

Extracorporeal membrane oxygenation: coming to an ICU near you

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Extra-corporeal membrane oxygenation has come of age after publication of the CESAR trial and the experience of its use during the 2009 H1N1 influenza pandemic, showing its increasing benefit for the treatment of hypoxaemic respiratory failure and combined cardiovascular and respiratory failure, including post-cardiac arrest. The article reviews the evidence for this technology and its indications, modes, methods, complications and recent advances. The authors suggest that ECMO will be used increasingly, even in non-cardiac specialist centres.

Keywords: ECMO; respiratory failure; ARDS; cardiac failure; intensive care

Introduction

Extracorporeal membrane oxygenation (ECMO) is an evolving life support technology which has been used for 40 years. There is a general consensus for the benefits of ECMO in neonates and children with reversible cardiorespiratory failure.¹ The evidence to support its widespread use in adults has only emerged recently, with the concomitant publication of the CESAR trial² and a report of a large number of influenza A (H1N1) patients presenting with acute respiratory distress syndrome (ARDS) treated with ECMO.³ The use of ECMO is likely to expand as the technology becomes simpler, safer and more reliable. This short review presents the current state of ECMO technology and data on outcomes.

ECMO technology and its utility

ECMO is used to temporarily support gas exchange and/or perfusion in patients with respiratory and/or cardiac failure refractory to conventional ventilatory and pharmacological treatments (see **Figure 1**). These patients have severely deranged physiological parameters despite maximal medical support. Imminent death is expected without ECMO.

ECMO is an adaptation of cardiopulmonary bypass technology used in cardiac surgery. It functions as an artificial heart and lung by providing propulsion pressure for blood flow through a circuit and an interface for oxygen and carbon dioxide exchange. ECMO can be categorised according to the organ supported (respiratory, cardiac, or cardio-respiratory), or according to the circuit used (veno-arterial (VA) and veno-venous (VV)). VA ECMO provides both gas exchange and circulatory support, while VV ECMO allows gas exchange only.

Although ECMO has the capability to support cardiorespiratory function temporarily, it is not a cure for the underlying disease. Potential candidates for ECMO must have a reversible cardiorespiratory pathology or be suitable for heart and/or lung transplantation.

According to the International Extracorporeal Life Support (ECLS) Registry Report, at least 4,400 adult patients in the

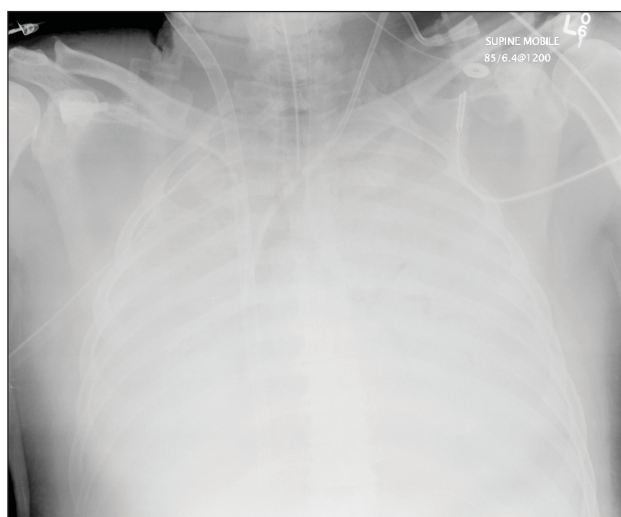


Figure 1 1 CXR of a typical H1N1 ARDS patient receiving ECMO support. It shows lung fields completely consolidated and devoid of aeration. There are multiple artefacts including right internal jugular dual stage cannula used for veno-venous ECMO. Mechanical ventilation is unlikely to contribute to the gas exchange and sustain life.

world have been managed with ECMO since 1990.⁴ Survival outcomes from these patients are presented in **Table 1**.

