Extracorporeal membrane oxygenation

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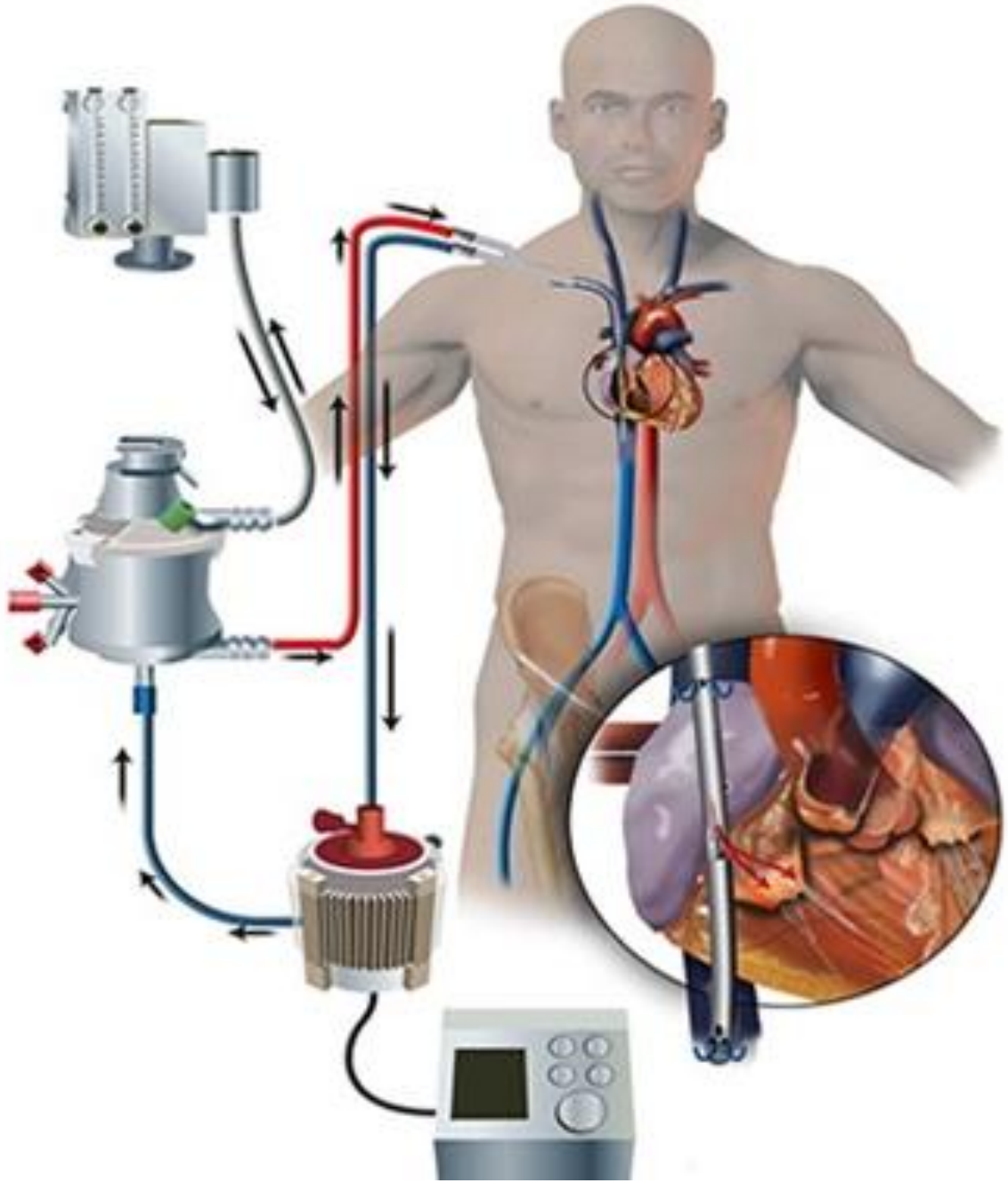
Outline

- Definition
- Types of ECMO
- Indications/contraindications
- ECMO management
- Anesthetic consideration and transportation
- Complications/Troubleshooting
- ECPR
- Weaning from ECMO



What is ECMO?

Extracorporeal

Membrane

Oxygenation

Hayanga AJ, Aboagye J, Esper S, Shigemura N, Bermudez CA, D'Cunha J, Bhama JK. Extracorporeal membrane oxygenation as a bridge to lung transplantation in the United States: An evolving strategy in the management of rapidly advancing pulmonary disease. *J Thorac Cardiovasc Surg* 2015;149:291-296.

CPB vs ECMO

Major differences	CPB	ECMO
Duration	Minutes to hours	Days to weeks
Open reservoir	Yes	No
Heparin(ACT)	> 400 sec	>180 sec
Hemodilution	Yes	Yes: lesser degree than CPB
Patient	Asleep	Asleep/Awake
Inflammation	More	Less

Long-term ECMO as support for severe respiratory failure was first successfully used in an adult patient with post-traumatic respiratory failure in 1972 by by J. Donald Hill

use of the Bramson Membrane Lung. N Engl J Med 286:629–634

Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO2 removal for adult respiratory distress syndrome.

A H Morris , C J Wallace , R L Menlove , T P Clemmer , J F Orme Jr, L K Weaver , N C Dean , F Thomas , T D East , N L Pace , M R Suchyta , Show All...

https://doi.org/10.1164/ajrccm.149.2.8306022 PubMed: 8306022

The impact of a new therapy that includes pressure-controlled inverse ratio ventilation followed by extracorporeal CO2 removal on the survival of patients with severe ARDS was evaluated in a randomized controlled clinical trial. Computerized protocols generated around-the-clock instructions for management of arterial oxygenation to assure equivalent intensity of care for patients randomized to the new therapy limb and those randomized to the control, mechanical ventilation limb. We randomized 40 patients with severe ARDS who met the ECMO entry criteria. The main outcome measure was survival at 30 day
(ext
38% (15 of 40) and was about four times that expected from historical data (p = 0.0002). Extracorporeal treatment group survival was not significantly different from other published survival rates after extracorporeal CO2 removal. Mechanical ventilation patient group survival was significantly higher than the 12% derived from published data (p = 0.0001). Protocols controlled care 86% of the time. Average PaO2 was 59 mm Hg in both treatment groups. Intensity of care required to maintain arterial oxygenation was similar in both groups (2.6 and 2.6 PEEP changes/day; 4.3 and 5.0 FIO2 changes/day).

No significant difference in survival between the mechanical ventilation and the extracorporeal CO_2 removal groups.

Lancet. 2009 Oct 17;374(9698):1351-63. doi: 10.1016/S0140-6736(09)61069-2. Epub 2009 Sep 15.

Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial.

Peek GJ[1], Mugford M, Tiruvoipati R, Wilson A, Allen E, Thalanany MM, Hibbert CL, Truesdale A, Clemens F, Cooper N, Firmin RK, Elbourne D; CESAR trial collaboration.

⊕ Collaborators (306)

