L/m<sup>2</sup>/min. The age based calculation of flow rates are: for neonates 100ml/kg/min; pediatrics 80ml/kg/min; adults 60ml/kg/min. Adequate systemic perfusion is best measured by venous saturation values targeted above 70%.

### 2.6. Management during ECMO

At the commencement of ECMO it is prudent to follow a checklist as mentioned in Table 3. Anticoagulation is monitored vigilantly. The ACT is measured every hour to titrate heparin infusion rate in the first 24hrs and there after every 6<sup>th</sup> hourly over 24hr. Target ACT of 180-200sec is maintained in non-bleeding patient having platelet count >80,000/mm<sup>3</sup>.<sup>14</sup> After 24hrs, APTT is primarily used to guide heparin therapy with target values of 45-55sec. Continuous monitoring of the patient guides us on outcomes and prognosis. The essential monitoring parameters are listed in Table 4. Apart from these, general management can be protocolized based on institutional norms. The protocol in our cardiac surgical ICU is listed in Table 5. These patients should also be thoroughly investigated on a daily basis with CXR, ABG and hematology tests. Blood cultures are sent as required or at least thrice a week from existing lines or circuit.

Analgesics, sedatives, anticoagulants, and antimicrobial agents should be administered to patients receiving ECMO as required with special attention to pharmacokinetics. Hemodilution from ECMO initiation, drug sequestration within the circuit, altered protein binding, and end organ dysfunction may all influence the pharmacokinetics of particular drugs as being reviewed under the antibiotic



**Table 5:** General protocol for management of ECMO patient

1. Doppler examination in the back-flow cannula is indicated in the moment of deteriorating leg perfusion in the cannulated leg.
2. Antibiotics at the initiation of ECMO; Other antibiotics are selected as per indication.
3. Prophylaxis for Stress ulcer
4. Patient to be nursed in supine position
5. Head of bed to be elevated to 30 degrees
6. Pressure relieving mattress should be in situ (because of decreased mobility and perfusion state these patient often high risk for pressure areas)
7. Blood cultures 3 times per week or as indicated. Unlike other patients, these samples should be taken from the circuit or through existing lines

**Table 6:** Monitoring used during continuation of ECMO

1. Blood flow, arterial inflow line pressure
2. Preoxygenator O<sub>2</sub> saturation
3. Postoxygenator O<sub>2</sub> saturation
4. perfusion pressure
5. CVP
6. Temperature
7. ACT
8. ABG
9. Lactate
10. platelet count
11. aPTT
12. Chest X-Ray (CXR)
13. Hematocrit
14. Urine out put
15. Blood loss
16. NIRS,
17. Echocardiography
18. BIS
19. LFT
20. RFT

sedative and analgesic pharmacokinetics (ASAP) ECMO study.<sup>15,16</sup>

Volume optimization is crucial to support LV decompression and allow improved end-organ function and should begin immediately after VA ECMO support initiation, as more positive fluid balances in this period have been associated with worse outcomes.<sup>17</sup> Optimal fluid status may be achieved through diuretics or renal replacement therapy. If dialysis is required, dialysis filter is added directly to the ECMO circuit avoiding additional risks of cannulation.