Respiratory ECMO

ECMO has been used to provide respiratory support in adult patients with various forms of acute lung injury including ARDS (**Table 2**). By replacing the gas exchange function of the lung, ECMO facilitates the institution of protective mechanical ventilation, as oxygenation and carbon dioxide clearance are provided by the extracorporeal circuit. This decreases the magnitude of ventilator-induced lung injury (VILI) secondary to volutrauma, barotrauma and oxygen toxicity.⁵ Respiratory ECMO constitutes 53% of the adult ECMO episodes reported to ELSO. The survival to discharge in patients receiving

Type of ECMO support	Diagnosis	% survived to hospital discharge or transfer
Respiratory		
	Viral pneumonia	65%
	Aspiration pneumonia	61%
	Bacterial pneumonia	59%
	Acute respiratory failure, non-ARDS	55%
	ARDS, postop/trauma	52%
	ARDS, not postop/trauma	48%
	Other	52%
Cardiac		
	Myocarditis	69%
	Cardiomyopathy	45%
	Cardiogenic shock	39%
	Congenital defect	36%
	Cardiac arrest	27%
	Other	

Table 1 ECMO use, diagnosis and outcome in adult patients.

respiratory ECMO is 54%.⁴

Cardiac ECMO

VA ECMO has been used to provide emergency cardiac support (**Table 3**). Conditions include cardiac surgical patients who fail to wean from cardiopulmonary bypass, or primary graft dysfunction after cardiac transplantation,⁶ cardiogenic shock, or as an advanced cardiopulmonary resuscitation.⁷ There have been no randomised, controlled trials (RCTs) studying the efficacy of ECMO support in cardiac failure patients.

Cardiac ECMO is generally associated with poorer outcomes than respiratory ECMO, and only 39% of patients survive to hospital discharge or transfer.⁴ Of these patients, a diagnosis of myocarditis is associated with the highest survival rate, of 69%.

ECMO circuits and equipment

Deoxygenated blood is taken via a vascular access cannula placed in a major vein or the right atrium and pumped around a circuit within connecting tubing, across an oxygenator and heat exchanger before returning to the patient via another cannula.

Cannulae – These are wire-reinforced. The flow resistance of the cannulae is the major factor limiting the maximum circuit flow. It is directly proportional to cannula length and inversely proportional to the fourth power of its radius.

Connecting tubing – This is made of polyvinyl chloride. Modern tubing used for ECMO is heparin-bonded to reduce activation of coagulation and inflammatory response.^{8,9} This allows lower levels of systemic anticoagulation.

Pump – The pump is used to provide propulsion pressure for blood flow. There are two basic types of pumps, centrifugal

Common	Uncommon
ARDS	Air leak
Severe pneumonia	Smoke inhalation injury
Acute graft failure following lung transplantation	Status asthmaticus
Pulmonary contusion	Airway obstruction
Reperfusion injury post pulmonary endarterectomy	Aspiration syndromes

Table 2 Indications for respiratory ECMO.

Common	Uncommon
Graft failure post cardiac transplant	Myocarditis
Post-cardiotomy circulatory failure	Chronic cardiac failure
Cardiogenic shock (ventricular rupture, papillary muscle rupture, ventricular septal defect, refractory VT)	Pulmonary or cardiac vessel trauma
Septic cardiomyopathy	Anaphylaxis
Drug overdose with cardiac depression	Pulmonary embolism

Table 3 Indications for cardiac ECMO.

and roller. The centrifugal pumps use the kinetic energy generated from a rapidly spinning impeller to drive blood flow. The pump is pre- and after-load dependent. Older roller pumps generate blood flow by squeezing specially reinforced tubing between a set of rollers and a back-plate.

As ECMO is a closed circuit, both types of pumps can generate high negative pressures, causing cavitation and haemolysis. The new generation of centrifugal pumps are used in preference to the roller pumps because they cause less pump-induced haemolysis.¹⁰

Oxygenator – The membrane oxygenator separates blood and gas phases while allowing gas exchange to occur. The maximum oxygenation capacity is determined by the membrane surface area, gas permeability, and mixing in the blood path. Silicone rubber and microporous hollow-fibre polypropylene oxygenators have largely been superseded by non-porous hollow-fibre polymethylpentene (PMP) oxygenators. The life-span of oxygenators varies, depending on the degree of heparinisation, circuit blood flow and blood product usage. PMP oxygenators typically last more than two weeks.

