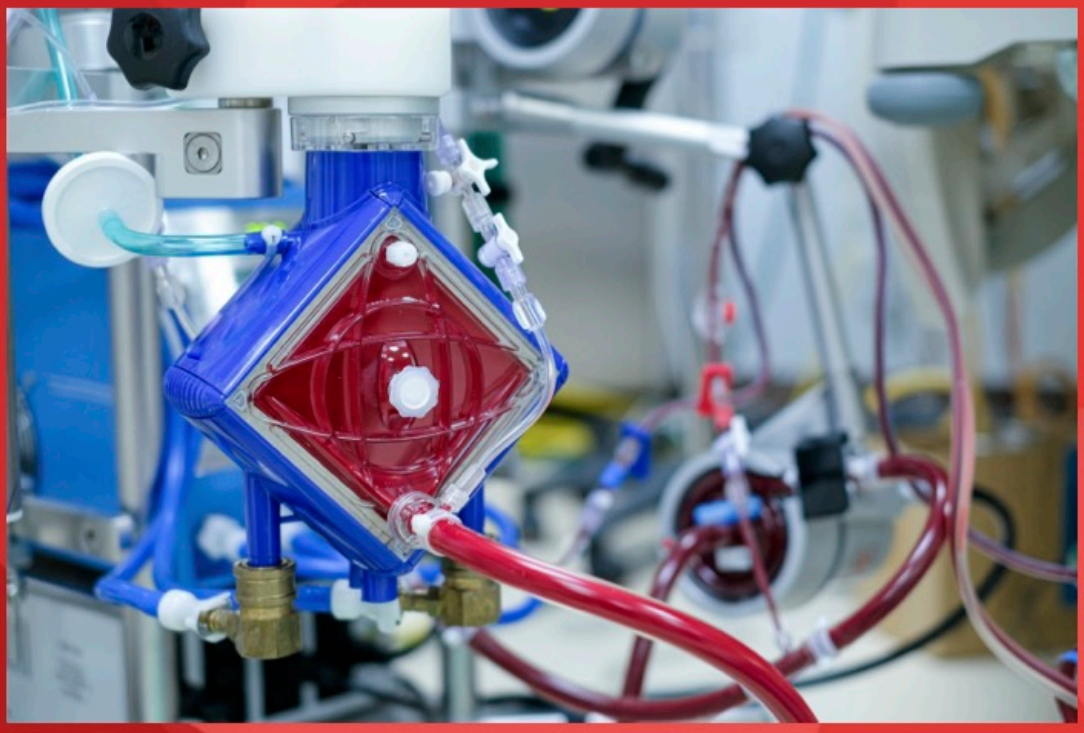
GUIDELINES FOR ADULT EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO)



PUBLISHED BY

MALAYSIAN CARDIOTHORACIC ANAESTHESIOLOGY
AND PERFUSION SOCIETY
MASCAP

GUIDELINES FOR ADULT EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO)

Published by

Malaysian Cardiothoracic Anaesthesiology and Perfusion Society (MASCAP)

1st Edition 2023

CONTENTS

FOREWORD

Extracorporeal Membrane Oxygenation (ECMO) is a form of extracorporeal life support for children and adults suffering from life-threatening cardiorespiratory failure. It is a highly complex treatment option where patient outcome depends on the knowledge and skills of dedicated multidisciplinary ECMO teams.

ECMO is now increasingly available in Malaysia, especially in Ministry of Health cardiac centers. It provides a treatment option to support patients with cardiorespiratory failure who otherwise have no survival chance.

Management of patients on ECMO requires a thorough understanding of applied physiology and application of this knowledge in severely ill patients who are under extreme physiological stress. Essential to the medical team managing such a patient is continuous education and upskilling in ECMO related sciences and technologies to ensure resources spent result in desired outcomes in patient care. Hence, on a day to day run of ECMO in intensive care units, written protocol and guidelines serve as important reference tools.

The Malaysian Cardiothoracic Anaesthesiology and Perfusion Society (MASCAP) has taken the initiative to develop a guideline on ECMO for use in Malaysian hospitals. The contents of this guideline include not only theoretical and practical aspects of ECMO but also recommendations on training and competency. It is my sincere hope that this guideline will assist ECMO teams in the appropriate use of this technology, decision making and clinical care of ECMO patients which will ultimately improve patient care.

I wish to thank the members of the writing group and contributors led by Dr Hasmizy Muhammad for their commitment and hard work in producing the first edition of "Guidelines on Adult Extracorporeal Membrane Oxygenation". This guideline will serve as a useful reference for ECMO teams as well as other stakeholders involved in the management of patients with severe cardiorespiratory failure.

Dato' Dr Jahizah Hassan
President
Malaysian Cardiothoracic Anaesthesiology and Perfusion Society (MASCAP)

CONTRIBUTORS

Dr Hasmizy Muhammad (Editor)
Senior Consultant Cardiothoracic Anaesthesiologist and Head
Department of Anaesthesiology and Intensive Care
Pusat Jantung Sarawak
Sarawak

Dr Mohamad Hanafi Mohd
Consultant Cardiothoracic Anaesthesiologist and Head
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Pulau Pinang
Penang

Dato' Dr Yong Chow Yen
Senior Consultant Cardiothoracic Anaesthesiologist
Hospital Lam Wah Ee
Penang

Dr Maseeda Mohamed Yusof
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Pulau Pinang
Penang

Dr Azmiza Maharani
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultanah Aminah
Johor Bharu, Johor

Dr Hanafi Sidik
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Pusat Jantung Sarawak
Sarawak

Dr Noordini Mohamed Dani
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Tengku Ampuan Afzan
Kuantan, Pahang

Dato' Dr Norly Ismail
Senior Consultant Cardiothoracic Anaesthesiologist and Head
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Dr Zuhrah Zakaria
Senior Consultant Cardiothoracic Anaesthesiologist and Head
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Dr Haslan Ghazali
Consultant Cardiothoracic Anaesthesiologist
KPJ Pahang Specialist Hospital
Kuantan, Pahang