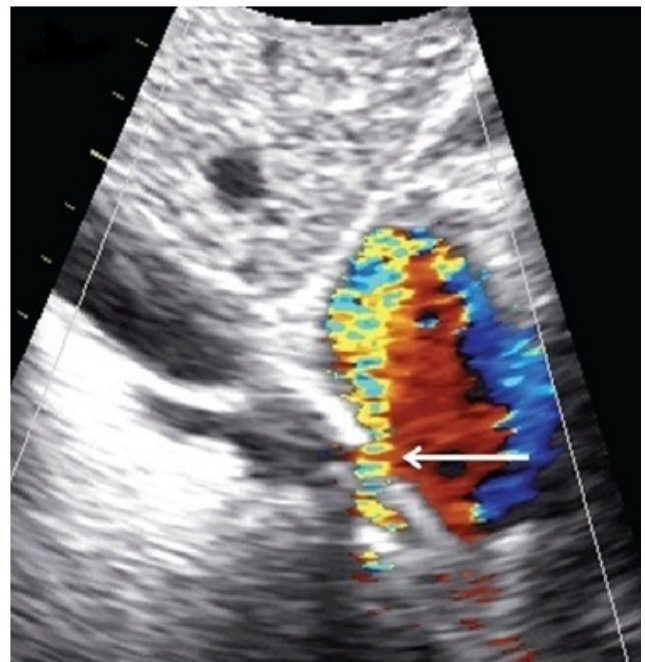
### 2.7. Monitoring during ECMO

Constant and vigilant monitoring is necessary during ECMO care. The monitoring must include parameters for ECMO system and its effect on various vital organs of the patient. Different monitoring are mentioned in the Table 6.

Blood flow is monitored by ultrasonic detectors. The pre-oxygenator saturation is used to monitor the adequacy of tissue oxygen extraction. The post-oxygenator blood saturation and PaO<sub>2</sub> signify oxygenator function.

### 2.8. Echocardiography in ECMO

Transesophageal echocardiography (TEE) is a useful tool in initiation of ECMO. It guides in correct placement of guide wires and subsequently the cannula. Color flow Doppler using TEE imaging is used to demonstrate flow of blood at the tip of return cannula and side holes of the access cannula. Any turbulence will guide for repositioning the cannula (Figure 4).



**Fig. 4:** TEE lower esophageal hepatic vein / IVC view color Doppler showing the obstruction to blood flow ( white arrow) in venous cannula tip

Cardiac functions can be monitored and any improvement should be documented during the conduct of ECMO. The prime focus of assessment during VV-ECMO is RV size and systolic function. The preferred views for assessing the same are the focused apical 4chamber view at end-diastole. The size is best estimated by measuring the maximal short axis dimension at the level of the base. Tricuspid annular plane systolic excursion (TAPSE) as a measure to RV systolic function can be assessed by using M-Mode at the tricuspid annulus level. The peak systolic integral of the tricuspid lateral annular plane should also be obtained using tissue Doppler imaging (RV TDI S'). During VA-ECMO, assessment of biventricular function and dimensions becomes prudent. Measurement of serial LV dimensions is helpful as any increase in dimensions is

suggestive of stasis of blood flow within cardiac chamber. This acts as a guide to initiate or escalate inotropic support or need for other mechanical device to increase forward flow. While on ECMO support, position of the cannula should be constantly monitored as it will help in preventing inadvertent injuries to vital structures.

## 2.9. Medications, nutrition and special care

### 2.9.1. Sedation and analgesia

The goals of sedation and analgesia are to alleviate discomfort, avoid hypertension and prevent excessive movement in patients, while allowing for neurological evaluation and periodic interaction with family members. Deep sedation sufficient to inhibit respiratory movement is required initially. This requires an infusion of fentanyl or morphine, Midazolam and muscle relaxation (vecuronium or atracurium or cisatracurium) during cannulation, decannulation, surgical re-exploration and excessive movement

### 2.9.2. Medications

Vasopressors and inotropes should be adjusted to the desired hemodynamic for the patient. Negative fluid balance is adopted to reduce tissue edema by hemofiltration and furosemide infusion (0.2-0.3mg/kg/hr). Low dose dopamine (2-3mcg/kg/min) is occasionally preferred by some clinicians.

Antibiotics use to be followed as per the institute protocol. The adoption of wide range coverage for the organisms is essential due to the open sternum, ECMO cannula and tubes. No tubing or circuit should hang on the floor. Personnel handling the ECMO should have antiseptic hand wash and strict aseptic precautions. Antibiotic may be added separately to ECMO priming and circuit. No alcohol should be applied on the circuit as it can damage the circuit integrity

### 2.9.3. Nutrition

Enteral feeding is first choice. It retains integrity of gut mucosa, limit translocation of enteric bacteria into blood stream, reduce frequency of cholestasis and offers low cost. If not tolerated total parenteral nutrition (TPN) is to be initiated. Stress ulcer prophylaxis in the form of pantoprazole may be used.