Heat exchanger – This is used to control blood temperature. It is bulky and takes more space than the pump and oxygenator. It is difficult to handle if included in transportable kits.

Monitoring and safety devices – Blood flow is monitored by ultrasonic detectors. The pre-oxygenator saturation is an approximation of the mixed venous oxygen saturation and is used to monitor the adequacy of tissue oxygen extraction. The post-oxygenator blood saturation and PaO₂ signify oxygenator function. An increased trans-oxygenator pressure gradient indicates the possibility of blood clots in the oxygenator.

Circuit access – Side ports and sampling outlets can be

fitted to the circuits for connecting haemofiltration or monitoring. Circuit interruptions increase the risks of infection, embolism and errors and should be avoided when possible.

The history of ECMO

The first reported successful use of ECMO was for an adult patient with post-traumatic ARDS in 1972.¹¹ The first RCT comparing conventional mechanical ventilation with the addition of VA ECMO in adult patients with severe acute respiratory failure in 1979 showed similar high mortality rates in both control and ECMO groups (91.7% vs 90.5% respectively).¹² In 1994, a second RCT studied the use of VA ECMO for CO₂ removal in combination with improved ventilator strategy in patients with respiratory failure.¹³ No survival benefit was seen in the ECMO group compared to the control group (33% survival vs 42% survival respectively). This study highlighted the haemorrhagic complications associated with the high degree of systemic heparinisation, as one-third of the patients receiving extracorporeal support had therapy discontinued due to uncontrolled bleeding.

In recent years, successive non-randomised comparative studies and case series have shown improved survival rates of up to 50-55% for ECMO-treated patients,¹⁴⁻¹⁷ with similar survival to non-ECMO patients despite ECMO patients being sicker initially. One study concluded that more than 80% of patients would have died without the use of ECMO.¹⁶ This increased survival benefit is likely to be due to improved ECMO technology, newly developed adjunct treatments and lung-protective ventilation.¹⁸

Recent advances

Clinical evidence

The multicentre CESAR trial was conducted in the UK from 2001-2006.² It compared conventional ventilator management in ICUs without ECMO facilities to transfer to a single specialist centre with ECMO capabilities for treatment of patients with severe respiratory failure. The results of CESAR showed that the transfer to this single centre significantly reduced the risk of death or severe disability at six months (RR=0.69, CI 0.05-0.97, p=0.03). The authors attributed improved outcomes to:

1. The extra time available to diagnose and treat patients whose lives were being supported by ECMO.
2. Protective ventilation and reduced iatrogenic lung injury.
3. The use of a standardised management protocol.

The influenza A (H1N1) pandemic in 2009 highlighted the usefulness of ECMO. The H1N1 pandemic led to a specific type of severe respiratory failure with a high proportion of patients suffering from severe hypoxaemia. Australian and New Zealand ICUs provided respiratory ECMO to a large number of patients with H1N1-associated ARDS during the winter of 2009.³ One third of these mechanically-ventilated H1N1 patients received ECMO support. This represented an incidence of 2.6 ECMO cases per million population. The hospital mortality rate was 21%, showing an improvement from any trial previously published. The authors attributed the

observed mortality rate to the patients' young age, favourable survival outcome associated with ARDS secondary to viral pneumonia and to improvements in ECMO technology and staff training. Although these case series did not show survival benefit for ECMO patients over patients who did not receive this support, there is emerging evidence of ECMO treatment survival benefit as well.¹⁹

Extracorporeal cardiopulmonary resuscitation (E-CPR) is emerging as an effective adjunct to conventional cardiopulmonary resuscitation for patients suffering from refractory in-hospital cardiac arrests. A prospective, observational study reported survival benefit for E-CPR over conventional CPR.²⁰ The E-CPR group had a survival rate of 28.8% at discharge and 18.6% at one year, while the conventional CPR group had survival rates of 12.3% and 9.7% respectively. The E-CPR group also had better neurological outcome at discharge. Survival to hospital discharge was associated with patients with acute viral myocarditis, higher pre-ECMO arterial blood PaO₂, the use of percutaneous ECMO cannulation techniques, and absence of renal replacement therapy during ECMO.²¹ The Extracorporeal Life Support Organization (ELSO) guidelines recommend consideration of ECMO to aid CPR in patients who have an easily reversible event, and have had excellent CPR.²² ECMO is likely to be futile if the CPR is unsuccessful for 5-30 minutes. As E-CPR is instituted emergently, usually using direct femoral vessel cannulation, it is only used in centres that have immediate availability of ECMO equipment and a cannulation team.