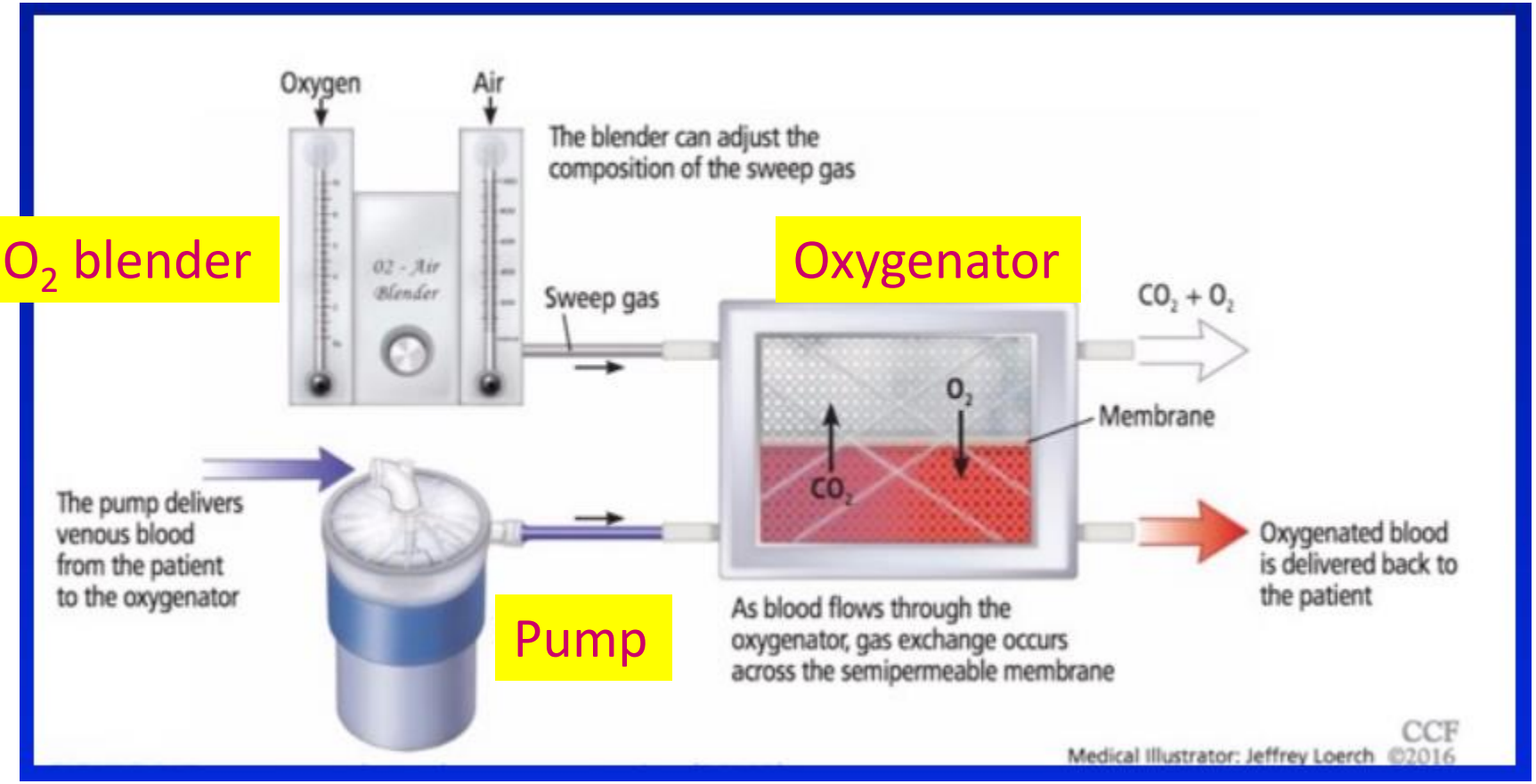
⊕ Author information

- FINDINGS:766 patients were screened; 180 were enrolled and randomly allocated to consideration for treatment by ECMO (n=90 patients) or to receive conventional management

63% (57/90) of patients allocated to treatment by ECMO survived to 6 months without disability compared with 47% (41/87) of those allocated to conventional management (relative risk 0.69; 95% CI 0.05-0.97, p=0.03).

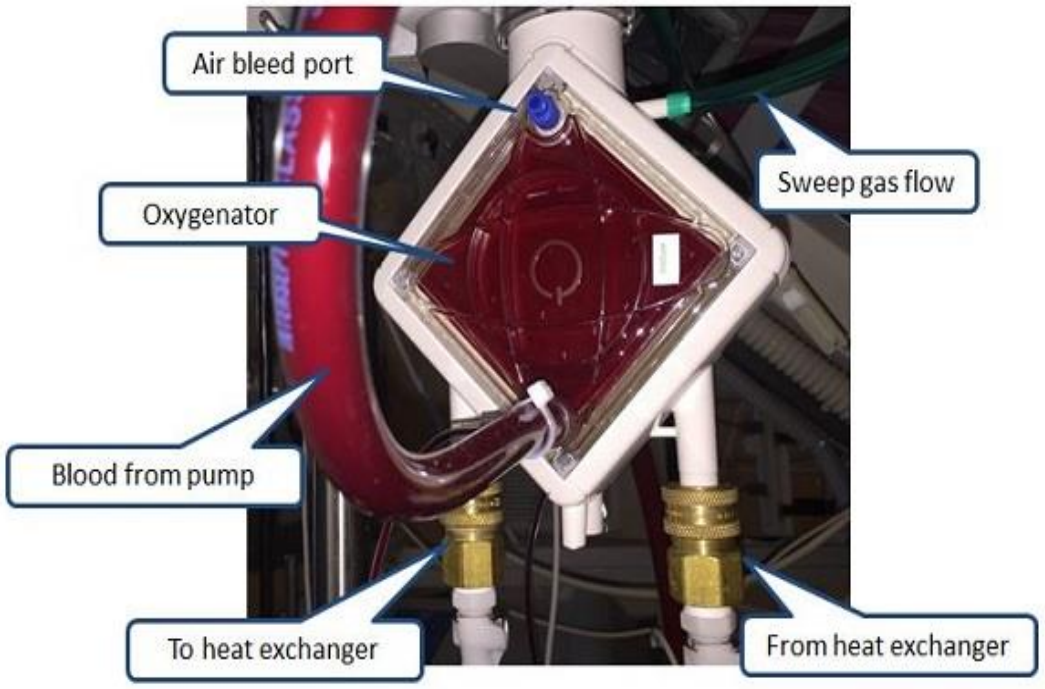
life-years (QALYs) at 6-month follow-up [corrected]. A lifetime model predicted the cost per QALY of ECMO to be pound19 252 (95% CI 7622-59 200) at a discount rate of 3.5%.

ECMO Circuit



Cleveland Clinic Journal of Medicine 2016;83,5:373

Oxygenator

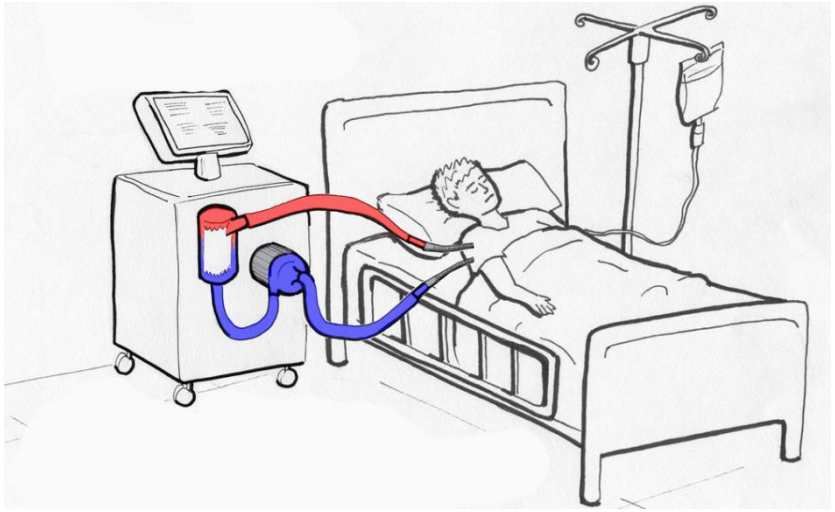


- Semi permeable membrane
- Blood flows across one side while a “sweep” gas 100% O_2 moves in opposite direction
- Principle of **concentration gradient**
- The higher the gas flow rate the more CO_2 is removed
- Trans- membrane pressure gradient should be less than 50 mmHg
- An increase in the trans-membrane pressure may indicate clot formation within the oxygenator

http://icuecmo.ca/icuECMO_content/icuECMO_ECMO_circuit.html

Oxygenation depends on:

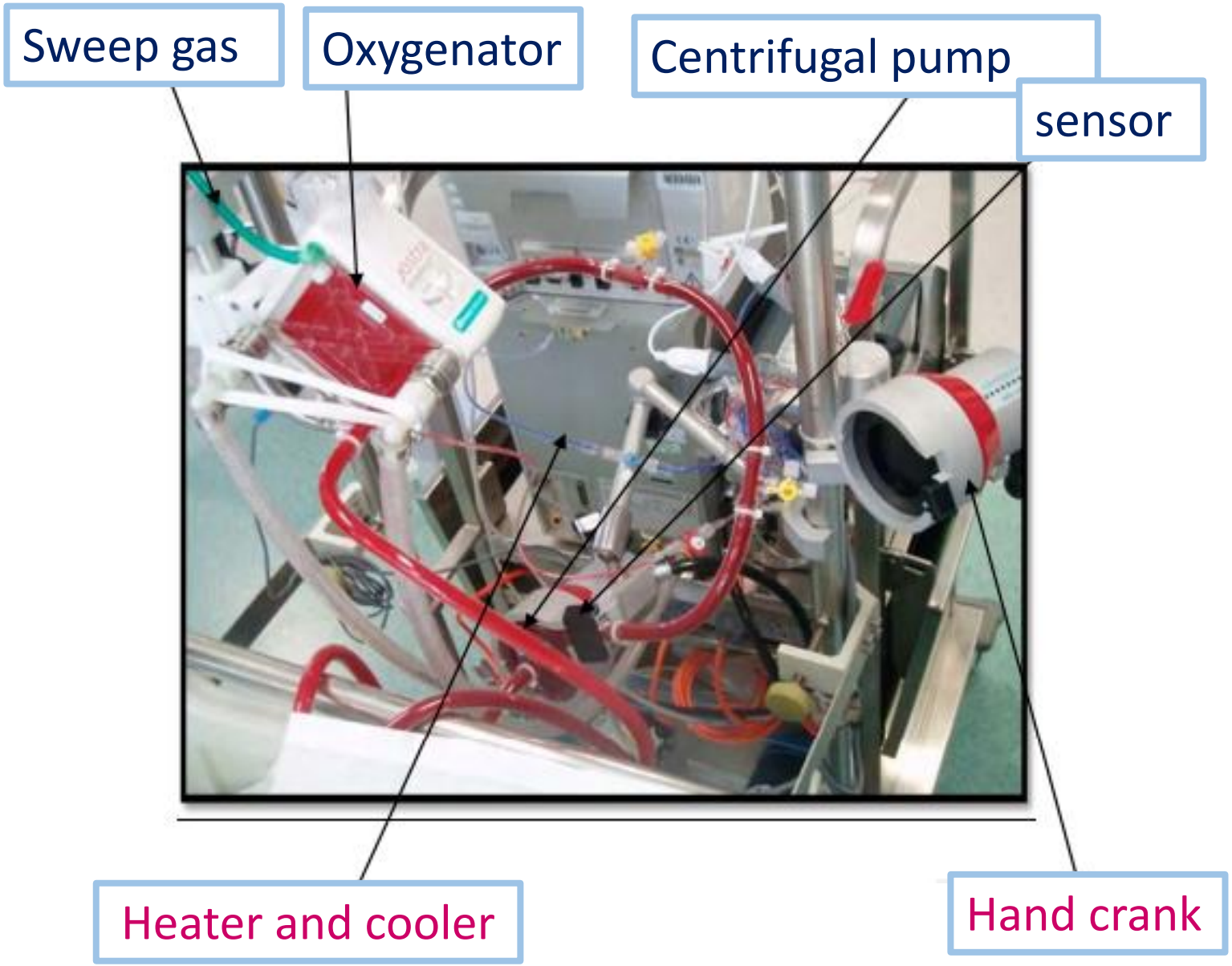
- Blood Flow
- FiO_2
- The membrane integrity



Carbon dioxide removal depends on:

- The sweep speed
- The flow
- The presence of water vapor in the membrane

http://icuecmo.ca/icuECMO_content/icuECMO_ECMO_circuit.html


Sweep gas
Oxygenator
Centrifugal pump
sensor
Heater and cooler
Hand crank

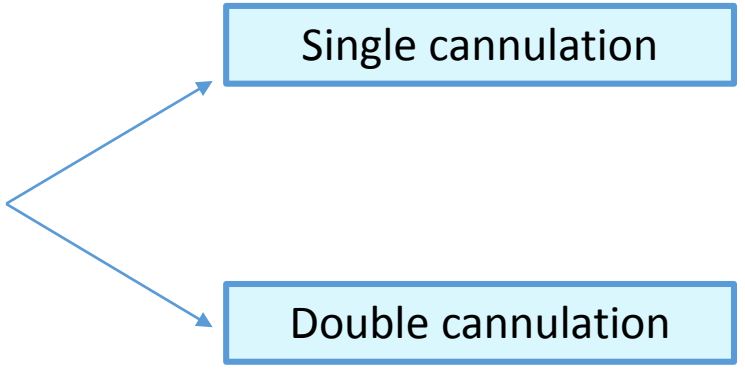
Pump Console

- Provides the controls for **pump blood flow rate and speed**
- Battery backup of **90 minutes**
- It can be incorporated into the bypass machine or stand alone mode