## 2.10. Management of ventilation during ECMO

Mechanical ventilation depends on level/ flow of ECMO support. The ventilatory goals are  $\text{FiO}_2$  weaned to  $<0.5$ , PIP  $< 30\text{cmH}_2\text{O}$ , PEEP  $< 10\text{-}15\text{cmH}_2\text{O}$  and respiratory rate 6-10bpm. All adjustments are to be performed as per ABG findings. In practice, an arterial  $\text{PaO}_2$  of 50-55mmHg or an oxygen saturation of 85-90% is acceptable. Patients with severe air leak from lungs benefit from CPAP.

## 2.11. Complications of anticoagulation

The activated clotting time (ACT) during ECMO support should be maintained between 200-250seconds. Risks of clot formation are observed if ACT is less than 200sec. Activated clotting time above 300sec increases risk of bleeding. The standby circuits should not be stopped rather recirculation continued to avoid stasis due to stagnation of blood. Use of blood and blood components may alter the coagulation level.

## 2.12. Weaning from ECMO

Weaning should be initiated when the disease process for which ECMO was initiated has sufficiently resolved such that patient can be safely and adequately managed with low amounts of ventilatory and inotropic support. There are no universally accepted weaning guidelines. While weaning from VV-ECMO, flow rates are maintained and patient's full ventilation is resumed. Oxygen supply to the oxygenator is turned off. After observing for hemodynamic/ respiratory stability for at least six hours, decannulation is performed.

In VA-ECMO, during weaning period ACT is maintained at  $>400\text{sec}$  to avoid clotting. Flow rates are decreased by one liter and LV function assessed using TEE. After providing a period of low flow of less than 1.5 liters/ min and exclusive mechanical ventilation, if patient remains stable, decannulation should be considered after 6h. Arterial cannula should be removed by open surgical procedure with vessel wall repair. Transesophageal echocardiography is a useful guide while weaning. During the period of trial of reduced blood flow to 1litre/min for 30 minutes, the goal should be to maintain left ventricular ejection fraction (LVEF) $>25\%$ , aortic VTI $>12\text{cm}$  and TDI lateral S' $>6\text{cm/sec}$ . Strain and strain rate calculation could also be a predictive marker for successful weaning. The aim should be an increase of 20% over baseline with concomitant increase of EF.<sup>18</sup>

## 2.13. Complications during ECMO

The complications can either arise due to primary pathology or from ECMO condition<sup>19-22</sup> and are listed with the management in Table 7. There are complications specific to VV-ECMO like hypoxia or hypercarbia due to leakage, oxygenator failure and higher demand on flows. Complications specific to VA-ECMO are cerebral or coronary hypoxia, thrombus formation and cannulation related injuries like dissections. VV-ECMO has better outcomes as compared to VA-ECMO and should be preferred when permissible. Left Ventricular myocardial stunning during VA ECMO is observed in some patients with white lungs and distension of chamber. The treatment is unloading of LV and increasing coronary oxygen content.<sup>23</sup>

**Table 7:** Complications during ECMO and management

	<b>Complication</b>	<b>Management</b>
1.	Hemorrhage- Most frequent complication (10-30%) <sup>19,20</sup>	Stop heparin, Transfuse platelets and clotting factors, Factor 7 infusion <sup>21,22</sup>
2.	Pulmonary hemorrhage	Stop heparin, steroids, bronchoscopy to clear airway
3.	Systemic thromboembolism	Heparin infusion should be ACT targeted to prevent this
4.	Heparin induced thrombocytopenia	Stop heparin, replace with non- heparin anticoagulant like Argatroban, Bivalirudin
5.	Mechanical complications	
	ECMO flow decreased but RPM unchanged	Optimise fluid status, preload, afterload & contractility, Sedation & analgesia
	Pump failure	Call for help, Ventilate & hemodynamic support, Clamp line & turn off pump. If the cause is not immediately rectified, commence hand cranking till new console arrives
	Air embolism	If embolus entered patient arterial system (VA) –hypothermia, barbiturates, steroids, mannitol and lignocaine. If embolus entered venous system (VV)- aspiration of right heart using existing lines. Circuit management- clamp circuit, turn off pump, examine site for air & seal if possible.

