Extracorporeal Membranous Oxygenation (ECMO)
Bedside Reference Manual
University of California San Diego

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Calling a CODE ECMO (2 steps)

First: Patient’s ICU attending pages on call-ECMO MDs (CT Surgery and Interventional Cardiology) for discussion of the case and decision on ECMO initiation

- In webpaging search “ECMO,” and select the correct link and fill in the paging information needed
- Figure 1. Screenshot of the UCSD webpaging search page

Second: If ECMO initiation is decided on, the on call ECMO MD calls a formal “CODE ECMO” by calling x6111

- Will need to indicate the name of the attending approving ECMO as well as the type of ECMO being initiated (cardiac anesthesia comes to VV initiations for TEE)
- The formal “CODE ECMO” initiates the additional support needed including anesthesia, perfusionist, etc
UCSD Specific Policies

Placing ECMO Orders (2 order sets need to be completed)

1. “ECMO Cannulation” order set
   - Includes patient care orders, IV fluids and anticoagulation bolus
2. “ECMO Maintenance” order set
   - Includes auto-consult to palliative care, CPR/defibrillation parameters, vascular checks, labs and maintenance medications including anticoagulation

Figure 2. Screenshot of the EPIC order sets for ECMO

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ECMO Documentation
All ECMO documentation can be found in nursing flowsheet entitled “ECMO”

Nursing Chain of Command for ECMO Related Issues

**Emergency**
For any ECMO specific emergency (i.e. pump failure, arterial air bubble, no flow) RN to “Activate Crisis Action Plan” by paging on call perfusionist and consulted ECMO attending (PCCM or ACCM)

**NON-emergency**
RN to page on-call perfusionist who will help determine urgency of issue and appropriate next contact (primary team, ECMO MD, covering attending)
Indications

VA ECMO

- Moderately to severely reduced cardiac function with/without concurrent respiratory failure. Specific indications include but are not limited to:
  - Post-MI
  - Myocarditis
  - Bridge to definitive therapy such as LVAD or transplant
  - Refractory ventricular arrhythmias (including consideration during cardiac arrest)
  - Massive pulmonary embolism
  - OB indications: Post-partum cardiomyopathy, amniotic fluid embolism

VV ECMO

- Hypoxemic respiratory failure: ECMO should be considered in hypoxemic respiratory failure with a 50% mortality risk (which translates to P/F < 150 on FiO₂ > 90%) and even more so with a P/F < 100 despite optimal care for more than 6 hours)
- Hypercarbic respiratory failure: refractory CO₂ retention on mechanical ventilation despite high (>30 cm H₂O) plateau pressures (e.g. status asthmaticus)
- To avoid mechanical ventilation in a patient awaiting lung transplant (may allow increased mobility, avoid sedation)
- Sudden respiratory collapse despite optimal care
ECMO should be considered and discussed with the ECMO team when:

- New diagnosis of Pulmonary Arterial Hypertension (with PAH team involvement)
- Pregnant with Pulmonary Hypertension
- Post partum cardiomyopathy
- Pre-heart or lung transplant
- Post heart transplant patient with vasculopathy
- Post lung transplant with FiO₂ >50%
- ARDS with FiO₂ on ventilator >80% or considering proning

If ECMO is indicated, the earlier they go on, the better they do. If you are considering ECMO (non-urgently) for one of the above conditions, email ecmo@ucsd.edu or contact the ECMO MD on call.

Contraindications

Relative Contraindications:

- Advanced Age
- Trauma
- Septic Shock
- Advanced dementia/brain damage/severe prior stroke
- ESRD on dialysis
- Bleeding diathesis
- Recent or expanding CNS hemorrhage
- Terminal malignancy
- Decompensated cirrhosis
- Vasculature technically inaccessible
- Mechanical ventilation >7 days
- Aortic insufficiency or aortic dissection

Absolute contraindications:
• Open chest
• Massive hemorrhage (>1 PRBC per hour)

**ECMO Basics**

**Two main modalities of ECMO:**

• Venoarterial (VA) provides both hemodynamic and respiratory support in the setting of cardiac failure with/without concurrent respiratory failure. Blood is taken from the venous circulation and returned to the arterial circulation. Note, E-CPR is the use of VA-ECMO in refractory cardiac arrest (although used at UCSD, it is not currently standard protocol)