Technological improvement

The technological evolution of oxygenators has greatly contributed to the simplicity, safety and efficiency of modern ECMO. Oxygenators facilitate gas exchange between blood and gas phases but direct blood-gas contact results in haemolysis, consumption of platelets and coagulation factors, activation of the inflammatory response and thrombus formation. Membrane oxygenators use gas-permeable membranes at the blood-gas interface to reduce blood trauma. However, this protective membrane itself presents problems of biocompatibility, structural integrity, barrier to gas diffusion, and distribution of blood and gas flows for optimal mixing.²³

Silicone membrane oxygenators are biocompatible and durable but have inefficient gas exchange and high resistance to blood flow. The microporous hollow fibre polypropylene membrane oxygenators use micropores to provide excellent gas diffusion, at the cost of limited blood-gas contact. The hollow fibre cross-flow layout design increases the surface area-to-volume ratio, allowing a reduction in oxygenator size and priming volume. The inverse-flow design, where gas flows within the hollow fibres and blood flows between the hollow fibres, improves the mixing of oxygen in the blood, thus lowering blood path resistance and circuit pressure.²⁴ However, the long-term use of microporous oxygenators is impeded by plasma leakage and poor gas exchange. This necessitates frequent changes of the oxygenators and interruption of ECMO support. The newest nonporous hollow-fibre PMP membrane oxygenator offers excellent gas exchange capability and less plasma leakage with longer lifespan.²⁵ Its smaller

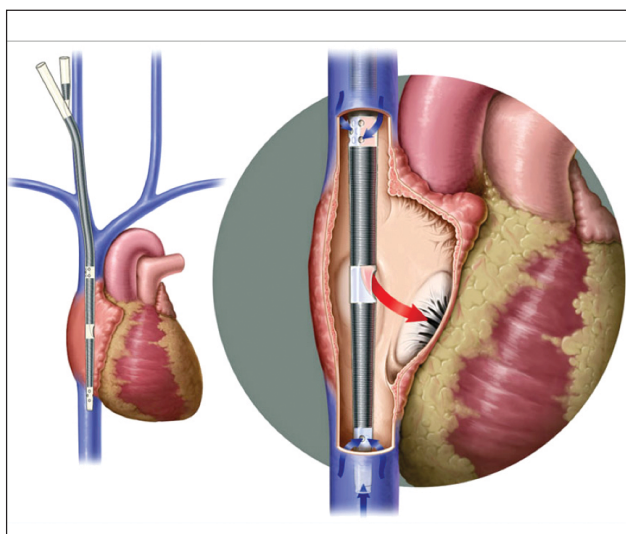


Figure 2 Positioning of an Avalon cannula.

surface and heparin-coated design also result in less consumption of platelets and coagulation factors.²⁶

Hand-held smaller ECMO systems have been introduced recently²⁷ as a result of the development of compact and efficient PMP membrane oxygenators, smaller and less blood-damaging centrifugal pumps, heparin-coated circuits enabling minimal systemic heparinisation and peripheral access cannulae designed for rapid percutaneous insertion. These devices have priming volumes less than 600 mL of normal saline, provide pump flow rates up to 4.5 L/min, and weigh as little as 9 kg.²⁸ They have been used for emergency implantation of extracorporeal life support in patients with cardiogenic shock or acute respiratory failure, including severe trauma patients with coexisting haemorrhagic shock. These systems have been shown to facilitate safe inter-hospital transfer, provide rapid improvement in gas exchange, tissue perfusion and vasopressor requirement, enable an initial period of heparin-free ECMO support in coagulopathic trauma patients without thromboembolic events, and have been associated with improved survival in these patients.²⁷⁻³¹