#### 2.14. Transport of a patient on ECMO

Role of ECMO in saving many lives is worth the efforts. However not all centers are specialized in providing such a support and many patients need to be transported to specialized centers. Patients suitable for ECMO support are generally in critical condition with ventilator support and multiple ongoing therapies.

There are two types of transport facilities:

1. Primary transport- assessment of the patient, cannulation and initiation of ECMO at the referring hospital followed by transport to the ECMO centre.
2. Secondary transport- transport of patient already on ECMO between different specialized centers.

Primary ECMO transport is briefly performed in the following order:<sup>24</sup>

1. Call for help from the referring hospital and launch of mobile ECMO team
2. Arranging transport vehicle (ground ambulance, fixed wing aircraft, helicopters) with sufficient electrical supply for electrical equipments, oxygen supply, adequate lightning, suction and climate control
3. Composing the transport team as per the ELSO guidelines- cannulating physician, surgical assistant, ECMO physician, ECMO specialist and a transport nurse, respiratory therapist. If it is an international transport every member should carry valid transport and viable currency for emergency situations
4. Check list before initiating transport- disposable ECMO circuitry, spare emergency ECMO circuit, surgical equipment for cannulation, electrical cautery, blood products, devices for monitoring blood

gases and anticoagulation monitoring, transport ventilator, infusion pumps, pharmaceuticals and patient monitoring devices.

5. After initiating ECMO at the referring centre, patient should be transported to the ECMO facility with utmost safety with time being of secondary importance.
6. The transport team must also be well versed with the management of complications, both anticipated and unanticipated, during such transports. The complications are summarized in Table 8.

**Table 8:** Complications at the time of transport of a patient on ECMO

<b>Immediate threat</b>	<b>High risk</b>	<b>Variable risk</b>
Clotting of ECMO circuit	Loss of tidal volume	Airport delay
Inadequate ECMO System/ pump change	Bleeding	Wrong ambulance
Oxygenator clot	Circulatory instability	Ambulance utility malfunction
Cannula clot	Broken ventilator circuit	Traffic accident
Air in the circuit	Broken sweep gas supply	
	Power supply lost	

#### 2.15. The next generation ECMO

Major changes in technology have occurred in the past decade and the quest to achieve more is still on. There will be development of future generation of ECLS pumps which have advanced machinery for automation and servo regulation. The surface of the circuitry will inhibit platelet

adhesion thereby decreasing the need for anticoagulation. The field is moving towards a portable extracorporeal gas exchange device. Also the choice of anticoagulant may switch over to direct thrombin inhibitors (DTI) such as Argatroban and Bivalirudin.<sup>25</sup>

The long duration of ECMO support on patients who are awaiting transplant put burden on available resources as well need for more medical personals. We will be seeing a growth of ambulatory ECMO<sup>26,27</sup> where patient can be managed at home with some extra training.

#### 2.15.1. E-CPR or ECMO supported CPR

This is defined as the implantation of VA-ECMO in a patient who experienced a sudden and unexpected pulse less condition attributable to cessation of cardiac mechanical activity.<sup>28,29</sup> E-CPR is recognized by both ELSO<sup>30</sup> and American Heart Association (AHA) guidelines in selected patients after cardiac arrest when the suspected etiology is potentially reversible.<sup>31</sup> It has demonstrated its superiority to conventional CPR in many retrospective studies<sup>32</sup> in the treatment of refractory cardiac arrest. However, despite the technical progress the acceptance is slow; as many ethical questions have to be addressed.

#### 2.15.2. Implantable membrane lungs

These can be described as membrane devices that are attached by conduits directly to the circulation, either to the heart or peripheral vessels. They can be used as bridge to lung transplantation or as destination therapy. They can be utilized without blood pumps, depending either on pulmonary artery pressure or systemic blood pressure to drive blood through the membrane.<sup>33</sup>