Types of ECMO

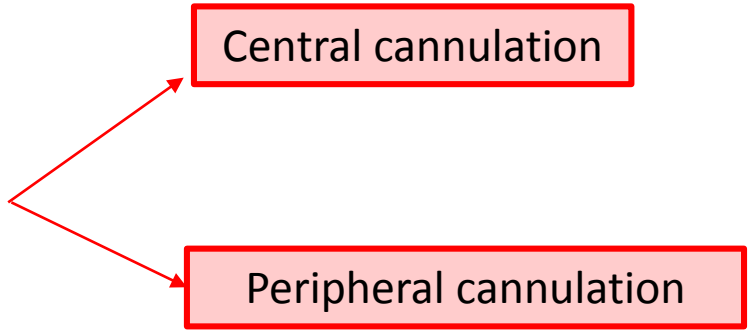
Veno-venous (VV) ECMO

provides support for the lungs only



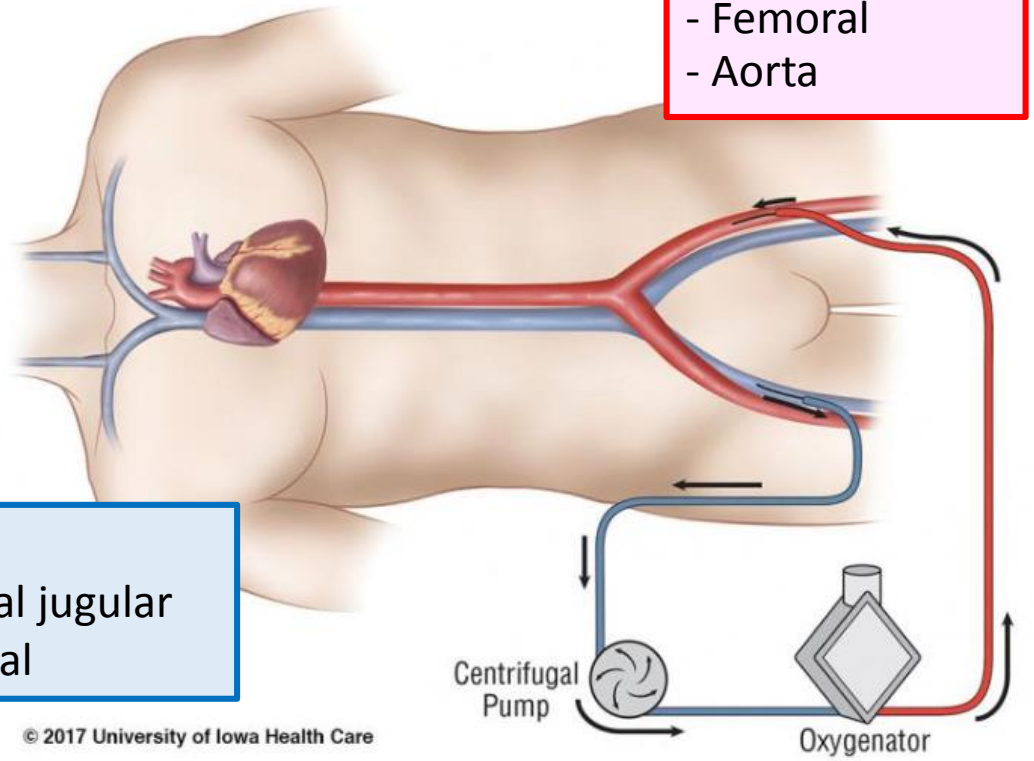
Veno-arterial (VA) ECMO

provides support for both the heart and the lungs



V-A ECMO

Artery:
- Right common carotid
- Axillary
- Femoral
- Aorta

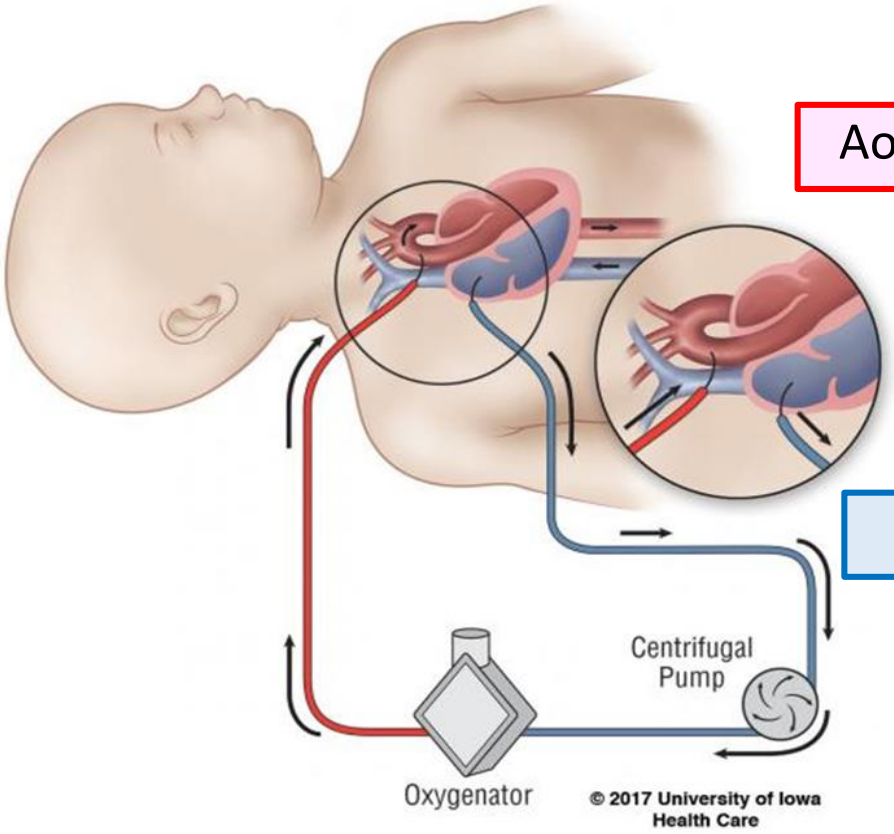


Vein:
- Internal jugular
- Femoral

Peripheral cannulation

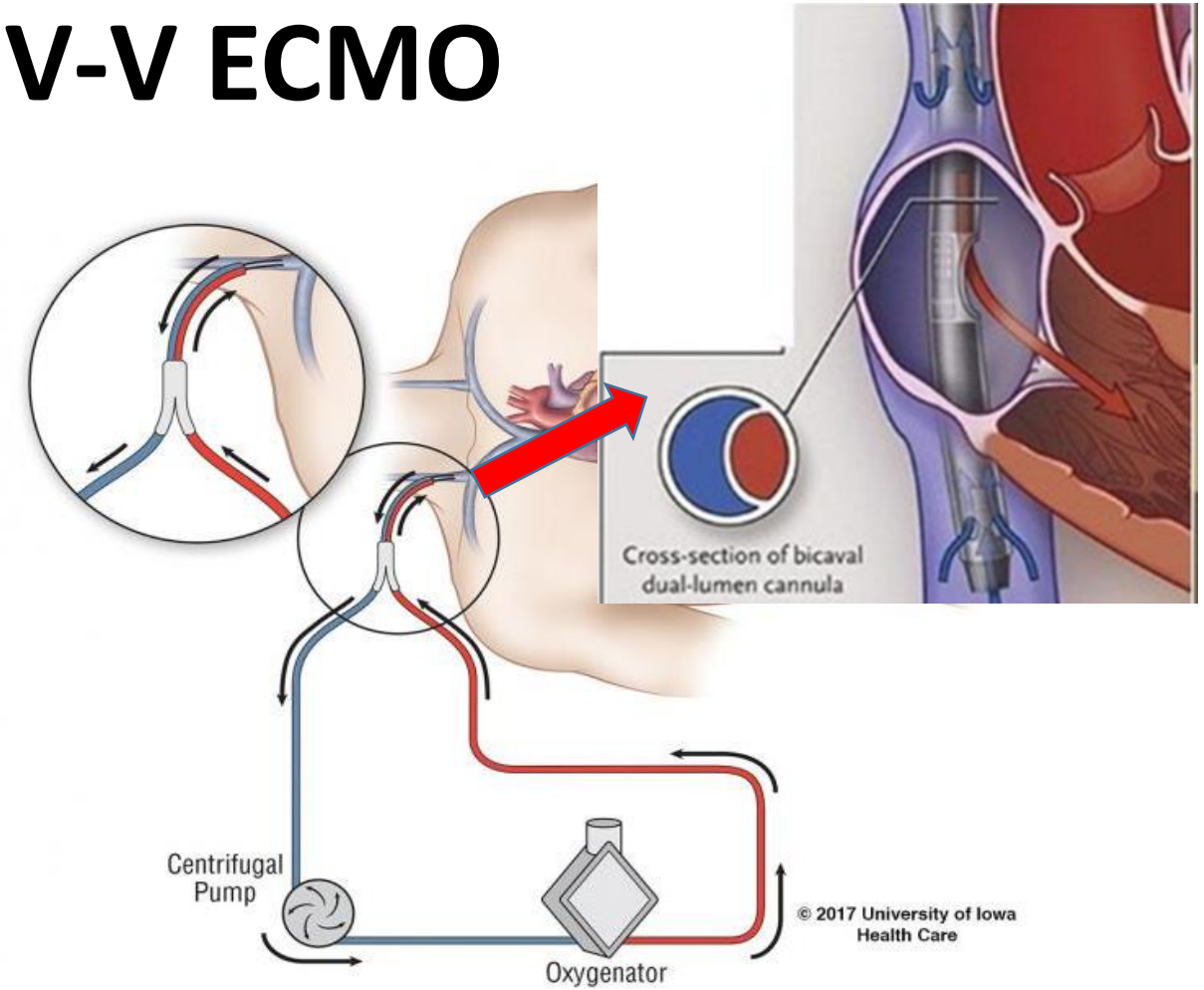
Aortic root

Rt atrium

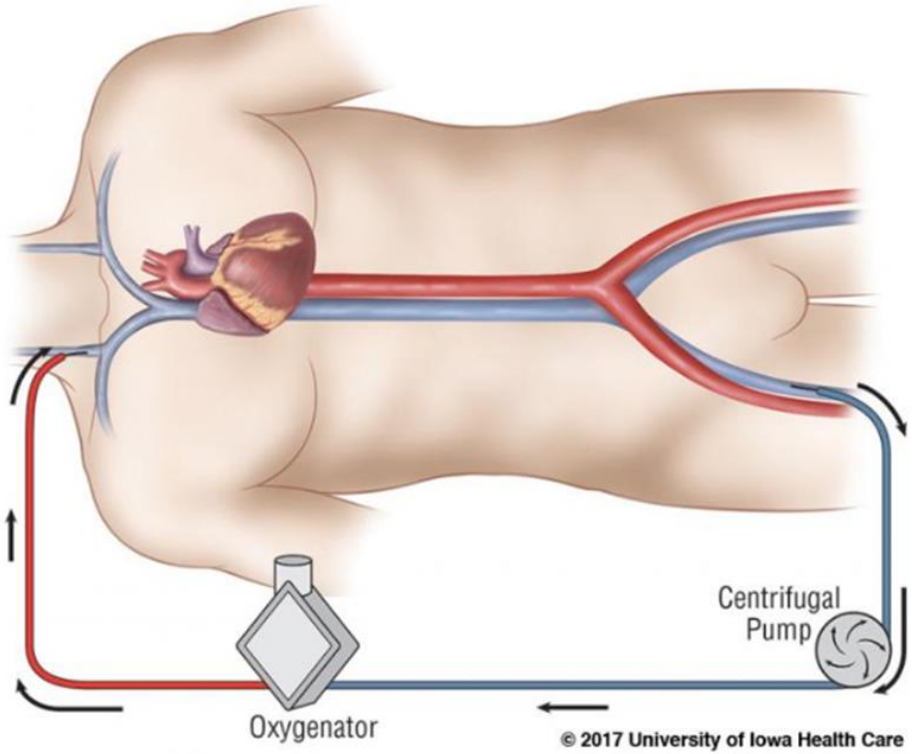


Central cannulation

V-V ECMO



Single cannulation



Double cannulation

Differences between VA and VV ECMO

	VA ECMO	VV ECMO
Cardiac effects	**Preload:** decreased **Afterload:** increased Pulse pressure: lower CVP: varies Coronary O_2: varies - LV blood desaturated - Cardiac Stunned syndrome	May reduce RV afterload Rest unaffected
O_2 delivery capacity	High	Moderate
Circulatory support	Partial to complete	No direct support, increased O_2 delivery to coronary and pulmonary circuit → improving cardiac output

Indication for ECMO

Cardiac failure	Respiratory failure
MI associated cardiogenic shock	ARDS
Severe heart failure -severe exacerbation of chronic systolic HF -fulminant myocarditis -stress cardiomyopathy -septic cardiomyopathy	Hypercapnic respiratory failure
Refractory arrhythmias	Bridge to lung transplantation
Bridge to VAD implantation or heart transplantation	Primary graft dysfunction after lung transplantation
Extracorporeal CPR	
Severe pulmonary hypertension	

https://www.sciencedirect.com/science/article/pii/S0735109714021408?via%3Dihub

Contraindication

Absolute Contraindications

- Severe irreversible neurological condition
- Encephalopathy
- Cirrhosis with ascites
- History of variceal bleeding
- Moderate-severe chronic lung disease
- Terminal stage malignancy
- HIV

Relative Contraindications

- Age >65
- Multiple trauma with uncontrolled hemorrhage

Contraindication

VV ECMO	VA ECMO
Absolute Contraindications • Severe left ventricular failure EF <25% • Cardiac arrest **Relative Contraindication** • High pressure / high FiO_2 IPPV for >1 week	**Absolute Contraindications** • Aortic dissection • Severe aortic regurgitation **Relative Contraindication** • Severe peripheral vascular disease

ECMO management

Patient preparation and monitoring

Large-bore venous access for large volume infusions

Central venous catheter for vasoactive drugs administration

Pulmonary artery catheter for the monitoring of right and left heart pressure

Urinary catheter for the assessment of the hourly diuresis

Arterial line for invasive blood pressure monitoring and serial blood gas analysis are recommended strongly for all patients under- going ECMO support.