The recently introduced adult VV ECMO double lumen cannula (Avalon™ elite bi-caval dual lumen catheter) is designed for single site percutaneous right internal jugular vein insertion. (see **Figure 2**) The distal end of the cannula (in the IVC) and the proximal port (in the SVC) allow drainage of deoxygenated blood, while the infusion port (for oxygenated blood) is positioned in the right atrium. The advantages of the dual lumen cannula are:

- avoidance of recirculation of oxygenated blood through the ECMO
- ease of patient mobilisation
- diminished risk of inadvertent cannula dislodgement
- avoidance of femoral cannulation with its higher infection risk.³²

As a result of these technological advances, it is likely that the use of ECMO may spread from specialised cardiothoracic intensive care units to general intensive care units, as long as they have access to immediate cardiovascular support, as

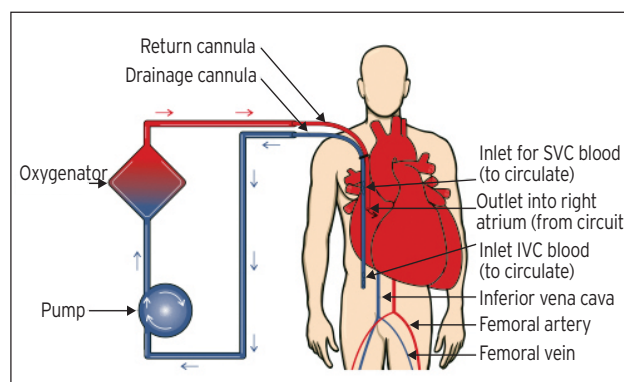


Figure 3a Peripheral VV ECMO (Avalon cannula): Blood is pumped from venae cavae through oxygenator and returned into RA.

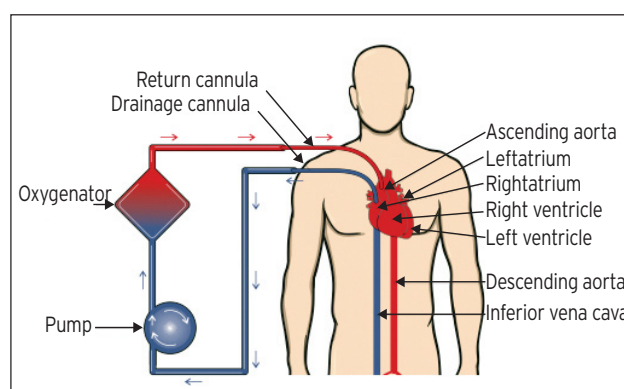


Figure 3b Central VA ECMO: Blood is pumped from venae cavae or RA through oxygenator and returned into the ascending aorta.

manipulation of a large cannula can cause major vascular trauma. This has been the natural evolution of intra-aortic balloon counterpulsation and renal replacement therapy.

Modes of ECMO

Veno-venous (VV) ECMO

Patients who received ECMO for severe ARDS during the 2009 influenza A (H1N1) pandemic were often young adults with no major cardiac morbidity³ and the majority received VV ECMO. VV ECMO (**Figure 3a**) is used to manage isolated respiratory failure when cardiac function is adequate. In practice, compromised cardiac function secondary to hypoxia and hypercarbia frequently improves with the commencement of VV ECMO as gas exchange improves. VV ECMO usually involves peripheral venous cannulation using single-lumen cannulae inserted via the internal jugular and femoral veins or, more recently, a dual lumen cannula placed via the right internal jugular vein.

Once the ECMO circuit returns the oxygenated blood to the right atrium, the patient's own heart pumps the oxygenated blood through the pulmonary and systemic circulations. VV ECMO effectively functions in series with the patient's own heart and lungs. The tissue oxygen delivery capability of the VV ECMO is determined by the cardiac output, haemoglobin concentration, ECMO inlet haemoglobin oxygen saturation and properties of the oxygenator.