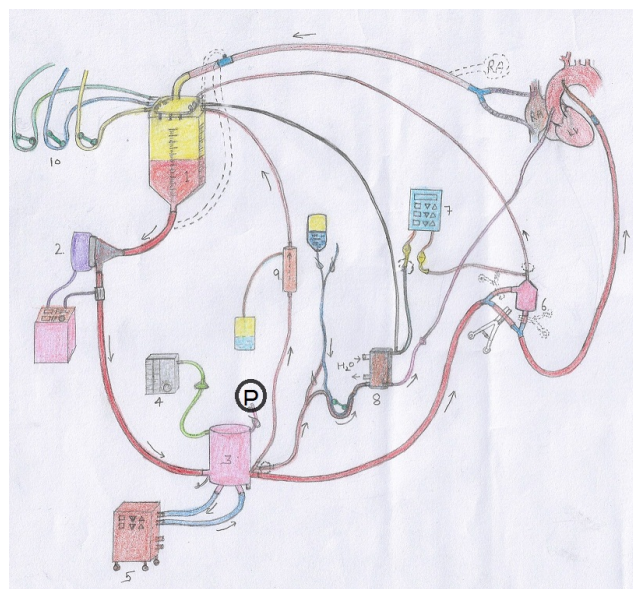
The application of such devices will transform the next generation of ECMO management.<sup>34</sup> It will be characterized by an awake and spontaneously breathing patient without systemic anticoagulation, and can be managed in general hospital or even at home.

#### 2.15.3. Integrated ECMO

The ECMO circuit is combined with the CPB circuit and blood cardioplegia device (BCD) circuit and named as integrated ECMO (Figure 5). The routine oxygenator is replaced by ECMO oxygenator. The integrated ECMO is used both in operation room and postoperatively in ICU. This model reduces the cost and time to setup ECMO circuit in the moment of emergent cardiopulmonary deterioration. This model is routinely used in authors' institute in management of regressed left ventricle patients.

#### 2.16. Indian overview with ECMO

The perioperative clinical use of ECMO in India is stepping up gradually. The use is expanding from respiratory pathology to cardiac surgery, transplant, pulmonary alveolar proteinosis (PAP), management of poisoning, emergency



**Fig. 5:** Integrated CPB-ECMO (1= Reservoir, 2= Centrifugal pump, 3= Oxygenator, 4= Gas blender, 5= TCM, 6= Arterial filter, 7= Pressure module, 8= Cardioplegia system, 9= Hemofilter, 10= Roller pumps, Dotted line represents the part to be removed after CPB completion)

resuscitation, transport of sick patient, organ donation and many more (Table 9).

ECMO has been successfully used for more than 19 years with fruitful outcomes in authors' institute. Initial application was limited to cases where weaning from cardiopulmonary bypass (CPB) failed following complex congenital heart diseases. However, there has been a paradigm shift with our understanding and application of ECMO. Teaching and training programs were initiated at the institute for training students about the principles and practices of ECMO.

Recent studies have reported data on outcomes of children with complex congenital heart disease weaned off on ECMO support after surgical repair. The authors have found a significantly increased survival rate in cases with planned integrated CPB-ECMO circuit (Figure 5). We have initiated ECMO support as a bridge to transplant in patients in decompensated heart failure waiting for suitable donor to undergo heart transplant. Also it has been used in post heart transplant patients presenting with acute rejection with multi-organ failure. It has been successfully used in a patient with autoimmune PAP following renal transplant who presented with marked hypoxemia and was managed by whole lung lavage (WLL) under ECMO support. Recently it was used in patient with 28 weeks of gestation diagnosed with H1N1 influenza to provide respiratory support while waiting for fetal maturity. Apart from this it is being used in the department of pulmonary medicine in treating patients with ARDS not responding to conventional therapy with