Dr Jusmidar Abdul Jamil
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Pulau Pinang
Penang

Dr Mohd Khairul Anwar A. Rahim
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultanah Aminah
Johor Bharu, Johor

Dr Chua Chen Chen
Consultant Cardiothoracic Anaesthesiologist
Department of Cardiothoracic Anaesthesiology and Perfusion
Hospital Queen Elizabeth II
Sabah

Dr Nazri Mohamed
Consultant Cardiothoracic Anaesthesiologist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Raja Perempuan Zainab II
Kota Bharu, Kelantan

CONTRIBUTORS

Abdul Ghani Manan
Former Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Hermi Safian
Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Rosedy Tiyut
Former Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Pusat Jantung Sarawak
Sarawak

Faradh Anas Masdokhi
Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Pulau Pinang
Penang

Nurasmayanti Leman
Matron
Cardiothoracic Intensive Care Unit
Hospital Sultan Idris Shah
Serdang, Selangor

Mohd Shahrul Nizal Saad
Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Vikneshwaran Seenivasagam
Former Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Sultan Idris Shah
Serdang, Selangor

Andy Sherman Khung
Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Pusat Jantung Sarawak
Sarawak

Mohd Ezihan Saufi
Former Senior Perfusionist
Cardiothoracic Anaesthesiology and Perfusion Unit
Department of Anaesthesiology and Intensive Care
Hospital Raja Perempuan Zainab II
Kota Bharu, Kelantan

Section 1: Introduction

1.1 Extracorporeal membrane oxygenation (ECMO) has significantly advanced in recent years, and it is a vital tool in the treatment of adults with severe cardiac and pulmonary dysfunction who are resistant to conventional treatments.[1]

1.2 The objective of this guideline is to outline the standard management of adult patients with cardiac or respiratory failure receiving extracorporeal membrane oxygenation life support.

1.3 This guideline may be useful for those who work in critical areas, including operation theatres and invasive cardiology laboratories.

Section 2: The ECMO Team

2.1 The ECMO team includes:

a) Cardiothoracic Anaesthesiologist
b) Cardiothoracic Surgeon
c) Intensivist
d) Cardiologist
e) Perfusionist
f) ICU Nurse

2.2 Job description for the ECMO team

a) Cardiothoracic Anaesthesiologist, Cardiothoracic Surgeon, Intensivist and Cardiologist. The service cover for:

i. Assessment and selection of all patients referred for ECMO.
ii. Involvement in all key decision-making.
iii. Optimal cannula configuration.
iv. Daily review of all ECMO patients.
v. Retrieval.
vi. Supervision of trainees.

b) Perfusionist

i. Responsible for the technical support required for all phases of ECMO.
ii. Attendance for all cases of ECMO initiation and in the event of patient's instability.
iii. Perfusionist should attend the morning ward round and review patients prior to leaving the hospital.
iv. Dedicated perfusionist on–call for ECMO patients.

c) ICU Nurse

i. The nursing team is responsible for the direct care of patients.
ii. Only nurses who have attended the ECMO education courses can provide primary care for patients on ECMO.
iii. Patients on ECMO must be nursed in a 2:1 ratio for the first 48 hours and subsequently until stable.
iv. Patients requiring transport throughout the hospital (e.g., CT scan) or having CRRT running also require 2:1 nursing.

Section 3: Indications and Contraindications of ECMO

3.1 Indications of Veno-Arterial (VA) ECMO [2]

a) VA ECMO is used to provide both respiratory and cardiac support.
b) Cardiac conditions with low cardiac output (cardiac index < 2L/min/m^2) and hypotension (systolic blood pressure <90 mmHg) despite inotropic and intra-aortic balloon pump support.
c) Cardiogenic shock secondary to either acute coronary syndrome, refractory cardiac arrhythmia, sepsis leading to cardiac depression, myocarditis, pulmonary embolism, drug toxicity, cardiac trauma, anaphylaxis, and acute decompensated heart failure.
d) Periprocedural for high-risk cardiac interventions.
e) Postoperative heart failure: inability to wean from cardiopulmonary bypass after cardiac surgery.
f) Post-heart transplant: after heart or lung-heart transplantation in cases of primary graft failure.
g) Bridge to long-term VAD support or bridge to heart/lung transplant.

3.2 Indications of Veno-Venous (VV) ECMO [3]

One or more of the following:

a) Hypoxemic respiratory failure (PaO2 /FiO2 < 80mm Hg), after optimal medical management.
b) Hypercapnic respiratory failure (pH < 7.25), despite optimal conventional mechanical ventilation (respiratory rate ≥ 35 bpm and plateau pressure [Pplat] ≤ 30cm H2 O).
c) Ventilatory support as a bridge to lung transplantation or primary graft dysfunction following lung transplant.

Specific clinical conditions:

a) Acute respiratory distress syndrome (e.g., viral/bacterial pneumonia and aspiration).
b) Acute eosinophilic pneumonia.
c) Diffuse alveolar hemorrhage or pulmonary hemorrhage.
d) Severe asthma.
e) Thoracic trauma (e.g., traumatic lung injury and severe pulmonary contusion).
f) Severe inhalational injury.
g) Large bronchopleural fistula.
h) Peri-lung transplant (e.g., primary lung graft dysfunction and bridge to transplant).