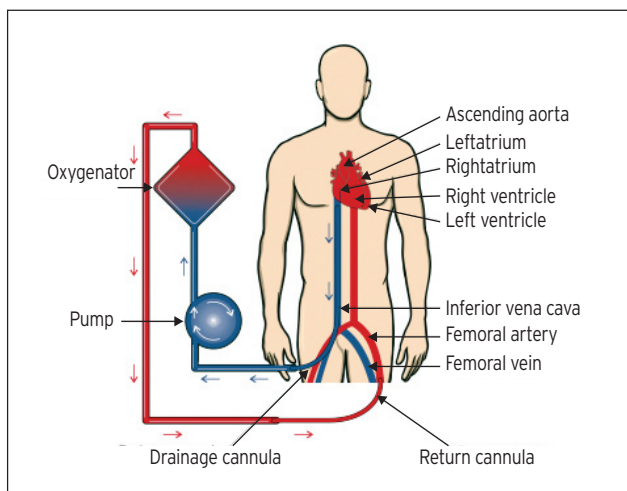


Figure 3c Peripheral VA ECMO: Blood is pumped from right atrium/inferior vena cava through oxygenator and returned into a femoral artery.

In VV ECMO, the oxygen content of the blood entering the pulmonary circulation is a mixture of the deoxygenated venous return and the oxygenated blood from the circuit. As the ECMO circuit has limited flow, patients with very large cardiac outputs may still have low systemic arterial oxygen tension. This should be borne in mind when assessing the efficiency of ECMO. The effects of injecting oxygenated blood into the right atrium on hypoxic pulmonary vasoconstriction have not been studied.

VV ECMO is preferred over VA ECMO for respiratory support because the patient's native haemodynamic physiology is maintained, cannulation of a major artery is avoided, and the potential for systemic embolism is minimised.

Veno-arterial (VA) ECMO

VA ECMO requires cannulation of the ascending aorta (central ECMO, **Figure 3b**) or femoral artery (peripheral ECMO, **Figure 3c**) for return of oxygenated blood. VA ECMO functions in parallel with the heart and lungs. By bypassing them, VA ECMO decreases pulmonary artery pressure, augments systemic perfusion and achieves higher PaO₂ than VV ECMO. It can be used for both left and right ventricular failure.³³

Both ECMO flow and output from the left ventricle contribute to the total systemic blood flow. Similarly, the relative flows and their associated oxygen saturations determine systemic oxygen saturation. This has important implications in the setting of peripheral VA ECMO in a patient with normal cardiac function but impaired lung function. The poorly oxygenated blood from the left ventricle preferentially supplies the cerebral and coronary circulations, while well-oxygenated blood from the femoral arterial cannula supplies the lower body. Therefore, peripheral VA ECMO is used to manage patients with adequate respiratory function, while central VA ECMO is more commonly used in patients undergoing cardiac surgery or in patients with combined cardio-respiratory failure. In patients requiring central VA ECMO post-cardiac surgery, placement of a left ventricular vent should be considered to decompress and rest the ventricle.

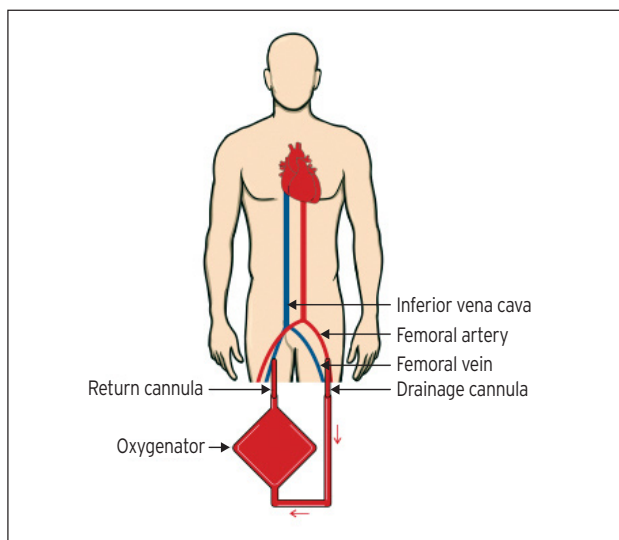


Figure 3d Peripheral AV ECMO (Novalung): Femoral arterial blood flow is redirected through oxygenator and returned into a femoral vein.