• Venovenous (VV) provides isolated respiratory support in the setting of lung failure. Blood is taken from and returned to the venous circulation

Depending on the ECMO cannulation, goals include the following:

1. Blood Oxygenation
2. CO2 removal
3. Protective Lung ventilation
4. Cardiac support

**ECMO Circuit Components Overview:**

• Inflow cannula (venous): Deoxygenated blood
• Blood pump (capable of up to 5L.min flow)
• Oxygenator with inline gas blender/sweep
• Outflow canula (venous or arterial): oxygenated blood

Additional Components May Include:

• Saturation Sensor- for H&H SvO₂
• Flow probe- sits on arterial tubing and measures flow, and detects air bubbles
• Pre- and post-oxygenator pressure monitor
• Console for adjustments
• Ports for access
• Heat Exchanger and heater/cooler
The ECMO Circuit

Figure 3. Circuit in Graphic Form. Cyi 2019
ECMO Console/Controller/Pump Options at UCSD

Maquet Cardiohelp – Preferred. Can be managed by RNs

Figure 4 Maquet Cardiohelp System. Adapted from the Maquet Cardiohelp brochure

Maquet Rotaflow – alternative option, can only be managed by a perfusionist

Figure 5. Maquet Rotaflow ECMO system. Adapted from Getinge rotoflow brochure.

Blood Pump:

- Centrifugal
- Note with the cardiohelp system, the disposable component (HLS module) contains the blood pump as well as the oxygenator and heat exchanger
- The pump speed is set by the provider between 0 – 4000 RPM’s (which can drive up to 5 L/min of blood flow depending on the circuit)
The ECMO Circuit

Cannulas:

- Increased resistance to blood flow with smaller diameter, longer cannulas (by way of Poiseuille’s Law, $R = \frac{8 \eta L}{\pi r^4}$)
- A cannula with increased resistance causes a greater pressure drop; goal pressure drop across venous cannula is $< 40$ mm Hg and across an arterial cannula is $< 100$ mm Hg

Figure 6. Flow Rate and Pressure Drop based on Cannula Diameter. Increasing cannula size yields a larger flow rate with a small pressure drop. Red signifies an arterial cannula (length of 23 cm); blue signifies a venous cannula (length of 55 cm). Adapted from the Maquet Cardiohelp System brochure.
**VA ECMO Cannulas:**
- Arterial cannula: 15 – 25 Fr, Venous cannula 19 – 25 Fr
- Peripheral or Central cannulation
- Peripheral cannulation usually percutaneous
- Open cannulation- peripheral cannulation cut down via the femoral or internal jugular vein for the venous drainage and the femoral or axillary artery for arterial outflow
- Central cannulation- median sternotomy or thoracotomy. The venous access is generally from the right atrium and the arterial access via the ascending aorta

**VV ECMO Cannulas:**
- Drainage cannula 22 – 30 Fr, Return cannula is slightly smaller at 15 – 23 Fr
- Generally placed via peripheral cannulation via Seldinger technique with inflow: outflow options as follows:
  - Femoral (IVC):Internal Jugular (RA) or subclavian
  - Femoral (IVC):Femoral (RA)
  - Single dual lumen cannula in the internal jugular or subclavian vein (most common option used at UCSD). See following section for more details

**VAV cannulation:**
- Sometimes utilized as well
  - Return cannulas to both venous and arterial side
  - Option for patients who start on VV and then require VA as heart fails; also option for PH patients

Figure 7. Medtronic venous and arterial cannulas. Note the arterial cannula’s have side port. Adapted from Getinge website
Single Dual Lumen Cannulas:

- Drainage access point resting in the IVC and SVC and the return port in the right atrium directed at the tricuspid valve (most common option used at UCSD). Single lumen options are generally between 13 – 31 Fr and include the following:
  - Avalon ELITE® bi-caval dual lumen catheter
  - MC3 Crescent ® jugular dual lumen catheter
- Placed with TEE guidance to confirm placement
- Dressing markings on skin to ensure migration has not occurred
- Advantages include maximizing flow rate while minimizing the risk of recirculation