**Table 9:** Indian experience with ECMO: summary

Author and year published	Indication for ECMO	Population	Study design	Outcome
Chauhan S et al, 2016 <sup>35</sup>	Severe hypoxemia in pulmonary alveolar proteinosis	Case report	Case report	VV ECMO was successfully used for whole lung lavage thereby improving oxygenation
Singh SP et al, 2016 <sup>36</sup>	Arterial switch operation in a child with dTGA with regressed LV	Case report	Case report	Serial lactate clearance estimation aided in initiation and termination of ECMO successfully in this case
Chauhan S et al, 2011 <sup>37</sup>	Pediatric cardiac surgery	94 patients	Retrospective record analysis of 10 years	Significantly improved survival rate with the use of integrated ECMO-CPB circuit and early time of intervention rather than using ECMO as a last resort in the management.
Rawal G et al, 2017 <sup>38</sup>	ARDS due to H1N1 influenza	Case report	Case report	The authors present a case of H1N1 influenza related severe ARDS who was successfully rescued by the early use of ECMO.
Mohan B et al, 2016 <sup>39</sup>	Outcome of patients with aluminium phosphide poisoning supported by ECMO	83 patients with AIP poisoning	Prospective randomized controlled trial	The authors reported improved short term survival of patients with AIP poisoning having severe LV dysfunction supported on VA ECMO
Kumar L et al, 2017 <sup>40</sup>	Severe hypoxemia in post liver transplant patient with HPS	1 Case	Case report	VV ECMO was established with instant improvement in oxygenation (PaO <sub>2</sub> 68 mm Hg), and the patient was eventually salvaged
Oza P 2017 <sup>41</sup>	Transport of ECMO patients	45 patients	Retrospective study	Road transport of ECMO supported patients from 9-250km distance without any loss of life.
Gopalapurugan AB et al <sup>42</sup>	Successful TAVI implantation with ECMO	1 Case	Case report	Percutaneous ECMO circuit improved the success of TAVI, maintained hemodynamic stability throughout the procedure and reduced complications.

promising results. The publications related to perioperative clinical uses of ECMO from India are listed in Table no. 9.<sup>35–42</sup>

Cost is the main hurdle in many of the indicated patients who are deprived of the benefit of ECMO support in India. Limited centers/ hospitals have the facility of ECMO. Trained personals still less in numbers. In India the patient survival is 40-50%, which is comparable with international standards. The innovation, research and economical support will boost the perioperative and routine use in India.

### 3. Conclusion

ECMO is an advanced life support system for pulmonary and cardiac diseases. Selecting the appropriate ECMO for the patient requires the clinical judgment. It should be used as a tool for reversible organ failure situation or as a bridge to transplantation or decision making. The establishment, maintenance and weaning should follow strict guidelines, monitoring, indications with involvement of trained personnel. Anaesthesiologist being the perioperative physician will come across in managing these patients and should play a leading active role. The developing countries like India are progressively using ECMO as a mechanical circulatory support. It needs dedicated centers and financial support for further technological development. The authors hope that with increase in knowledge in the perioperative use of ECMO, cardiac and pulmonary diseases can be better managed with improved outcome and survival in India in more number of patients

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### 5. Conflict of Interest

None.