Pumpless extracorporeal lung assist (Novalung)

This is a simple and efficient gas exchange membrane which uses the patient's own cardiac output to drive blood flow through a circuit (Novalung, **Figure 3d**).³⁴ An oxygenator with low flow resistance and high gas transfer efficiency is connected to cannulae placed in the femoral artery and vein. The circuit flow is driven by the femoral arterial pressure. Typical flows are up to 1 L/min, which allows excellent CO₂ removal. Oxygenation is limited, due to the inflow of relatively well-oxygenated arterial blood. The capability for efficient CO₂ removal allows for a reduction in ventilator settings. There is growing evidence that this approach might help prevent VILI and improve outcome in patients with acute respiratory failure.³⁵ The simplicity of the circuit and its portability also make it suitable for emergency use and transfer. Its use is relatively contraindicated in patients with haemodynamic instability, cardiac insufficiency or peripheral atherosclerosis.

Management of ECMO

The National Institute for Health and Clinical Excellence (NICE) and the European Association for Cardio-Thoracic Surgery have published guidance and a position statement on ECMO.³⁶⁻³⁸

Cannulation

Vascular access is obtained either peripherally via the neck or femoral vessels, or centrally via the right atrium and aorta. Cannulae can be placed using open surgical access, percutaneously by a Seldinger technique, or by direct central cannulation via sternotomy or thoracotomy. Percutaneous cannulation is commonly used for VV ECMO in adults. Direct cardiac cannulation is usually used for patients who cannot be weaned off cardiopulmonary bypass during cardiac surgery. A bolus of heparin (eg 2500-5000 IU) is administered prior to cannula placement. This prevents clotting within the circuit due to blood-surface interaction. The femoral artery may

become significantly occluded by the cannula resulting in leg ischaemia. A separate perfusion line is usually placed in the distal superficial femoral artery for retrograde perfusion.

ECMO flow

The optimal ECMO blood flow is the lowest flow rate required to provide adequate cardiopulmonary support. For VV ECMO, ELSO general guidelines³⁹ define adequate support as that which achieves an arterial saturation greater than 80% and venous saturation greater than 70%. For central VA ECMO, the optimal pump flow is achieved by adjusting the flow until the arterial pulse pressure is at least 10 mm Hg in order to maintain continuous flow through the heart and pulmonary circulation (pulsatility may not be achievable in patients without ventricular ejection). Usually flows of 3-6 L/min in average-size adults are sufficient for ECMO.

Anticoagulation

An infusion of unfractionated heparin is maintained to prevent thrombus formation within the circuit and subsequent embolism. Minimal anticoagulation is required due to the lack of blood/air interface in a reservoir, as well as to the use of heparin-bonded circuits and newer-generation pumps. For patients with heparin-induced thrombocytopenia, alternative anticoagulation could be used, but the risk of haemorrhagic complications is very high.

Haemodynamic support

Inotropic drugs can be used to maintain contractility during cardiac ECMO. If the systemic perfusion pressure or oxygen delivery is inadequate as indicated by low urine output, poor tissue perfusion, or mixed venous saturation less than 70%, optimisation of haemoglobin level and/or increased doses of vasopressors can be used.

Oxygenation

During VV ECMO, infused well-oxygenated blood mixes with systemic venous blood in the right atrium. This usually results in a mixed venous oxygen saturation of 80% or PO₂ of 5.3 kPa. In the absence of any native pulmonary function, this blood admixture will provide systemic arterial oxygenation. Achievement of normal oxygenation and normocarbica contributes to return of normal homeostasis and avoidance of complications,⁴⁰ but it is not always possible. The main aim of VV support is to avoid iatrogenic pulmonary injury by facilitating protective ventilation.