Figure 8. Graphic Representation of the Avalon ELITE® Bi-caval Dual Lumen Catheter. On the left, cannula shown entering the R internal jugular vein and terminating in the IVC. On the right, close up showing drainage ports in the SVC and IVC with return port resting in the RA with the jet aiming at the tricuspid valve. Adapted from Lezar et al, J Ped Surgery, 2012
Oxygenator and Blender:

- Composed of a heparin-coated polymethylpenene hollow fiber membrane.
- Removes carbon dioxide, oxygenates blood
- In line with the Gas Blender and Sweep

Figure 9. Blender set-up. C. Yi. 2019

- Oxygenation is affected by gas blender (i.e. \( \text{Fdo}_2 \)) and ECMO blood flow
- Ventilation is affected by sweep (usually started at 1:1 to blood flow) but is independent of blood flow
- Both are affected by diffusion gradients and surface area based on Fick’s Law of Diffusion (\( V_{\text{gas}} \alpha (A/T) \times D \times (P_1 - P_2) \))

Figure 10. Fick’s Law of Diffusion. Adapted from Respiratory Physiology, 10e. John West 2015.
Additional ECMO Components:

S\textsubscript{v}O\textsubscript{2} Probe:

- Connected on venous side, just proximal to the oxygenator
- Measures (very reliably) S\textsubscript{v}O\textsubscript{2} and H&H
- May not work if patient has high lipids, or a PaO\textsubscript{2} <45 mm Hg
- S\textsubscript{v}O\textsubscript{2} (and lactate) are surrogate markers of O\textsubscript{2} delivery (DO\textsubscript{2}) and O\textsubscript{2} consumption (VO\textsubscript{2})

Pressure Sensor:

- Measures venous, arterial and inlet pressures (see next section)

Figure 11. Arterial side of Cardiohelp HLS oxygenator. C. Yi. 2019
**Flow probe:**

- Connected on the arterial side, just distal to the oxygenator
- Measures blood flow in L/min, and detects air
- If air is detected, machine intervention is set to automatically alarm, and to reduce RPMs to zero. Will initiate high priority alarm for no flow, and air bubble detection

Figure 12. Flow probe attached to arterial tubing. C. Yi. 2019

**Heat Exchanger:**

- Connects to oxygenator and circulates warm water for temperature regulation
- Actively warms to 37 ºC
- Can also passively cool (by blood being outside of the body and exposed to room air) but cannot actively cool, so if therapeutic hypothermia is desired, the Arctic sun or thermoguard should be considered.

Figure 13. Cincinnati SubZero Heater. C. Yi. 2019, and Fig 14. Cardioquip Heater. Cardioquip.com
The Cardiohelp Console

Home Screen:

Figure 14. Cardiohelp Home Screen  C. Yi. 2019

Lab Screen:

Figure 15. Cardiohelp lab Screen  C. Yi. 2019
<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>“Normal” Value</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed</strong></td>
<td>Rotation per minute of pump</td>
<td>0-4000. Usually around 3500</td>
<td>Titrated by RN/Perfusionist to maintain ordered flow</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>Flow in liters per minute</td>
<td>2-5L/min</td>
<td>Ordered by Provider</td>
</tr>
<tr>
<td><strong>P_{VEN}</strong></td>
<td>Pressure the pump generates to pull venous blood</td>
<td>&gt; -150mmHg</td>
<td>More negative venous pressure → Assess for kink, clot, or volume</td>
</tr>
<tr>
<td><strong>P_{ART}</strong></td>
<td>Pressure pump must generate to return blood</td>
<td>&lt;300mmHg</td>
<td>Increased arterial pressure → Assess for kink, clot, or high blood pressure</td>
</tr>
<tr>
<td><strong>P_{INT}</strong></td>
<td>Pressure pump must generate to push through oxygenator</td>
<td>&lt;300mmHg</td>
<td>Not clinically significant: used to calculate DeltaP</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>Delta P: Pressure drop across oxygenator. Tells us if oxygenator is compromised due to clots</td>
<td>Usually around 20 mmHg</td>
<td>Abnormal if &gt;40 or if doubles from baseline.</td>
</tr>
<tr>
<td><strong>T_{ART}</strong></td>
<td>Return blood temp</td>
<td>37°C</td>
<td>Heater set by nursing/perfusion per provider order</td>
</tr>
<tr>
<td><strong>S_{V}O_{2}</strong></td>
<td>Dependent on CO, oxygen consumption, H&amp;H, and FdO_{2}. If high, consider recirculation</td>
<td>65-75% (VV maybe slightly lower due to lack of oxygen and low arterial saturation)</td>
<td>Measured on venous tubing just after oxygenator.</td>
</tr>
<tr>
<td><strong>Hb</strong></td>
<td></td>
<td>&gt;7g/dL</td>
<td>Measured on venous tubing just after oxygenator.</td>
</tr>
<tr>
<td><strong>Hct</strong></td>
<td></td>
<td>&gt;25%</td>
<td>Measured on venous tubing just after oxygenator.</td>
</tr>
</tbody>
</table>
ECMO Initiation