TEE always should be considered for intraoperative monitoring unless contraindicated (eg , esophageal surgery).

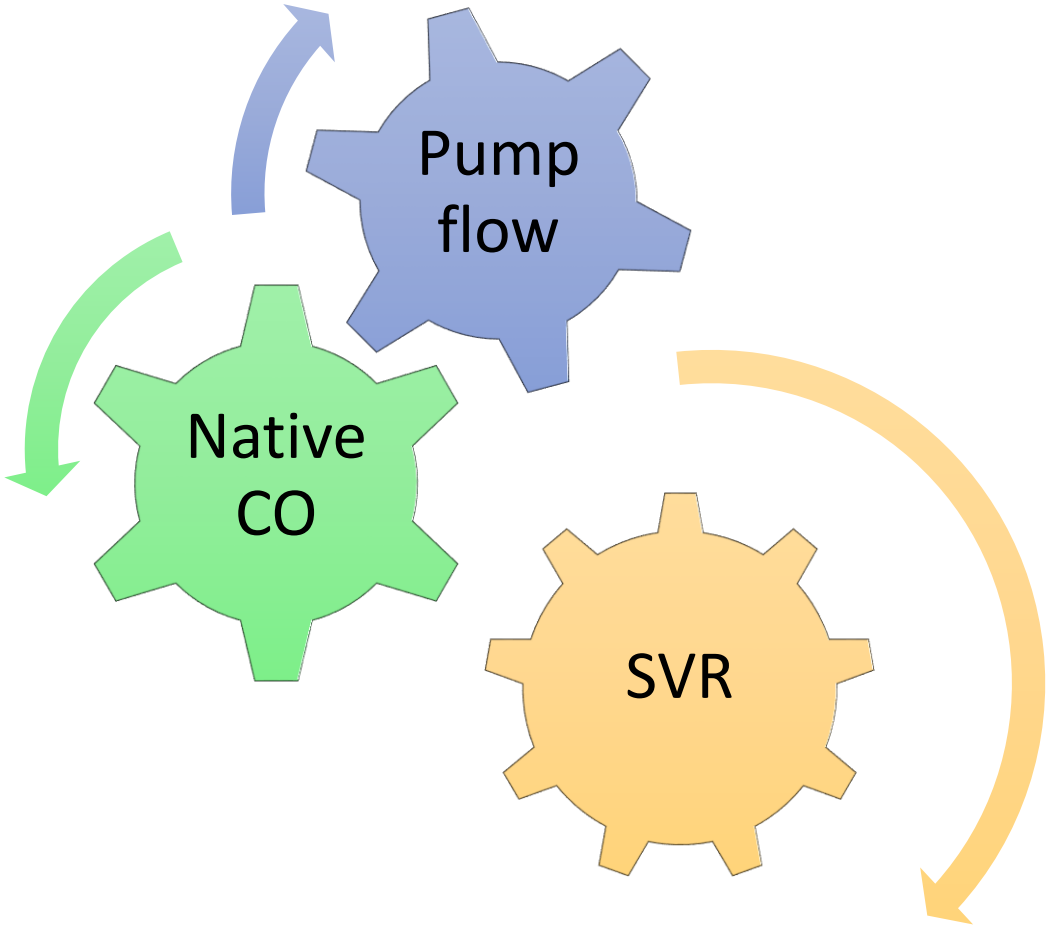
F. Monaco et al. / Journal of Cardiothoracic and Vascular Anesthesia 32 (2018) 1955–1970

Before cannulation

- Heparin IV bolus 50-100 U/kg
- Continuous infusion of heparin during ECMO
- Keep ACT 180-220 sec
- ACT is measured at the bedside q 1-2 h
- Keep PTT 1.5 times normal

*ACT = activated clotting time, PTT = partial thromboplastin time

Hemodynamics controlled



Hemodynamic management

Keep **SaO_2 ≥ 95%** , mixed venous blood saturation SvO_2 ≥70% indicates systemic oxygen delivery is adequate. (MAP may be low)

If Oxygen delivery is not adequate increase the pump flow or give extra blood volume or crystalloid solution if needed

The blood volume should be maintained at a level high enough to keep **right atrial pressure 5-10 mmHg**

Minimized use of inotropes/vasopressors

Proper control of arrhythmias

Pulmonary artery wedge pressure (PCWP) ≤ 22 mm Hg to 24 mm Hg

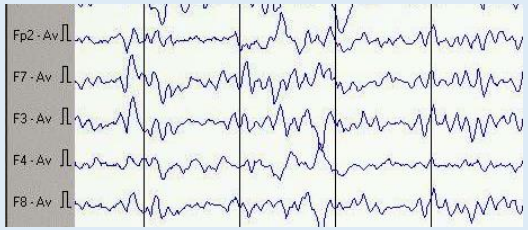
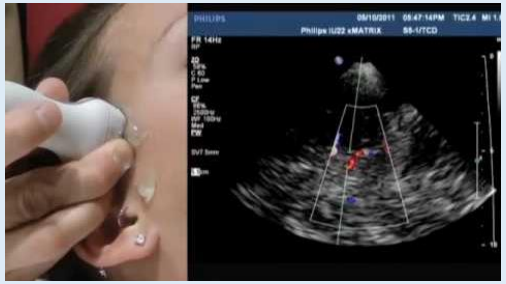
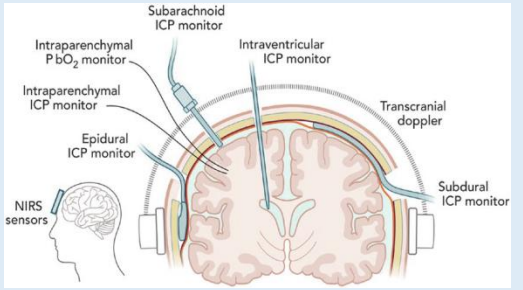
Respiratory management

- **Ventilator setting (Rest lung strategy)**
- Reduction of respiratory rate 4-10/min
- Plateau airway pressure 20-25 cmH_2O
- PEEP 5-15 cmH_2O
- F_iO_2 0.3-0.4 or lowest
- Tidal volume < 6 cc/kg predicted body weight
- Ventilator may be reduced or eliminated in patients on VA ECMO→ monitor for cerebral hypoxia
- Do not recruit lung volume during the acute inflammatory stage early in ECLS

Neurologic management

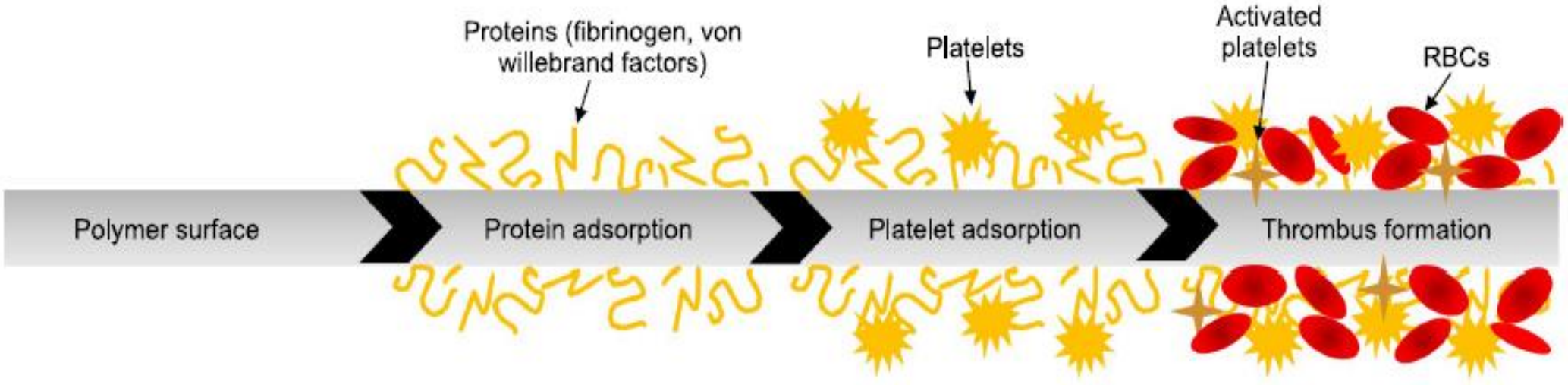
- Daily neurological assessments
- Using least sedation
- Neuromuscular blocker for only extremely ill patients or movement limited ECMO flow