During VA ECMO, mixing of infusion blood with arterial blood occurs at various levels of the aorta, depending on the site of arterial cannulation (central vs peripheral) and the relative contribution of ECMO and the native heart to the circulation. Significant LV ejection and severe respiratory failure, especially if coupled with peripheral VA ECMO, can result in upper-body hypoxaemia, while the lower body is perfused with well-oxygenated ECMO blood. For this reason, arterial oxygenation should be monitored via the right upper limb to reflect coronary and cerebral oxygenation.

Sweep gas

The sweep gas delivers oxygen to the oxygenator and its flow rate alters the CO₂ clearance. Gas bubbles can pass through the

oxygenator membrane into the blood if the sweep gas pressure exceeds the blood pressure, resulting in air entrainment into the circuit. This is important to remember during air transfers. Some circuits contain bubble traps for this reason.

Complications during ECMO

A wide variety of ECMO-related complications have been reported to the ELSO Registry.⁴ These can be broadly divided into circuit- or patient-related complications.

Air in the circuit (1.6-1.8%) leads to massive gas embolism. Tubing rupture (0.4-1.8%) results in catastrophic haemorrhage. These are potentially fatal circuit complications and require immediate clamping of the circuit. This will result in temporary loss of ECMO support for the patient, and immediate alternative cardio-respiratory supports will be required.

Reduction of circuit flow is the most commonly encountered problem and is usually due to hypovolaemia, indicated by a reduction in the inlet pressure or 'tugging' of drainage tubing. Failure of the oxygenator (17.5-18.9%) is a common mechanical complication. Thrombus formation occurs most frequently in the oxygenators (11.6-12.2%), and may cause disrupted circuit blood flow, oxygenator or pump failure, or systemic embolism. Other life-threatening causes of reduced circuit flow include cardiac tamponade, tension pneumothorax and obstructed cannula or tubing.

Systemic heparinisation reduces thrombus formation but increases the risk of bleeding, which is further exacerbated by thrombocytopenia. Bleeding is an expected complication of ECMO, mainly occurring at cannulation sites (17.1-21.3%) and surgical sites (19.0-27.9%). It is managed by decreasing or stopping the heparin infusion, maintaining a platelet count greater than 150,000/ μ L, and correcting any coagulopathy. Intracranial haemorrhage (1.4-3.8%) is the most serious ECMO complication due to its potentially fatal consequence.

Hypoxaemia and hypoperfusion before and during ECMO frequently result in organ dysfunction. The majority of patients require inotropic support at some point during ECMO (61.1-77.5%). Most patients will require haemofiltration. Clinically determined seizures occur in 1.4-2.5% of patients, while brain CT scan detects infarctions in 1.9-3.2% of patients.

Discontinuing ECMO

Signs of recovery of respiratory function include improving arterial oxygen saturation, lung compliance and chest X-ray appearance. For central ECMO, increased pulsatility of arterial waveform reflects increased myocardial contractility and ejection fraction.

To wean patients off respiratory ECMO, mechanical ventilatory support is first set to an appropriate level, then the ECMO flow reduced to a safe lower level and eventually the gas sweep is discontinued. If the respiratory physiological parameters remain stable for a period of time, eg 12-24 hours, the ECMO flow is stopped and cannulae removed.

To wean patients off cardiac ECMO, inotropic support should be established and ECMO flow reduced in a stepwise fashion. Monitoring of ventricular function using transoesophageal echocardiography during the weaning stage

is essential. If patients remain stable for a pre-determined period of time, the ECMO circuits are clamped and cannulae removed.

Conclusion

ECMO outcomes are constantly improving. This is the result of evolving technology, improving experience and decreasing complication rates. Patients receiving this treatment would have died without it. With further improvement in technology and our understanding of the extremes of pathophysiology, it is likely the use of ECMO in ICU will expand and become a standard critical care therapy like continuous veno-venous haemofiltration or intra-aortic balloon counterpulsation. The new era of mobile ECMO, for transportation of the critically ill and as an adjunct to conventional resuscitation, opens the horizons for improvement in critical care medicine.

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Declaration of interests

The authors declare that there is no conflict of interest or financial support.

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