Initiation:
• After sedation and/or neuromuscular blockade, cannulation can begin
• Heparin bolus (20-100 U/kg) is given via IV formulation after the wire is in place; goal ACT > 150 seconds
• Set temperature on heat sensor (normothermia) and initiate ECMO as follows:
  • Set sweep gas flow rate (usually starts as 1:1 ratio with goal blood flow)
  • Set F\textsubscript{O}\textsubscript{2} to 100%
  • ECMO flow rate is increased to 2000 RPMs followed by removal of the cannula clamps
  • ECMO flow rate is increased over the next 5-10 minutes to achieve goal blood flow (BSAxflow index; flow index generally 1.8 L/min/m\textsuperscript{2})
  • Once goal flow is achieved, ventilator can generally be set to lung protective settings
  • Address sedation, neuromuscular blockade needs (see subsequent section)
  • Address anticoagulation needs (see subsequent section)

Sedation/Analgesia:
• Pharmacokinetics and pharmacodynamics of medications is affected, via changes in volume of distribution (V\textsubscript{D}) and clearance
• Expect considerably higher doses of all sedation and pain medications (especially propofol and fentanyl)
• Prolonged use of propofol (at higher doses) can increase lipids and cause failure of the SvO\textsubscript{2} sensor
General ECMO Management

Guidelines outlined by ELSO

- **Crisis action plan**: all patients on ECMO should have a Crisis Action Plan and Emergency Ventilator settings posted in the room

- **If ECMO flow stops**, patient lines should be clamped to prevent back flow (arterial is clamped first; venous is unclamped first)

- Orders written for **goal blood flow**, then RPMs are titrated

- Orders written for **goal Co2**. Then Sweep titrated: Starts at 1:1 to ECMO blood flow.

- **Cannula sites**: cautious with all positioning due to risk of migration/dislodgement
  - Dressings are occlusive and changed q7 days and PRN
  - Limb ischemia can develop; pulse checks are necessary

- **Monitor for hemolysis** with usual hemolysis labs (LDH, haptoglobin, fibrinogen, coags)
  - If high levels of hemolysis are seen, flow rate should be reduced
General ECMO Management

Anticoagulation:

- Following the heparin bolus during cannulation, a heparin gtt is initiated based on ECMO specific heparin protocol (included in ECMO order set) unless contraindicated
  - ACTs followed initially, then aPTTs q6 hours after heparin adjustment (goal generally 40-60sec)
  - ATIIIIs daily after 3 days

Lab Goals:

<table>
<thead>
<tr>
<th>Lab Test</th>
<th>Normal Values</th>
<th>Targeted values on Anticoagulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTT</td>
<td>25-35s</td>
<td>40-60s</td>
</tr>
<tr>
<td>Platelets</td>
<td>150,000-450,000/mL</td>
<td>&gt;50,000/mL</td>
</tr>
<tr>
<td>Fibrinogen</td>
<td>150-400mg/dL</td>
<td>&gt;180mg/dL</td>
</tr>
<tr>
<td>Hgb/Hct</td>
<td>35-45%</td>
<td>&gt;25%</td>
</tr>
<tr>
<td>ACT</td>
<td>70-120s</td>
<td>180-200s</td>
</tr>
<tr>
<td>ATIII</td>
<td>75-120%</td>
<td>&gt;40%</td>
</tr>
</tbody>
</table>

ECHO contrast: can cause micro bubbles in circuit which trigger the pump to alarm, and reduce RPM to zero

- Should be avoided when possible
- When necessary, advise ECMO specialist to temporarily turn off arterial air bubble intervention
VV ECMO Management

Pre-ECMO mortality calculated using the RESP Score (respscore.com)