3.3 Contraindications

a) Contraindications for VA ECMO [4]

i. Cardiac recovery is unlikely and no indication for heart transplant or left ventricular (LV) assists device.
ii. Poor life expectancy (end-stage peripheral-organ diseases, malignant tumors, etc.).
iii. Severe aortic valve regurgitation.
iv. Severe vascular disease with extensive aortic and peripheral vessel involvement.
v. Acute Type A or B aortic dissection with extensive aortic branches involvement.
vi. Severe neurologic impairment (i.e., prolonged anoxic brain damage, extensive trauma, and bleeding).
vii. Liver cirrhosis (Child-Pugh class B and C).

b) Absolute contraindications for VV ECMO [5]

i. Patient refusal.
ii. Advanced cancer stage.
iii. Fatal intracerebral hemorrhage/cerebral herniation/intractable intracranial hypertension.
iv. Irreversible destruction of the lung parenchyma without the option of transplantation.
v. Contraindications to lung transplantation.

c) Relative contraindications to all forms of ECMO [3,5]

i. Age > 70 years.
ii. Immunocompromised patients/pharmacological immunosuppression.
iii. Duration of conventional mechanical ventilation > 7 days, with high inspiratory pressures (Pplat > 30 cmH_2O), high FiO_2 (FiO_2 >0.8).
iv. Hematologic malignancies, especially bone marrow transplantation and graft-versus-host disease.
v. Trauma with multiple bleeding sites.
vi. Intracranial bleeding.
vii. CPR duration > 30 min without documented neurological recovery.
viii. Severe multiple organ failure (≥ 2 organs).
ix. CNS injury.
x. Contraindications to anticoagulation.
xi. BMI < 18 or > 40.

Section 4: Patient Preparation Before ECMO Cannulation

4.1 Lines inserted prior to ECMO cannulation:

a) Arterial line (preferably right radial for veno-arterial with femoral cannulation).
b) Long-term Internal Jugular Cannula.

4.2 Inotropes and vasopressor infusions connected to the patient.

4.3 Adequate sedation and paralysis.

4.4 Look for the patency of blood vessels by using vascular ultrasound before cannulation.

4.5 Consider Transesophageal Echocardiography (TEE) guidance of cannula position.

4.6 Inform the patient's family member regarding the need for ECMO.

Section 5: Vascular Access

5.1 Mode of vascular access[6]

a) VA ECMO - drainage cannula is inserted in the femoral vein or internal jugular vein, and a return cannula is inserted in the femoral artery, carotid artery, or ascending aorta.

b) VV ECMO - drainage cannula, as well as a return cannula, is placed in the major veins.