### References

- Schmidt M, Tachon G, Devilliers C, Muller G, Hekimian G, Bréchet N, et al. Blood oxygenation and decarboxylation determinants during venovenous ECMO for respiratory failure in adults. *Intensive Care Med.* 2013;39(5):838–46.
- MacLaren G, Combes A, Bartlett RH. Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. *Intensive Care Med.* 2012;38(2):210–20.
- Shekar K, Mullany DV, Thomson B, Ziegenfuss M, Platts DG, Fraser JF. Extracorporeal life support devices and strategies for management of acute cardiorespiratory failure in adult patients: a comprehensive review. *Crit Care.* 2014;18(2):219.
- Extracorporeal Life Support Registry Report; 2015. Available from: <https://www.elso.org/Registry/Statistics/InternationalSummary.aspx>.
- Kolff WJ, Berk HT, Terwelle M. The artificial kidney: a dialyser with a great area. *J Am Soc Nephrol.* 1997;8:1959–65.
- Gibbon JH. Application of a mechanical heart and lung apparatus to cardiac surgery. *Minn.* 1954;37:171–85.
- Rashkind WJ, Freeman A, Klein D, Toft RW. Evaluation of a disposable plastic, low volume, pumpless oxygenator as a lung substitute. *J Pediatr.* 1965;66(1):94–102.
- Hill JD, O'Brien TG, Murray JJ, Dontigny L, Bramson ML, Osborn JJ, et al. PROLONGED EXTRACORPOREAL OXYGENATION FOR ACUTE POST-TRAUMATIC RESPIRATORY FAILURE (SHOCK-LUNG SYNDROME). *Surv Anesthesiol.* 1972;16(6):551–2.
- Bartlett RH, Gazzaniga AB, Jefferies MR. Extracorporeal membrane oxygenation (ECMO) cardiopulmonary support in infancy. *Trans Am Soc Artif Intern Organs.* 1976;22:80–93.
- Peek GJ, Clemens F, Elbourne D, Firmin R, Hardy P, Hibbert C, et al. CESAR: conventional ventilatory support vs extracorporeal membrane oxygenation for severe adult respiratory failure. *BMC Health Serv Res.* 2006;6(1):163.
- Navia JL, Atik FA, Beyer EA, Vega PR. Extracorporeal Membrane Oxygenation With Right Axillary Artery Perfusion. *Ann Thorac Surg.* 2005;79(6):2163–5.
- Moazami N, Moon MR, Lawton JS, Bailey M, Damiano R. Axillary artery cannulation for extracorporeal membrane oxygenator support in adults: An approach to minimize complications. *J Thorac Cardiovasc Surg.* 2003;126(6):2097–8.
- ELSO Anticoagulation Guidelines 2014. Extracorporeal Life Support Organization. Available from: <http://www.elso.org/Portals/0/Files/elsoanticoagulationguideline8-2014-table-contents.pdf>.
- Aissaoui N, Luyt CE, Leprince P, Trouillet JL, Léger P, Pavie A, et al. Predictors of successful extracorporeal membrane oxygenation (ECMO) weaning after assistance for refractory cardiogenic shock. *Intensive Care Med.* 2011;37(11):1738–45.
- Dzierba AL, Abrams D, Brodie D. Medicating patients during extracorporeal membrane oxygenation: the evidence is building. *Crit Care.* 2017;21(1):66.
- Shekar K, Roberts JA, Welch S. ASAP ECMO: antibiotic, sedative and analgesic pharmacokinetics during extracorporeal membrane oxygenation: a multi-centre study to optimise drug therapy during ECMO. *BMC Anesthesiol.* 2012;12:29.
- Staudacher DL, Gold W, Biever PM, Bode C, Wengenmayer T. Early fluid resuscitation and volume therapy in venoarterial extracorporeal membrane oxygenation. *J Crit Care.* 2017;37:130–5.
- Aissaoui N, Guerot E, Combes A, Delouche A, Chastre J, Leprince P, et al. Two-Dimensional Strain Rate and Doppler Tissue Myocardial Velocities: Analysis by Echocardiography of Hemodynamic and Functional Changes of the Failed Left Ventricle during Different Degrees of Extracorporeal Life Support. *J Am Soc Echocardiogr.* 2012;25(6):632–40.
- Bartlett RH, Gattinoni L. Current status of extracorporeal life support (ECMO) for cardiopulmonary failure. *Minerva.* 2010;76:534–40.
- Hemmila MR, Rowe SA, Boules TN, Miskulin J, McGillicuddy JW, Schuerer DJ, et al. Extracorporeal life support for severe acute respiratory distress syndrome in adults. *Ann Surg.* 2004;240(4):595–607.
- Peek G, Wittenstein B, Harvey C. Management of bleeding during ECLS. In: ECMO in Critical Care. Extracorporeal life support organization; 2005.
- Wittenstein B, Ng C, Ravn H, Goldman A. Recombinant factor VII for severe bleeding during extracorporeal membrane oxygenation following open heart surgery. *Pediatr Crit Care Med.* 2005;6(4):473–6.
- Meani P, Pappalardo F. The step forward for VA ECMO: left ventricular unloading! *J Thorac Dis.* 2017;9(11):4149–51.
- ELSO. Guidelines for ECMO Transport Ann Arbor: ELSO; 2015. Available from: <http://www.elso.org/Resources/Guidelines.aspx>.
- Coughlin MA, Bartlett RH. Anticoagulation for extracorporeal life support (ECLS): direct thrombin inhibitors and heparin. *ASAIO J.* 2015;61(6):652–5.
- Garcia JP, Kon ZN, Evans C, Wu Z, Iacono AT, McCormick B, et al. Ambulatory veno-venous extracorporeal membrane oxygenation: Innovation and pitfalls. *J Thorac Cardiovasc Surg.* 2011;142(4):755–61.
- Mangi AA, Mason DP, Yun JJ, Murthy SC, Pettersson GB. Bridge to lung transplantation using short-term ambulatory extracorporeal