- Validated tool to predict survival for a patient receiving ECMO for respiratory failure
- Variables include age, duration of mechanical ventilation, etiology of respiratory failure, NMB use, NO use, HCO3- infusion, PaCO2 and PIP
- Scored between -22 and +15 to yield 5 mortality classes (I-V with class I having the highest chance of survival and V having the lowest)
- A RESP score of 0 (class III) = 40-60% chance of survival
- Can be calculated at RESPSCORE.COM

Figure 16. RESP Score versus Survival. Based on a cohort study of 2355 patients. Dotted black lines and curved black lines signify the 95% and 99% confidence intervals, resp. Adapted from Schmidt et al, AJRCCM, 2014
VV ECMO Management

• 60-70% of cardiac output (CO) can be re-routed through the oxygenator
  • Blood flow should be 2/3 of CO
  • If unable to oxygenate, consider lowering CO with beta blockers (e.g. esmolol) or other CO depressants
• CO formula: \[ CO = \text{LPM} \times \frac{(\text{SaO}_2(\text{ECMO circuit}) - \text{SvO}_2(\text{patient}))}{(\text{SaO}_2(\text{patient}) - \text{SvO}_2(\text{patient}))} \]
• Oxygenation is dependent on the FdO\(_2\) as well as the percentage of the cardiac output going through the oxygenator, Hb concentration and the oxygenation of the venous blood not passing through the oxygenator (including coronary sinus blood)
• Chest compressions are OKAY
• Blood gases:
  • ABGs are accurate and can be drawn anywhere
  • VBGs are only accurate when drawn from venous side of ECMO machine
• Fick CO is not accurate (as MvO\(_2\) is not accurate)
• ECHO EF and CO measurement generally accurate

Ventilator Management

• Ideally managed at low setting in effort to “rest” lungs
  • Low RR (<10 BPM), moderate PEEP (5-15 cm H\(_2\)O ), \( V_T < 6\text{cc/kg} \), FiO\(_2\) <50%, PIP<30cm H\(_2\)O; can utilize long inspiratory time
  • ECMO FdO\(_2\) titrated to oxygenation with the following goals:
    ➢ SaO\(_2\) 100%; SvO\(_2\) 60-75%; PaO\(_2\) 40-50 mm Hg; SpO\(_2\) 85-100%
  • Ventilation: pCO\(_2\) 35-45 mm Hg; pH 7.35-7.45
Weaning VV

- Consider weaning on VV ECMO following improvement in the underlying respiratory failure as evidence by the following:
  - Increasing PaO₂ or decreasing PaCO₂ without changes on the ventilator or ECMO settings
  - Improving compliance
  - Radiographic Improvement
- Done in conjunction with CT Surgery
- ECMO blood flow remains the same

If primary ECMO indication is for Oxygenation:
- FiO₂ incrementally titrated down to 21%, then sweep turned to 0L/min
- Monitor hemodynamics and venous saturation. After an hour, draw ABG. If SaO₂ >95% and PaCO₂ <50 mm Hg, consider decannulation

If primary ECMO indication is for Hypercarbia:
- Sweep and FiO₂ incrementally titrated down to sweep of 0L/min
- Monitor hemodynamics and venous saturation. After an hour, draw ABG. If SaO₂ >95% and PaCO₂ <50 mm Hg, consider decannulation
- Ventilator settings will be adjusted to account for less ECMO support
  - Ensure that the ventilator settings allow room for increasing support once decannulated
- During decannulation perfusionist must be present
VA ECMO Management

- Pre-ECMO mortality calculated using the SAVE Score (save-score.com)
  - Validated tool to predict survival for a patient receiving ECMO for cardiogenic shock
  - Variables include age, weight, duration of mechanical ventilation, PIP, etiology of cardiogenic shock, pre-ECMO objective data including HCO3-, pulse pressure and diastolic pressure
  - Scored between -35 and +17 to yield risk classes I-V (I with the highest rate of survival (75%) and V with the lowest (18%))
  - SAVE score of 0 (class III) = 40% chance of survival
  - Can be calculated at SAVE-SCORE.COM

Figure 17. SAVE Score versus Survival. Based on a cohort study of 3846 patients. Curved blue lines and curved black lines signify the 95% and 99% confidence intervals, resp. Adapted from Schmidt et al, *Euro Heart Journal*, 2015
General Considerations: VA