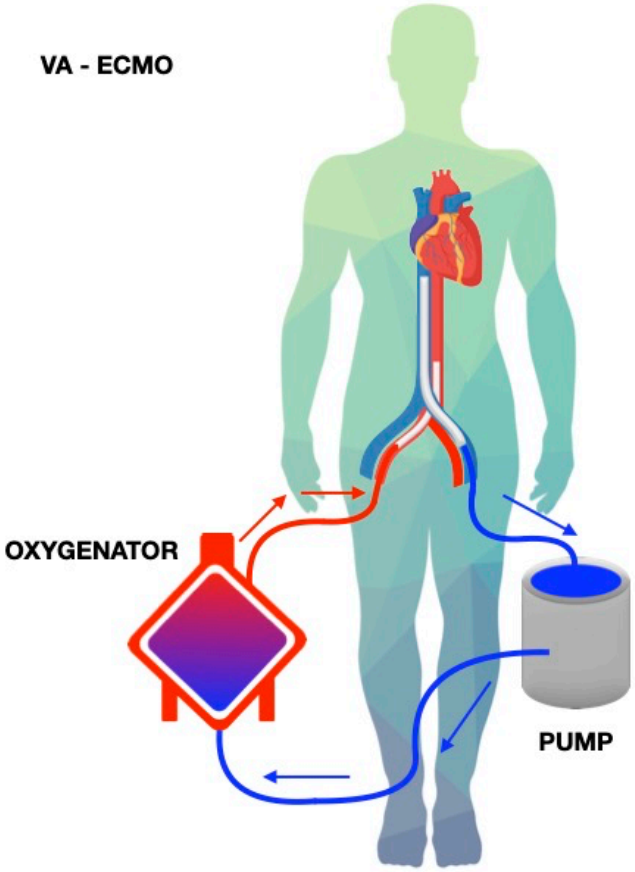


Figure 5.1: Peripheral Veno-arterial ECMO

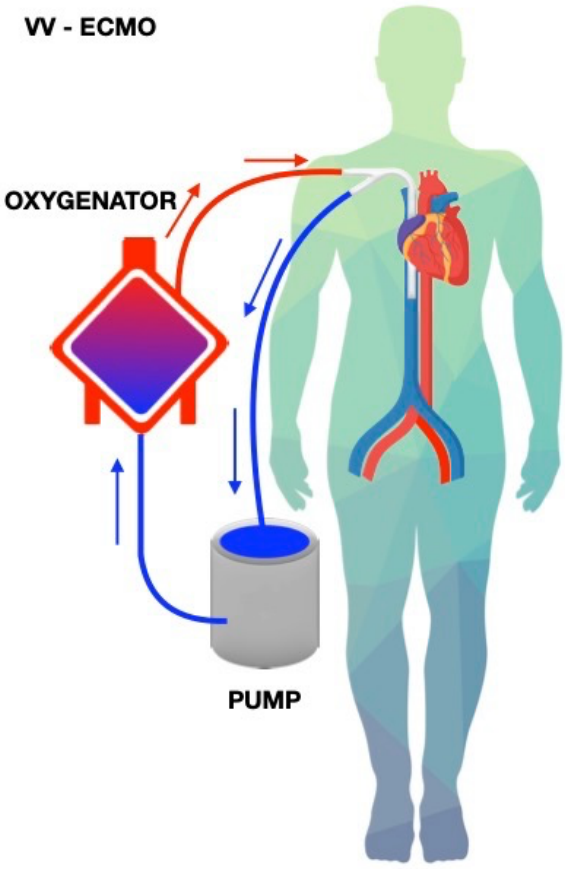


Figure 5.2: Dual lumen, single cannula Veno-venous ECMO

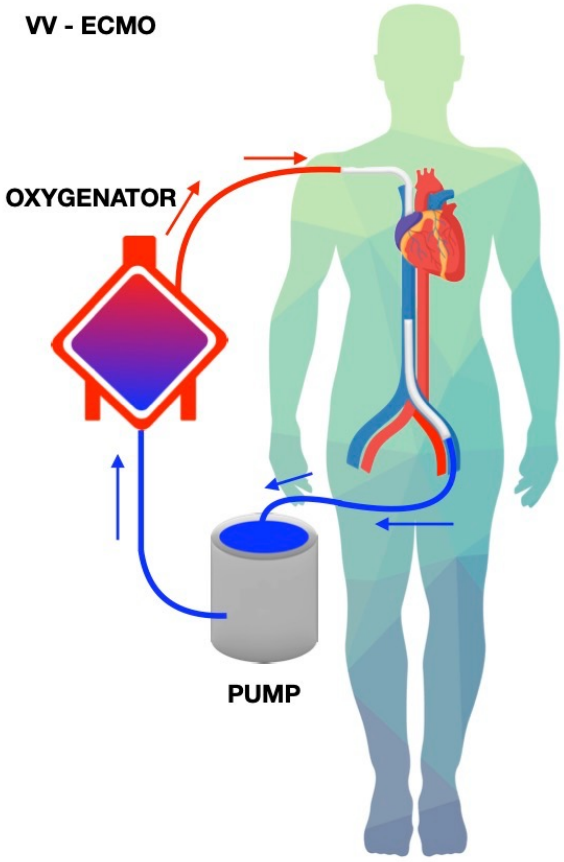


Figure 5.3: Femoro-jugular Veno-venous ECMO

5.2 Cannulation methods

Cannulas can be placed via:

a) Cut down.
b) Percutaneously by a vessel puncture, guidewire placement, and serial dilation (Seldinger technique).
c) A combination of cut-down exposure and Seldinger cannulation.
d) Direct cannulation of the right atrium and aorta via sternotomy.

5.3 Securing access and return lines.

a) Lines should be secured with at least 3 points of suture to the skin, a biopatch applied and the line insertion site dressed with a transparent film dressing.
b) The right internal jugular cannula should be secured by suturing to the chest wall.
c) The lines should be covered at points of fixed curvature with split tubing to prevent kinking.

Figure 5.4: Cannulation for dual lumen, single cannula VV ECMO

5.4 Cannulas

The blood flow resistance of vascular access cannulas is directly proportional to the length and inversely proportional to the radius to the fourth power.

a) Cannula for central ECMO[7]

Manufacturer	Size [Fr]	Length, cm	Pressure gradient for 20 Fr at 4 L/min, mmHg
Terumo	Arterial [10–26]	15	60
	Venous (two-stage) [28–36]	39	5–10
Medtronic	Arterial [15–24]	18	40
	Venous (two-stage) [28–36]	38	4–6
Maquet	Arterial [20–24]	23	13
	Venous (two-stage) [32–36]	40	5

Table 5.1: Cannula for central ECMO

b) Cannula for peripheral ECMO[7]

Manufacturer	Size [Fr]	Length, cm	Pressure gradient for 20 Fr at 4 L/min, mmHg
Terumo	Arterial [20–24]	24	50
	Venous (Medtronic) [19–26]	76	30
Maquet	Arterial [15–29]	38-55	32
	Venous [19–29]	55	30
Edwards	Arterial [16–24]	24	45
	Venous [18–28]	87	45

Table 5.2: Cannula for peripheral ECMO

c) Dual lumen cannula for VV ECMO[7]

Manufacturer	Size [Fr]	Length, cm	Pressure gradient at 4 L/min, mmHg
Avalon Elite	20–31	31	110 (31 Fr return)
			30 (31 Fr drainage)
Novaport	18-24	27	NA
OriGen	23-32	20-30	140 (13 Fr return)
			30 (13 Fr drainage)

Table 5.3: Dual lumen cannula for VV ECMO

Section 6: ECMO Equipment

6.1 Circuit components

The basic circuit includes a centrifugal pump, an oxygenator, heparin coated tubing, heat exchanger, monitors and alarms.

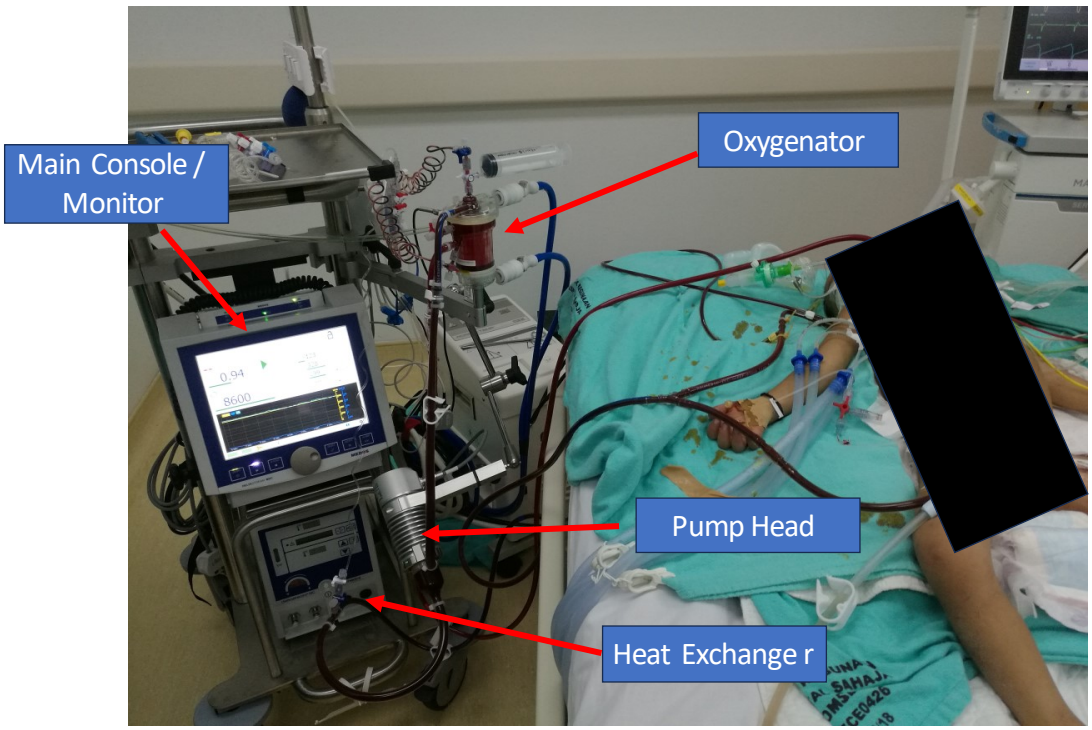


Figure 6.1 Circuit components

6.2 Oxygen supply lines and air/oxygen mixer/sweep gas

a) Oxygen supply lines provide oxygen delivery to the oxygenator from wall mounted oxygen system or oxygen tank.
b) During initial setup, sweep gas is 100% oxygen at a flow rate that is equal to the blood flow rate (1:1). Sweep gas is used to control CO_2 removal.