Neurologic monitoring

	EEG	TCD	NIRS
			
Advantages	- Real-time electrical activity of the brain - Useful in paralyzed patients	-Non-invasive, portable test that is based on the Doppler effect	-Non-invasive, near-infrared wavelength of light - Continuous measurement of regional tissue oxygen saturation
Limitation	- Require technician to set up and interpretation	-Frequencies of emitted and reflected waves is proportional to the cerebral blood flow	- Expensive

Anticoagulant management

- Target ACT 180-200 seconds with IV Heparin
- aPTT 60-80 seconds (40-60 seconds with high risk bleeding)
- ACT is less sensitive testing in low to moderate dose of heparin



Anticoagulant used in ECMO

	Unfractionated Heparin	Bivalirubin	Argatroban	Nafamostat mesilate
Metabolism	Hepatic	Intravascular proteolysis	Hepatic	Renal
Half life	90 min	15-18 min	39-51 min	8 min
Route	Intravenous	Intravenous	Intravenous	Intravenous
Dosage	50-100 units/kg bolus 20-50 units/kg/h continuously	Not established 0.125 mg/kg bolus infusion followed by 0.125 mg/kg/h continuously[34,35]	0.75 mcg/kg/min continuously[39]	Not established 0.48 mg/kg/h[48]
Monitoring methods	Anti factor Xa ACT, aPTT	Not established ACT, aPTT	Not established ACT, aPTT	Not established ACT, aPTT
Antidote	Protamine sulfate	Not established	Not established	Not established

Suggestion for monitoring in UFH treated patients

Once daily	Twice daily	Thrice daily
Fibrinogen	Haemoglobin	aPTT combined with:
MA-TEG/MCF-ROTEM	Platelet count	ACT or
Lysis index		R-time TEG/CT-ROTEM
D-dimer		
AT%		

Anesthetic consideration and Patient Transportation

Preoperative consideration

- **About ECMO:**
  - Indication , Type and cannulation site
  - Blood flow rate, $F_i O_2$, Sweep gas flow
- Preoperative **ventilator setting**
- Evaluate other **major organ system dysfunction**
- Prepare **blood component** and adequate venous access, **PRC ,FFP**
- Continue antibiotic regimen

Anesthesiology 2018; 128:181-201

Intraoperative management

- **Choice of anesthesia:**

  TIVA may be preferable to the use of volatile anesthetic agents

  -Titrate anesthetics to clinical effect

  Inhalation delivery is limited due to

  - Low tidal volume

  - Significant dead space

  - Impaired gas exchange

  Monitoring: Standard monitoring and Arterial line, Depth of anesthesia(BIS)

  Muscle relaxant may be administered if required

  Continue heparin infusion

  ACT goal : VV 160-180 seconds VA 180-200 seconds

Anesthesiology 2018; 128:181-201

Intraoperative management

- **Volume assessment and management**

  - Negative fluid balance in VV ECMO

  - Decreases in ECMO flows, venous pressure, and development of “chatter” can reflect low preload

  - Consider volume challenge if ECMO flows are decreasing during period of acute blood loss (especially if associated with decreased SpO2)

- **Transfusion** to Hb > 7 g/dl acceptable in selected patients

Anesthesiology 2018; 128:181-201

Intra-hospital Transport

- **Multi-disciplinary team**
- **Standard monitors:** pulse oximetry , EKG , arterial monitoring
- Focus on patients' hemodynamic and cannula
- Readily available replacement a dislodged ECMO cannula
- **Sedation and muscle relaxant** : based on hemodynamic stability and patients' status
- Weigh up the **risks and benefits**
- **Daytime hours** when staffing is optimal
- Battery of console , Oxygen tanks and ventilator

Team intra-hospital Transport

5 staff members –

I. Airway and ventilator
II. Infusion pumps
III. Move the bed
IV. Move the console
V. Mind the ECMO cannula.

ECMO TRANSPORT CHECKLIST

Complete prior to leaving to and from destination

Standard Checklist

- ☐ Standard Transport Checklist Complete

Monitoring

- ☐ Right Hand Art line & Sats Probe

ECMO Support

- ☐ ECMO O2 cylinder full
- ☐ O2 cylinder connected via green tubing
- ☐ Alarms set
- ☐ ECMO battery >24V

-if less then change console prior to leaving

Roles Assigned

(Minimum 1 airway doctor & 1 ECMO competent staff)

- ☐ Airway +/- Highflow cannula
- ☐ Ventilator
- ☐ IV Pole
- ☐ ECMO console
- ☐ ECMO lines (extra 3 lines added to each infusion for CT chest/abdomen
- ☐ Extra Assistance required

ECMO Transport Checklist

Equipment

- ☐ ECMO Clamps x4

Current patient status

- ☐ Is transport necessary?
- ☐ Plan A & Plan B

On Arrival To Destination

- ☐ Standard arrival checklist complete
- ☐ Connect and confirm ECMO power
- ☐ Connect ECMO to wall O2 via green tubing

On Arrival to ICU

- ☐ Standard arrival checklist complete
- ☐ Connect and confirm ECMO power
- ☐ Connect ECMO to wall O2 and Air
- ☐ Check 02 cylinder on ECMO & replace if required

Common pitfalls during transport

- **Battery failure** –hand crank and maintain same rpm as patient
- **Cannula displacement**
  - Partial – secure cannula and reassess immediately when returned to the unit
  - Complete – clamp circuit and compress site. Support patient using conventional support and call for help
- **Circuit rupture** – clamp the circuit and call for help.
- **Hypothermia** – connect the heater/cooler as soon as possible. Take preventive measures if longer transfer or cold environment anticipated.

Hand crank

Complications/Troubleshooting

Hypoxia

Symptom	Cause	Evaluation	Management
Hypoxia	**Oxygenator failure** **Disconnected gas supply** **Low circuit flows**	▪ Pre-and post oxygenator blood PaO_2 ▪ Gas connections ▪ Circuit blood flows	✓ Change oxygenator ✓ Ensure appropriate gas connections ✓ Increase circuit blood flows ✓ Relieve obstruction

Hypoxia

Symptom	Cause	Evaluation	Management
Hypoxia	**Recirculation (VV ECMO)**	▪ PaO_2 in blood in inflow cannula	✓ Reposition cannula or change to VA ECMO Maintain adequate intravascular volume
	Upper-body hypoxemia (VA ECMO) Harlequin syndrome	▪ Adequate oxygenation in lower half of body from VA ECMO	✓ Increase ventilatory support ✓ Change VA to VV ECMO Additional outflow cannula into the RA for upper-body hypoxia

Hypotension

Symptom	Cause	Evaluation	Management
Hypotension	**Hypovolemia**	▪ Volume status ▪ Bleeding	✓ Volume replacement ✓ Surgery to control bleeding
	Vasodilation	▪ ECMO flows ▪ Myocardial function ▪ Sepsis ▪ Transfusion reaction ▪ Allergic reaction	✓ Vasoconstrictors and inotropes ✓ Increase ECMO blood flow rate ✓ Treat source of sepsis ✓ Treat allergic reaction

Hypotension

Symptom	Cause	Evaluation	Management
Hypotension	**Reduced flow in ECMO**	▪ Obstruction to flow (displaced or kinked cannula, thrombosis in oxygenator) ▪ Myocardial function or PA pressure ▪ Cardiac tamponade or tension pneumothorax	✓ Relieve obstruction or change oxygenator ✓ Volume resuscitation ✓ Inotropes for left- or right-sided heart failure ✓ PA-to-LA ECMO for pulmonary hypertension

Other complications

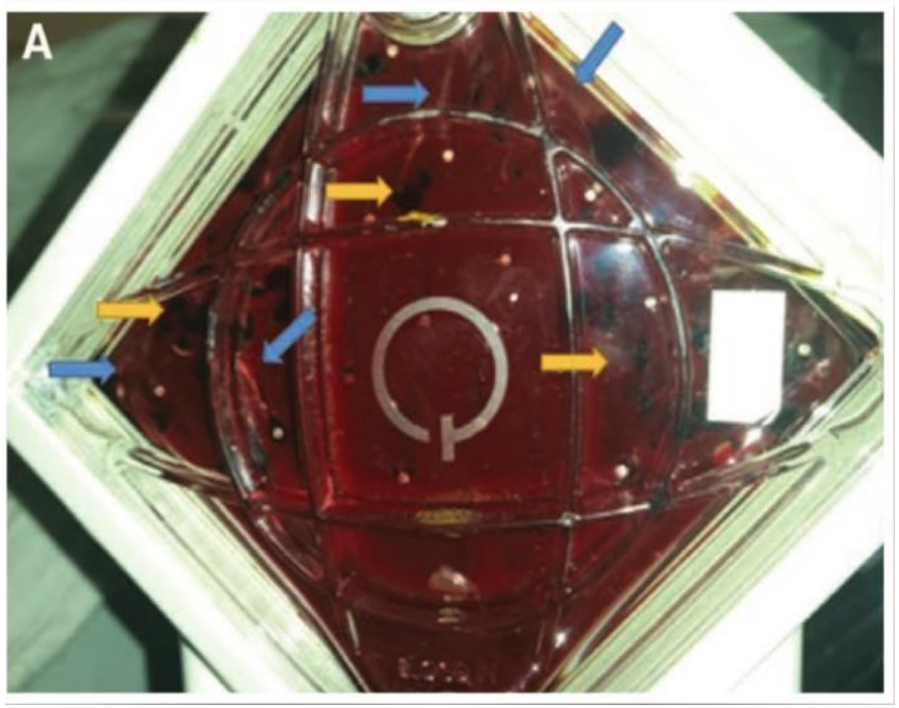
BLEEDING

✓ Prevention is primary objective

✓**If patient bleeding**

- Stop heparin
- Heparin coated circuits can run for couple days without heparin
- Investigate cause
- Platelets, Cryoprecipitate, FFP, packed cells