- NO chest compressions while ECMO is running
- CO measurements (including FICK) are not accurate as ECMO contributes to CO
- EF on ECHO only accurate if ECMO flow is reduced to 1-1.5 L
- CVP not accurate as inflow cannula empties into RA (falsely elevated)
- ECMO can increase afterload, leading to LV distension which may be offloaded by IABP or Impella
- Blood gases:
  - ABGs should be drawn from right radial/brachial arterial line if femoral arterial access and from a femoral arterial line if axillary arterial cannulation.
  - VBGs can be drawn from anywhere

Convergence: VA

- With myocardial recovery the point of convergence is pushed more distal along the aorta (meaning native CO begins taking over cerebral and coronary perfusion)
  - Upper body hypoxemia: North-South Syndrome; Harlequin Syndrome
  - Correction of such phenomenon can be achieved by increased ECMO flow rates to overcome native CO or increasing the oxygen content of pulmonary venous blood

Figure 18. Convergence variation for VA ECMO with femoral artery cannulation. Adapted from Rao et al, Circ Heart Failure, 2018
Ventilator Management: VA

- Ideally managed at low setting as outlined in prior section for VV ECMO although with VA ECMO the ECMO FiO$_2$ is kept between 70-100% to keep SpO$_2$ > 95%
- Other settings outlined in prior section:
  - Low RR (<10 BPM), moderate PEEP (5-15 cm H$_2$O ), $V_T <$ 6cc/kg, FiO$_2$ <50%, PIP<30cm H$_2$O; can utilize long inspiratory time

Weaning: VA

- Consider weaning if improvement of the underlying cardiac function is seen as evidenced by:
  - Improved ScvO$_2$ (with no change in VO$_2$)
  - Improved cardiac function on TTE
  - Improved hemodynamics via PAC
- Done in conjunction with CT surgery
- ECMO blood flow is slowly decreased by 0.5 L/min at a time
  - Flow should not go below 2 L/min due to increase risk of VTE
- Blender FiO$_2$ and sweep stay the same
- Ventilator settings will be adjusted to account for less ECMO support
  - Ensure that the ventilator settings allow room for increasing support once decannulated
  - During decannulation perfusion must be present

*If you are weaning a VA patient who is on ECMO for respiratory support, involve perfusion and CT surgery*
ECMO Troubleshooting

ECMO Specific Complications:

- **Recirculation**
  - Caused by cannula migration or occlusion
  - Signs include color change on venous line, increased $\text{SvO}_2$, low $\text{SpO}_2$

- **Bleeding/Hemorrhage**
  - Common locations include surgical incision site, cannula site, prior invasive procedural site, intra-thoracic intra-abdominal, intra-cranial or retroperitoneal bleeding

- **Coagulopathy, Hemolysis, Heparin-Induced Thrombocytopenia**

- **Thrombosis**
  - Includes DVT and CVA

- **Limb Ischemia** (when using femoral or axillary/subclavian cannula strategy)
  - A separate antegrade cannula for leg perfusion is often added

- **Complications from the mechanical circuit** are rare but include thromboembolism, membrane oxygenator failure, air entrainment, tubing rupture, accidental decannulation
ECMO Troubleshooting

More negative P ven with Tube Chattering (subsequent drop in blood flow):
(Note, when chattering is seen, the flow should be decreased first)

- Hypovolemia/Bleeding → can lead to hemolysis leading to a rise in plasma free Hb and LDH; can see chattering in the circuit. Note, hemolysis and chattering can also be seen with positioning as well as high pump speeds (> 3000 RPM)
  - Treat with fluid (crystalloid/colloid), blood product, assess/address bleeding source
- Increased intrathoracic pressure including mechanical obstruction such as tamponade, PTX
  - Treat with reduction in mean airway pressure (i.e. reduce PEEP)
  - Bedside echo to rule out tamponade
  - Note, tube thoracostomy for PTX can be complicated by significant bleeding diatheses
- Increased intra-abdominal pressure: abdominal compartment syndrome
  - Treatment to address intra-abdominal hypertension and may include paracentesis, decompressive laparotomy
  - Ensure venous cannula in correct position

More negative P ven without Tube Chattering (subsequent drop in blood flow):