6.3 Blood tubing

a) Tubing selection
   i. Arterial line (return line):
      - 1/4” tubing can be used up to flows of 2.0 l/min.
      - 3/8” tubing is used for flows above 2.0 l/min.

ii. Venous line (drainage line):
- 1/4” tubing is used up to selected flow of 1.0 l/min.
- 3/8” tubing is for flows above 1.0 l/min.

6.4 Heat exchanger - to control patients’ blood and body temperature at a desired level.

6.5 Alarm and monitors

a) Ultrasonic flow measurement and bubble detector devices are placed on blood return line - to detect low or high flow and air bubbles.
b) Pressure transducers (P1 and P2)
   i. Difference between P2 and P3 determine the transmembrane lung pressure gradient.
c) Temperature probe.
d) Arterial blood gas
   i. Measure from pre-oxygenator and post-oxygenator sites either by continuous online monitoring or batch sampling.
   ii. To determine the inlet and outlet PaO_2 and PCO_2.
   iii. To evaluate membrane lung function.
   iv. To determine blood pH, metabolic status and other parameters.
e) ACT machine - monitor and maintain adequate heparinization.

Section 7: Conduct of ECMO

7.1 Priming the ECMO circuit

a) Only the perfusionist may perform ECMO circuit priming.
b) Sterile attire and CO_2 priming is not required.
c) The circuit is primed from the pump head to the oxygenator, then to the sterile circuit.
d) All circuit connections to be performed with no touch technique.

7.2 Initiation of ECMO

a) IV Heparin (50 units/kg) should be given few minutes before initiating cannulation.
b) Ensure ACT >180 sec before cannulation.
c) Turn on gas flow to the oxygenator using an FiO_2 of 1.0 and a flow equal to the calculated or desired blood flow.
d) Hand clean loop to cannulating doctor.
e) Cut circuit between two clamps, allowing enough length on both access and return lines.
f) Connect circuit to cannula, ensuring that no air is introduced.
g) Target flow should be high enough to maintain adequate arterial oxygenation.
h) Check patient arterial and circuit pre- and post-oxygenator blood gases.
i) Manipulate cannula positions to obtain optimal circuit flows and minimise recirculation.

7.3 Maintenance of ECMO

a) Blood Flow

i. Gradually increase blood flow to mix the circulating blood with the prime until maximum flow is achieved.
ii. Maximum flow possible will be based on the patient and the cannula resistance.
iii. VA ECMO: target flows must provide adequate oxygen delivery.
iv. VV ECMO: target flows must provide adequate arterial oxygenation, defined as arterial saturation greater than 80%.

b) Oxygenation

i. Oxygen delivery from the circuit should be adequate for full support [systemic saturation > 95% (VA) or > 80% (VV) at low ventilator settings and FiO2].
ii. Venous saturation should be 20-30% saturation less than arterial saturation. This indicates that systemic oxygen delivery is 3-5 times oxygen consumption.

c) Sweep gas flow/ CO_2 clearance

   i. Initial setup, the sweep gas is set at 100% oxygen at a flow rate equal to the blood flow rate (1:1) later titrated to maintain desired P_aCO_2.
   ii. Increasing the sweep flow will increase CO_2 clearance but will not affect oxygenation.

Section 8: Anticoagulant

Interaction of blood and the biomaterial surface of the ECMO circuits results in a hypercoagulable state, increasing the risk of thrombosis for the patient and the circuit.[8]

Anticoagulation practices are based on patients' bleeding risk profile. Patients' Hb should be ideally maintained at 10 – 12 mg/dL.

8.1 Routine blood tests for ECMO patients include:

a) 2 hourly ACTs on Day 0.
b) Continue checking ACTs 2 hourly on day 1 until stable.
c) Target for the ACT in the non-bleeding patient with Platelets >80,000 is 180 - 210 seconds.
d) 6 hourly APTT (Commencing Day 0 concurrently with ACTs).
e) Daily FBC.
f) Every other day: D Dimer, Fibrinogen, TT.
g) Additional tests as indicated, e.g., Thromboelastogram (TEG), LDH.

8.2 APTTs guide heparin therapy with the usual target range for the non-bleeding patient with platelets > 80,000 of 60 - 80 seconds.

8.3 Heparin Infusion

a) Add 25000 units of heparin to a 50 cc syringe of 5% dextrose.
b) Concentration is 500 units per mL.
c) The starting rate is 20 unit/kg/hr.
d) If heparin is adjusted, repeat ACT and/or aPTT in 2 hours.

ACT	RESPONSE
< 130	Bolus 100 units/kg and increase infusion by 300 units/hr
130 – 150	Increase infusion by 200 units/hr
150 – 180	Increase infusion by 100 units/hr
180 – 210	No change
210 – 250	Decrease infusion rate by 200 units/hr
> 250	Cease infusion for 1 hour. Check ACT hourly and recommence when ACT < 210 at 300 units/hr less than original rate

Table 8.1: Heparin infusion titration guide for ACT.

APTT	RESPONSE
< 37	Bolus 60 units/kg and increase infusion by 4 units/kg/hr
37 – 44	Bolus 40 units/kg and increase infusion by 3 units/kg/hr
45 – 60	Bolus 20 units/kg and increase infusion by 2 units/kg/hr
61 – 80	No change
81 – 100	Decrease infusion rate by 2 units/kg/hr
> 100	Decrease infusion rate by 3 units/kg/hr

Table 8.2: Heparin infusion titration guide for APTT.