- membrane oxygenation. *J Thorac Cardiovasc Surg.* 2010;140(3):713–5.
28. Soar J, Nolan JP, Böttiger BW, Perkins GD, Lott C, Carli P, et al. Adult advanced life support section Collaborators. European Resuscitation Council Guidelines for Resuscitation 2015: Section 3. Adult advanced life support. *Resusc.* 2015;95:100–47.
  29. Mozaffarian D, Benjamin EJ, Go AS. American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2015 update: a report from the American Heart Association. *Circ.* 2015;13:29–322.
  30. ELSO ECPR Supplement to the ELSO General Guidelines Extracorporeal Life Support Organization (ELSO) Guidelines for ECPR Cases. 2013. Available from: <https://www.else.org/Portals/0/IGD/Archive/FileManager/6713186745cusersshydocumentselsoguidelinesforecprcases1.3.pdf>.
  31. Link MS, Berkow LC, Kudenchuk PJ, Halperin HR, Hess EP, Moitra VK, et al. Part 7: Adult Advanced Cardiovascular Life Support. *Circ.* 2015;132(18 suppl 2):S444–64.
  32. Richardson ASC, Schmidt M, Bailey M, Pellegrino VA, Rycus PT, Pilcher DV. ECMO Cardio-Pulmonary Resuscitation (ECPR), trends in survival from an international multicentre cohort study over 12-years. *Resusc.* 2017;112:34–40.
  33. Hoganson DM, Gazit AZ, Boston US. Paracorporeal lung assist devices as a bridge to recovery or lung transplantation in neonates and young children. *J Thoracic Cardiovasc Surg.* 2014;147:420–6.
  34. Bartlett H, Ecmo. ECMO: The next 10 years. *Egypt J Crit Care Med.* 2016;4:4–10.
  35. Chauhan S, Sharma KP, Bisoi AK, Pangeni R, Madan K, Chauhan YS. Management of pulmonary alveolar proteinosis with whole lung lavage using extracorporeal membrane oxygenation support in a postrenal transplant patient with graft failure. *Ann Card Anaesth.* 2016;19(2):379–82.
  36. Singh SP, Chauhan S, Bisoi AK, Sahoo M. Lactate clearance for initiating and weaning off extracorporeal membrane oxygenation in a child with regressed left ventricle after arterial switch operation. *Ann Card Anaesth.* 2016;19(1):188–91.
  37. Chauhan S, Malik M, Malik V, Chauhan Y, Kiran U, Bisoi A. Extra corporeal membrane oxygenation after pediatric cardiac surgery: A 10 year experience. *Ann Card Anaesth.* 2011;14:19–24.
  38. Rawal G, Kumar R, Yadav S, Sujana R. H1N1 influenza induced acute respiratory distress syndrome rescued by extracorporeal membrane oxygenation: A case report. *J Transl Int Med.* 2017;5(3):182–5.
  39. Mohan B, Gupta V, Singh B, Ralhan S. Outcome of patients supported by extracorporeal membrane oxygenation for Aluminium phosphide poisoning: A prospective observational study. *J Assoc Physicians India.* 2016;64:66–66.
  40. Kumar L, Balakrishnan D, Varghese R, Surendran S. Extracorporeal membrane oxygenation for post-transplant hypoxaemia following very severe hepatopulmonary syndrome. *BMJ Case Reports.* 2017;doi:10.1136/bcr-2017-221381.
  41. Oza P. ECMO transport challenges in India. *Qatar Med J.* 2017;2017(1):51.
  42. Gopalamurugan AB, Meenakshi MS, Abubacker RM. India's first successful ECMO assisted TAVI: A strategy for 'high risk' TAVI patients. *IJH Cardiovasc Case Rep(CVCR).* 2017;1(1):4–6.

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