Other complications



- **Clot formation: Impaired Oxygenator Function**

  Cause Low circuit flow state

  Diagnosis

  Visible the clot in the circuit

  High plasma hemoglobin (normally <100 mg/L)

  High pressure across oxygenator(>70 mmHg)

  Treatment

  Circuit replacement

Other complication

HAEMOLYSIS

Breakdown of RBC

Causes

- Clot in the circuit or near cannula orifice
- Access & return insufficiency or obstruction
- "over spinning" of pump speed

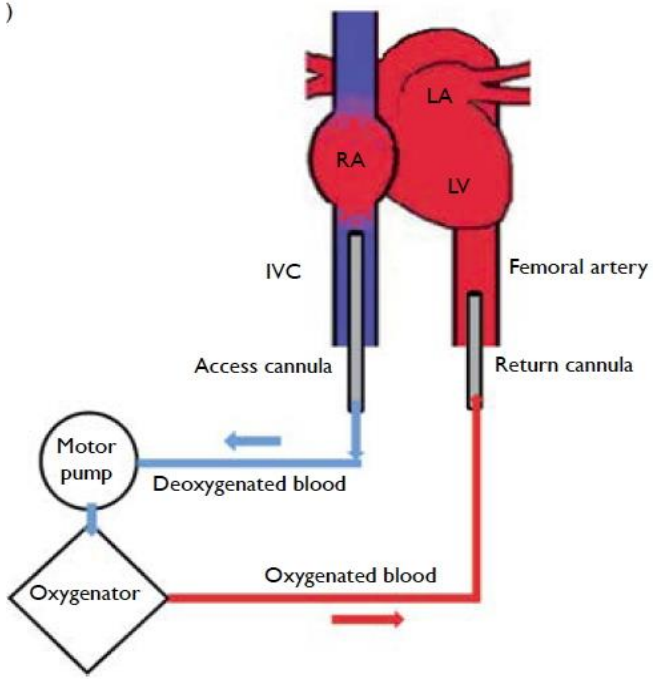
Signs

- Red or dark brown urine
- High K+
- Renal failure
- Jaundice (late sign)

Management

- ✓ Increase volume
- ✓ Review pump flow settings
- ✓ TEE to ensure cannula not obstructed
- ✓ Consider changing circuit

ECMO flow decreased (RPM unchanged)



Increase pre-membrane pressure?

No

Access line obstruction

- Exclude kinked line between patient and pump
- Caval collapse (inadequate preload) ?

  Diagnosis: Line shake

  Treatment: Raise CVP

  Reposition access cannula

  Second access cannula

Yes

Return line obstruction

- Exclude kinked line between pump and patient
- **Consider changing oxygenator if trans-membrane gradient > 150 mmHg**

Emergency complications

- Dramatic and life **threatening** that require immediate action
- **General rules**
  - Call for help, Intensivist, CT surgeon, Perfusionist
  - Clamp
  - Ventilate, hemodynamic support

Pump Failure

No flow due to electrical failure or pump head disengagement

→clotting is possible

Prevention:

- Always maintain the pump head in a position
- Minimize time on battery
- Ensure AC “Power Off” alarm is turned on when using wall power
- Console not in use, needs to be plugged into AC power and

“on Switch” turned on in order to recharge battery

Pump Failure

Management

Call for help

Ventilate & hemodynamic support

Electrical motor failure

- Clamp line & turn off pump

- If the cause is not immediately rectified, commence hand cranking till new console arrives

- Reinsert pump head

- Turn on pump to 1000 rpm & remove clamp

- Gradually increase rpm’s

Cardiac arrest

VV ECMO	VA ECMO
▪ No patient circulation ▪ ECMO flow decreases ▪ Patient in cardiac arrest with no output **Management** ▪ Call for help ▪ CPR ▪ Reversible causes	Little hemodynamic effect if flow > 4 l/min **Management** ▪ Establish adequate flow ▪ Call for help ▪ Reversible causes ▪ CPR may not be needed unless pump compromised

Decannulation

Accidental removal of access or return cannula

Prevention:

- Anchoring the cannula to the patient
- Use of a spotter to ensure that lines remain free during patient maneuvers

Management

- Call for help
- Clamp circuit
- Turn off pump
- CPR
- Establish ventilation & inotropic support
- Volume
- Peripheral: apply pressure
- Central: prepare chest opening

Circuit rupture

- This is the disruption of any part of the circuit
- Massive blood loss
- Hemodynamic collapse and hypoxemia of varying severity (depending on underlying cardiac and respiratory reserve)
- Possible introduction of air into ECMO circuit
- Fracture and breakdown of polycarbonate components after being cleaned with alcohol
- Broken three way tap
- Accidental cutting or puncturing of circuit tubing

Circuit rupture

Prevention:

- Do not allow any part of the circuit to come into contact with alcohol or other organic solvent such as volatile anesthetic
- Allocated person to act as “spotter” to ensure that three way taps are not snagged on anything during patient maneuvers
- Care with needles and instruments near tubing

Circuit rupture

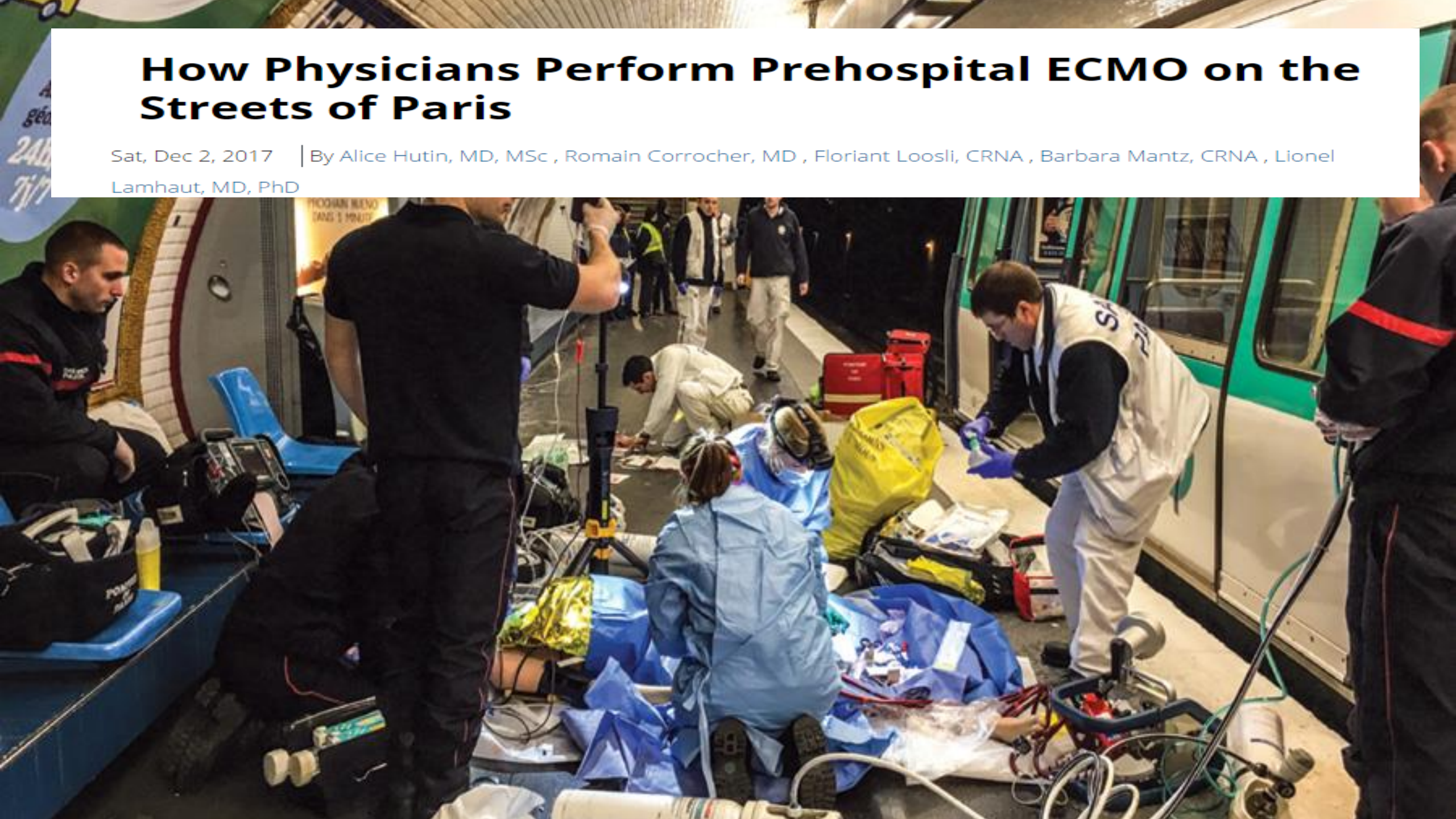
Management:

- ✓Clamp the circuit on either side of the circuit disruption
- ✓Call for help. Contact perfusion services and ICU consultant
- ✓Assign roles for concurrent patient and circuit management
- ✓Increase the ventilator settings and inotropes to compensate for loss of support.
- ✓Give volume to replace blood loss
- ✓If fractured three way tap: if possible place sterile gloved finger over leak
- ✓Connection change


ECPR

How Physicians Perform Prehospital ECMO on the Streets of Paris

Sat, Dec 2, 2017 | By Alice Hutin, MD, MSc , Romain Corrocher, MD , Floriant Loosli, CRNA , Barbara Mantz, CRNA , Lionel Lamhaut, MD, PhD

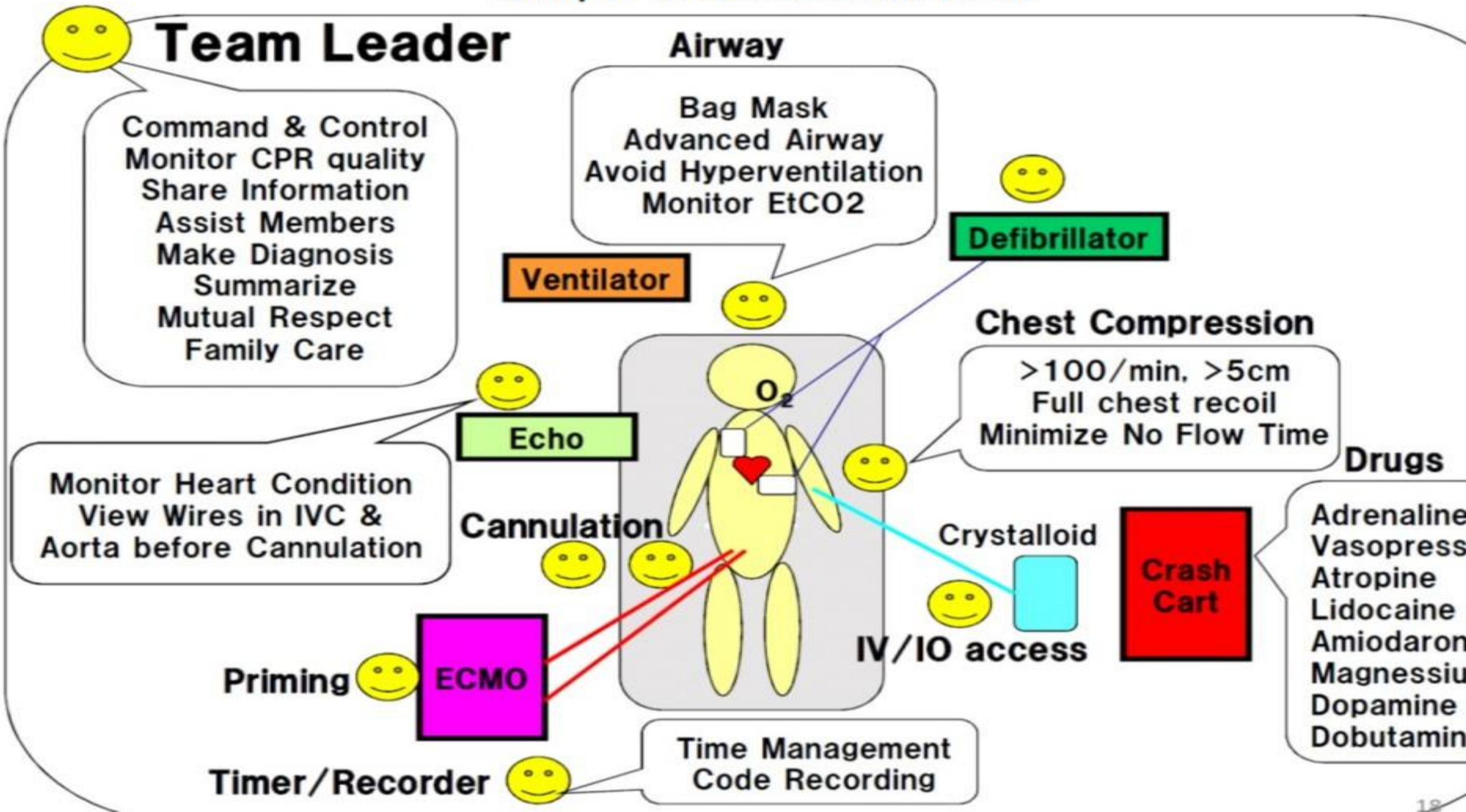


Definition

- Artificial circulation using VA ECMO as an alternative to ventilation and external cardiac massage Salvage therapy for patients suffering cardiac arrest refractory to conventional resuscitation
- In-hospital cardiac arrest(IHCA) with ECPR

  - survival rate 20-45%

Sample of ECPR Code team



Peri-ERCP Resuscitation

- **Goals:** achieve ROSC to optimizing critical organ perfusion and providing nueroprotection
- Preserve the **quality of chest compression** during refer to ECPR center or during cannulation on-scene
- **Early intubation** for airway protection
- Drug **epinephrine and amiodarone** and **defribillatory shocks**

Maintenance

Respiration

- Ventilator setting when cardiac function returns
- Target pO_2 70-90mmHg, pCO_2 40mmHg
- Use Tidal volume 6ml/kg, RR 8/min initial setting

Cardiac

- SBP >100mmHg, accept HR 35-50/min without treatment
- If need higher ECMO flow, consider second venous cannula

- Monitor electrolytes (K+, Mg++, PO4-)
- Avoid Calcium infusion in neurologic injury
- Hyperglycemia required insulin infusion
- Heparinize, ACT 180-220, APTT 50-70
- Sedation, midazolam if unstable BP
- Hypothermia (33C) for 24 hours post cardiac arrest
- Rewarm no faster than 3 Celsius over 12 hours

Weaning ECMO

Weaning from ECMO support follow by survival longer than 48 hours

Weaning ECMO

VV ECMO

- ✓ Maintain ECMO flow rate
- ✓ Re-establish patient full ventilation
- ✓ Turn off O_2 to oxygenator
- ✓ 6 hours stability then decannulation

VA ECMO

- ✓ Heparin so ACT >400 to decrease risk clotting
- ✓ Decrease pump flow 1 litre while ventricular function assess by TEE
- ✓ Period of low flow ECMO before decannulation
- ✓ Respiratory function is a concern: turn off gas flow (Only at circuit flows ≤1.5L/min) and assess oxygenation achieved using the ventilator
- ✓ If O_2 good & CO_2 managed by ventilator consider decannulation

Weaning ECMO

Removal of cannula:

- Removal of arterial ECMO cannula should always be removed as an “open” surgical procedure and be accompanied with the vessel wall repair.
- Venous cannula can be removed and pressure applied to the site for 20 minutes

Post-decannulation Doppler:

- Lower limb venous Doppler following decannulation as prolonged femoral venous cannulation promotes distal DVT formation.

Take Home Message

- **ECMO** is indicated for **potentially reversible**, life-threatening forms of respiratory and / or cardiac failure
- **VA-ECMO** is a proven rescue strategy for patients with **cardiac arrest** who are unresponsive or resistant to conventional cardiopulmonary resuscitation
- **VV-ECMO** as well as extracorporeal carbon dioxide removal to support the **respiratory system**, no effect on hemodynamic effect
- **Multi-disciplinary team** is one of key factor in ECMO management

KEEP CALM AND ECMO ON