Section 9: Hemodynamic Monitoring in ECMO Patients

These monitoring are suggested to assess the adequacy of perfusion, predict and assess the response of fluid therapy, and conduct right ventricle (RV) and left ventricle (LV) assessments from time to time.

9.1 VA ECMO

a) Aim:
   i. SaO_2 > 90%
   ii. Mixed oxygen venous saturation (SvO_2) ≥ 70%
   iii. Mean arterial pressure (MAP) 50 – 70 mmHg
   iv. Hb > 10 - 12 g/dL
b) The patient's haemodynamic is controlled by the blood flow (pump flow and native cardiac output), and vascular resistance.
c) If the systemic perfusion pressure is inadequate (low urine output, poor perfusion), low dose vasoconstrictor and blood or fluid can be added.

9.2 VV ECMO

a) A patient is dependent on his/her haemodynamic physiology.
b) Appropriate medications are used to control cardiac output, blood pressure and resistance.

9.3 Lower limb with arterial cannulation

a) Leg distal to the arterial cannulation is perfused by a backflow cannula.
b) Perfusion assessment based on temperature, capillary return, and Doppler ultrasound assessment.

	VA ECMO	VV ECMO
Arterial blood gases	Valid	Valid
Venous oxyhemoglobin saturation	Potentially valid	Valid
Pulse oximetry	Usually valid (Right arm)	Lacks validity
Indicator dilution	Lacks validity	Lacks validity
NIRS	Valid	Valid
LVOT VTI	Valid	Lacks validity
Pulse contour stoke volume	Valid	Lacks validity
POCUS / ECHO	Valid	Valid
PPV/SVV to predict fluid response	Lacks validity	Lacks validity

Table 9.1: Validity of monitoring during ECMO[9]

Section 10: Ventilatory Support in ECMO Patients

10.1 All patients are intubated endotracheally in initiating ECMO.

10.2 If a patient is on VA-ECMO for cardiac support and lung function is adequate, OR if the gas exchange is totally supported with ECMO, the patient can be extubated and managed without mechanical ventilation.

10.3 Ventilation management

a) Lung Rest Ventilation

i. To offer maximal lung rest with avoidance of atelectotrauma.
ii. Low rate (RR: 10bpm) with long inspiratory time.
iii. Low plateau inspiratory pressure (Pplat ≤ 25cmH2O).
iv. PEEP 10-15 cmH_2O.
v. Low FiO2: 0.3-0.6.

b) If there is a major pulmonary air leak or interstitial emphysema, the ventilator pressure can be reduced or turned off altogether for hours or days until the leak seals.

10.4 If there is pneumothorax

a) < 20% with no haemodynamic compromise: closely monitor.

10.5 Lung recruitment

a) Lung recruitment maneuvers (prolonged inflation at 25-30 cmH2O for 1-2 minutes) can be used when acute inflammation has subsided.

Section 11: Weaning of ECMO

11.1 VA ECMO

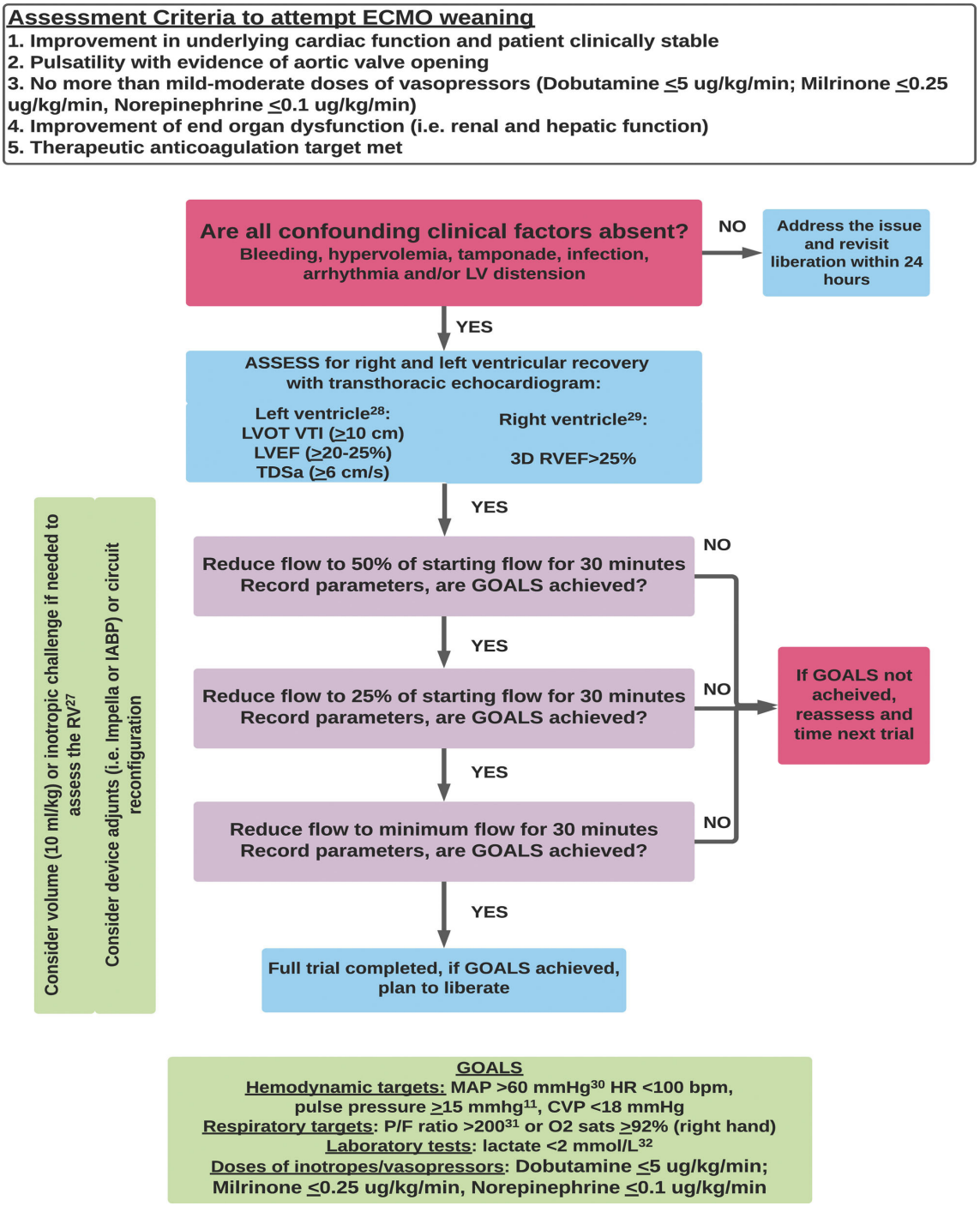


Figure 11.1: Weaning algorithm for veno-arterial extracorporeal membrane oxygenation.[10]