- Venous cannula or tubing issue such as kink, thrombus or small cannula size
  - Treatment includes correcting any kinks, increasing anticoagulation/switching pharmacologic agent, consider adding a second drainage cannula
Increase in $P_{\text{art}}$, and no change in $\Delta P$

- Arterial cannula problem such as kink, thrombus, small cannula or high SVR and MAP
  - Treat as above by fixing kink, increasing/changing anticoagulation or upsizing the cannula

No change in $P_{\text{art}}$, and increase $\Delta P$

- Gas exchange device failure

Low $O_2$ saturation:

- Check that oxygen source is connected, on, and not kinked
- Ensure the blood flow has not decreased
- Assess for re-circulation
- Assess patient for increased oxygen consumption
- On VV ECMO ensure that the CO is not too high
  - Consider why and fix the problem (e.g. fever; sepsis) or reduce CO with beta blocker, or sedation, etc.

Elevated $CO_2$ despite sweep titration:

- Water vapor can condense in the oxygenator, resulting in poor clearance. Clear by intermittently increasing sweep to 10L for a few seconds
- Blender failure – swap blender to switch to $O_2$ tank at a 1:1 sweep to blood flow ratio
Lack of Pulsatility (VA-ECMO):

- If pulsatility is variable, ensure adequate ventilator support to mitigate native cardiac output shunt.
- Lack of arterial pulsatility can be a representation of poor contractility of the heart and the heart’s inability to overcome the increase in afterload provided by the ECMO.
  - Need to assess for LV distention, consider LV vent
  - Without pulsatility, blood can become stagnant and lead to thrombus formation
- In addition, ongoing venous drainage from thesbian and bronchial veins into the LA can lead to increased LVEDV and hence LVEDP which can decrease coronary perfusion (diastolic pressure – LVEDP)
  - In the setting of severe AI or MR, this can lead to significant LA hypertension and cardiogenic pulmonary edema and hemorrhage
  - Management includes modalities such as IABP, Impella, Atrial septostomy, direct LV decompression (venting)

Flow Arrest:

- Unintentionally Clamps left in place (immediately after ECMO initiation)
- Pump Failure (Very rare! The only time hand crank is used)
- Significant Thrombus formation
- Air entrained
- Cannula migration or vessel dissection
## ECMO Emergencies (very RARE):

<table>
<thead>
<tr>
<th>EMERGENCY</th>
<th>INTERVENTIONS TO CH-ECMO CIRCUIT</th>
</tr>
</thead>
</table>
| Unintentional De-Cannulation | 1. Clamp arterial side first, then venous side near patient.  
2. Activate Crisis Action Plan  
3. Apply direct pressure to cannula site to control bleeding  
4. Notify CH-ECMO cannulating MD immediately  
5. Prepare to re-cannulate (will likely need to prime new disposable if arterial side was pulled) |
| Pump Failure               | 1. Clamp arterial side first, then venous side near patient  
2. Activate Crisis Action Plan  
3. Open safety bar, remove black pressure cable and disconnect venous probe  
4. Take Oxygenator out of Cardiohelp  
5. Place the Oxygenator into hand crank  
   • Fit oxygenator under the locating lug from below  
   • Open the lower locking device. Swing the unit up to the pump drive and release the lower locking device so that it fixes the oxygenator in place.  
1. Turn hand crank clockwise to reach patient’s prior settings (>2500 RPMs)  
2. Release clamps  
3. Prepare to change to back up console |
| Air Embolus in Circuit     | 1. Clamp arterial side first, then venous side near patient  
2. Activate Crisis Action Plan  
3. Place patient in Trendelenburg position  
4. Make sure pump is lower than patient and remove air burp cap (yellow)  
5. Locate air  
6. Close or correct air entry point if possible  
7. De-air circuit (chase air up to oxygenator [back side pig tail if venous, front side if arterial] or down to port near cannula)  
8. Clear alarm (arterial air alarm)  
9. Re-start ECMO |
| Blood Leakage from Oxygenator | 1. Clamp arterial (first) and venous side of circuit near patient  
2. Activate Crisis Action Plan  
3. Prepare for circuit exchange or repair |

Figure 19. Cardiohelp hand crank used for pump failure. Note: as you turn the crank, lights on the top will indicate RPM (NOT LPM). C. Yi. 2019
References