11.2 VV ECMO

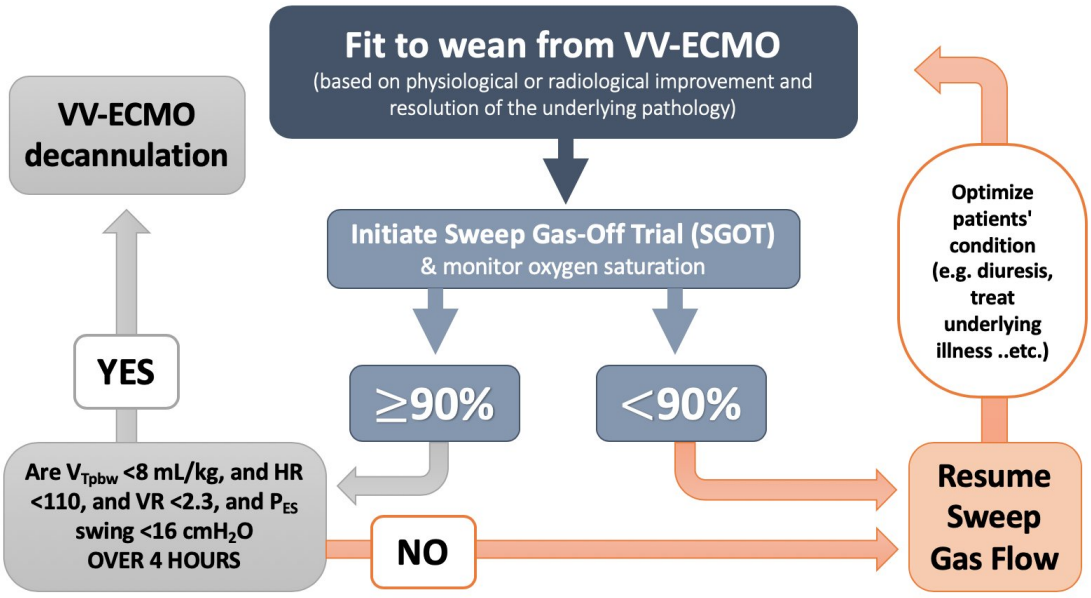


Figure 11.2: Weaning algorithm for veno-venous extracorporeal membrane oxygenation.[11] (VTpbw = tidal volume per predicted body weight, VR= ventilatory ratio, P_{ES}=inspiratory efforts)

Section 12: ECMO Complications

Complications can be related to either circuit components or patient conditions.[12]

12.1 Circuit-related complications

a) Blood clots in the circuit and thromboembolism.
b) Gas embolism.
c) Circuit fractures.

12.2 Patient-related complications

a) Cannulation vascular complication
    i. Vascular access complications - arterial dissection, creation of false ways, or perforation of the posterior wall of the vessel.
    ii. Leg ischemia - risk with femoral arterial cannulation.
b) Bleeding
    i. Surgical and cannulation site bleeding.
    ii. GI bleeding and airway bleeding
c) Coagulopathy – thrombocytopenia (common), heparin-induced thrombotic thrombocytopenia and DIC.
d) Neurological complications - intracranial hemorrhage varies between 1.6 and 18.9 %.
e) Cardiac complications - LV distention.
f) Infection/Sepsis - increased risk of nosocomial infection.

Section 13: Ultrasound and Echocardiography in ECMO Patients

The use of ultrasound can be considered for pre-ECMO initiation, during ECMO initiation, and post-ECMO initiation.[13]

13.1 Pre-ECMO initiation

a) Patient selection - focused echocardiogram in a patient, helps with the diagnosis and in determining the configuration of ECMO.
b) Identification of concurrent pathologies - moderate to severe aortic regurgitation precludes the patient from VA-ECMO.
c) Identification of vessels and assessment of vessel size.

13.2 During ECMO initiation

a) Vascular Ultrasound - real-time ultrasound guidance during percutaneous ECMO cannulation helps to identify and puncture the intended vessel.
b) Echo guidance during cannulation - guidewire can be visualised in the inferior vena cava (IVC) or aorta, ensuring safe dilatation of the vessel and desired position of the cannula.
c) Transesophageal echocardiography should be considered if transthoracic views are suboptimal.

13.3 Post ECMO initiation

a) In VV ECMO, echo has a very important role to play in the evaluation of a patient with refractory hypoxia on ECMO.
b) In VA ECMO, echo has a very important role to play in the evaluation of loss of pulsatility, pulmonary oedema and assessment for weaning from ECMO.

Section 14: Transportation of ECMO Patients

14.1 Intra-hospital

It may be necessary to transport to radiology, the operating room, or the cardiac catheterization lab:

a) Personnel – doctor, ICU nurse, perfusionist, and attendant.
b) Equipment preparation:
    i. Extra pump drive or hand crank must be ensured.
    ii. The battery should be fully charged before leaving.
    iii. Adequate oxygen supply for ECMO machine and transport ventilator.
    iv. Ensure all infusion pumps are fully charged and extension tubing length is adequate.
    v. Others:
        - Resuscitation drugs
        - Ambu bag

14.2 Inter-hospital

a) Personnel and equipment preparation is similar to intra-hospital transport.
b) Additional spare parts of all components including spare cannula sizes, operating instruments, medications, etc. must be brought along.
c) One of the accompanying staff must be able to recannulate in case of accidental decannulation.
d) Communication with referral hospital with instruction regarding family, consent and blood and platelets, and plasma preparation, OR team if necessary, etc.
e) Complete the ECMO transport checklist prior to leaving to and from destination.

Section 15: Training and Competency

15.1 Training Outline[14]

a) Didactic Course. Topics could include:
   i. Introduction to ECMO.
   ii. Physiology of the diseases treated with ECMO.
   iii. Pre-ECMO procedures.
   iv. Criteria and contraindications for ECMO.
   v. Physiology of coagulation.
   vi. ECMO equipment.
   vii. Physiology of veno-arterial and veno-venous ECMO.
   viii. Daily patient and circuit management on ECMO.
   ix. Emergencies and complications during ECMO.
   x. Management of complex ECMO cases.
   xi. Weaning from ECMO.
   xii. Decannulation procedures.
   xiii. Post ECMO complications.
   xiv. Short and long-term developmental outcome of ECMO patients.
   xv. Ethical and social issues

b) Water-drills
   i. Basic Session - review of circuit configuration and function, and basic troubleshooting.
   ii. Emergency Session.

c) Bedside Training

15.2 Competency

a) Institutional competency will be granted after successful completion of the ECMO training course (didactic, water drills/animal labs, bedside training) and successfully passing the oral and/or written exam.

Section 16: Record and Registry

16.1 All ECMO patients' records are stored electronically or by manual entry on the ECMO sheet at least once every hour or more frequently when any changes or adjustments take place.

16.2 ECMO patients' records at Appendix A.

Appendix A

ECMO Patient's Record

Patient Name:
Date of Admission:
Date of Cannulation:

Doctor Name:
Perfusionist Name:
Nurse Name:

Type of ECMO Support: VA, VV
Outflow/Drainage cannula position: (L/R), Femoral, Jugular, Central
Inflow/Return cannula position: (L/R), Femoral, Jugular, Central

	ECMO				OXYGENATOR				Labs/ABG							
Time	RPM	Flow, L/min	Pre, mmHg	Post, mmHg	Sweep, L/min	FiO2	SVO2	Hct	ACT	Heparin	pH	pO2	pCO2	Lactate	SpO2	Hct

References

1. MacLaren G, Combes A, Bartlett RH. (2012). Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. *Intensive Care Med*, 38:210-20.

2. Vyas A, Bishop MA. (2023). *Extracorporeal Membrane Oxygenation in Adults.* StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK576426/.

3. Tonna JE, Abrams D, Brodie D, Greenwood JC, Rubio Mateo-Sidron JA, Usman A, Fan E. (2021). Management of Adult Patients Supported with Venovenous Extracorporeal Membrane Oxygenation (VV ECMO): Guideline from the Extracorporeal Life Support Organization (ELSO). *ASAIO J*,67(6):601-610. doi: 10.1097/MAT.0000000000001432. PMID: 33965970; PMCID: PMC8315725.

4. Lorusso, Roberto; Shekar, Kiran; MacLaren, Graeme; Schmidt, Matthieu; Pellegrino, Vincent; Meyns, Bart; Haft, Jonathan; et al. (2021). ELSO Interim Guidelines for Venoarterial Extracorporeal Membrane Oxygenation in Adult Cardiac Patients*. ASAIO Journal*, p 827-844, DOI: 10.1097/MAT.0000000000001510.

5. Harnisch LO, Moerer O. (2021). Contraindications to the Initiation of Veno-Venous ECMO for Severe Acute Respiratory Failure in Adults: A Systematic Review and Practical Approach Based on the Current Literature. *Membranes (Basel)*, 30;11(8):584. doi: 10.3390/membranes11080584. PMID: 34436348; PMCID: PMC8400963.

6. Pooboni SK, Gulla KM. (2021). Vascular access in ECMO. *Indian J Thorac Cardiovasc Surg*, 37(Suppl 2):221-231. doi: 10.1007/s12055-020-00999-w. Epub 2020 Sep 17. PMID: 33967445; PMCID: PMC8062664.

7. Pavlushkov E, Berman M, Valchanov K. (2017). Cannulation techniques for extracorporeal life support. *Ann Transl Med*, 5(4):70. doi: 10.21037/atm.2016.11.47. PMID: 28275615; PMCID: PMC5337209.

8. Marasco SF, Lukas G, McDonald M, McMillan J, Ihle B. (2008). Review of ECMO (extra corporeal membrane oxygenation) support in critically ill adult patients. *Heart Lung Circ.* 17:S41–S47.

9. Krishnan, Sundara; Schmidt, Gregory A.b. (2019). Hemodynamic monitoring in the extracorporeal membrane oxygenation patient. *Current Opinion in Critical Care*, p 285-291. DOI: 10.1097/MCC.0000000000000602.

10. Brahmbhatt DH, Daly AL, Luk AC, Fan E, Billia F. (2021). Liberation From Venoarterial Extracorporeal Membrane Oxygenation: A Review. *Circ Heart Fail*, e007679. doi: 10.1161/CIRCHEARTFAILURE.120.007679. Epub 2021 Jul 12. PMID: 34247519.

11. Abdulrahman A. Al-Fares, Niall D. Ferguson, Jin Ma, Marcelo Cypel, Shaf Keshavjee, Eddy Fan, Lorenzo Del Sorbo. (2021). Achieving Safe Liberation During Weaning From VV-ECMO in Patients with Severe ARDS: The Role of Tidal Volume and Inspiratory Effort. *Chest,* Volume 160, Issue 5.

12. Sangalli F, Patroniti N, Pesenti A. (2014). *ECMO-Extracorporeal Life Support in Adults*. Springer-Verlag Italia.

13. Vinodh Bhagyalakshmi Nanjayya. (2015). *ELSO Ultrasound Guidance for Extra-corporeal Membrane Oxygenation General Guidelines.*

14. ELSO Guidelines for Training and Continuing Education of ECMO Specialists, Version 1.5 February 2010.