Macau Society of Emergency and Critical Care Medicine

Extracorporeal Membrane Oxygenation
An update

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## Types of ECMO

<table>
<thead>
<tr>
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<th>Bad lung good Heart</th>
<th>Good lung Bad heart</th>
<th>Bad lung Bad heart</th>
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<tbody>
<tr>
<td>V-V</td>
<td>√</td>
<td>X</td>
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<tr>
<td>V-A peripheral</td>
<td>X</td>
<td>√</td>
<td>√</td>
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<tr>
<td>V-A Central</td>
<td>√</td>
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*V-V ECMO* and *V-A ECMO* diagrams are shown.
Extracorporeal flow needed

Flow ml/min

- CRRT
- MARS
- Plasmaphoresis
- IHD
- ECCO2R
- ECMO
- Separate cannulae needed or Avalon cannula

Increasing size of cannulae

Regional citrate anticoagulation possible
Principles of ECMO

• Temporary support the failed lung
  – Not suitable for irreversible lung failure
  – Less suitable for the lung condition required long time to heal (complication risk > benefit)

• Buy time for the lung to recover
  – Keep patient alive
  – Create an optimal condition for the lung to heal

• Avoid complications related to ECMO
Complications of ECMO

- Vessel damage during insertion
- Unidentified heart failure
- Bleeding
- Circuit thrombosis
- Oxygenator failure
- Haemolysis
- Air embolism
- Circuit rupture
- Infection
- Access recirculation
Vessel damage

• Appropriate size

• Too large
  – More damage to vessel
  – Increase insertion failure
  – More chance of chattering (cf. size of IVC)

• Too small
  – Not enough flow_{e}
  – Haemolysis
  – May need to insert one more access cannula
Vessel damage

- Arterial damage
  - May be fatal
  - Or limb loss
  - Need surgical repair
- Better having ultrasound guidance
  - Don’t trust pre-existing central lines (re-wiring)
  - Especially in obese patients
- Difficult if ECMO is running, especially VA-ECMO
- Need expertise
Risk of unidentified heart failure

• Desaturation
  – No longer a sign of heart failure even with severe pulmonary oedema
  – CXR - can’t differentiate LVF with underlying lung problem
• Esp. with line chattering or hypotension
  – Need repeated fluid challenge
  – Very common especially in the first few days
• Monitor
  – Clinical examination
  – Daily I & O Input >> Output
  – Echocardiography
• Treatment
  – Diuretics
  – CRRT
Risk of haemorrhage

- Systemic anticoagulation
  - Regional citrate anticoagulation is not possible
- Major cause of mortality of the past ECMO series
  - 43% of deaths in ANZ ECMO series were related to ICH, JAMA 2009;302:1888-95
  - Zapol study JAMA 1979;242:2193-6
  - Gattinoni study JAMA 1986;256:881-6
- ICH, GIB, pulmonary haemorrhage or cannulation sites
- Too low anticoagulation
  - Risk of thrombosis
  - Keep flow_\text{e} >1 \text{ L/min}
  - Chinese less thrombosis, more haemorrhage
  - Target 40-50s APTT (more accurate than ACT for low level anticoagulation)
Risk of haemorrhage

• Tracheostomy
  – Prolonged intubation and ventilation
• Chest drain insertion or removal
• Pleural aspiration
  – Pneumothorax
  – Pleural effusion

• Don’t do unless you have no choice
Circuit thrombosis ➔ Oxygenator failure

- Oxygenator failure
- Colour of return blood, should be 100% saturated
- Monitor clot formation on oxygenator surfaces
  - Especially when no systemic anticoagulation
  - Difficult to detect sometimes
  - The process is accelerating
    - Very quick decision
    - Reserve set should be available at all time
Oxygenator failure

- Days of ECMO therapy
- Any evidence of DIC
- Systemic anticoagulation
- Post-oxygenator blood gases
  - PO2 >40-80kPa
  - PCO2 should not increased
- Pre & post oxygenator pressures (pressure drop)
  - Estimated by CRRT machines
  - Noted the pressure changes during blood flow or
  - Stopped the CVVH blood flow and record the pressures
Pressure Monitors

- Venous pressure
  - Detect insucking
- Arterial pressure
  - Detect obstruction to outflow
- Pressure drop across oxygenator
  - Detect oxygenator clotting
- Risk of thrombosis / infection as a segment of stagnant blood is introduced
  - Integrated sensor in the Cardiohelp system (cannot recalibrate)
Bioline coating form Maquet

- Covalently bonded heparin to an albumin layer on PVC surface
  - Reduced clotting activity
  - Reduction of platelet adhesion and of thrombi creation
  - Less complement activation & neutrophil activation
Risk of haemolysis

- Minimize
  - Larger cannulae size
  - Lower flow\textsubscript{e}
    - Lowest possible to maintain adequate oxygenation
    - Still >1.5L/min to prevent circuit thrombosis
- May need to insert one more access cannula; high-flow ECMO
- Change oxygenator if lots of clots exist
- Monitor
  - Dec. Hb
  - Inc. plasma free Hb
  - Inc. bilirubin
  - Urine colour
  - Renal function test
Haemoglobinuria
Membrane Lung
Polyurethane
0.6 m²

PMP membrane
1.8 m²
Risk of air embolism

• Life threatening

• Disconnection before the centrifugal pump
  – Negative pressure
  – Virgin area
  – No connection over these sites
  – Plastic binders to reinforce tightness

• After pump
  – Positive pressure
  – Bleeding
  – Connection to CRRT circuit
Air embolism

- Total disconnection before pump
  - Circuit embolism and pump failure
- Partial disconnection
  - Circuit embolism and patient gas embolism
- Air embolism during CVC insertion while ECMO is running especially VA-ECMO
- Clamping of circuit in drainage line (pre-pump area) with pump running at high speed
Three fatal scenarios with ECMO gas flow

- **Failure to connect O₂ tubing**
  - Staff teaching
  - To & after transport
- **Obstructed gas outlet**
  - During transport (putting oxygenator on bed upright)
  - Water collection cup too close to gas outlet
- **Gas flow too high**
  - As in resuscitation to >15L/min
  - Normally Gas flow < 2x ECMO blood flow
Risk of bleeding from circuit rupture

• Much less with centrifugal pump
  – Compared with roller pump
  – Important advancement in ECMO design

• If it really happens, what would you do?
  – Clamp the line with two line clamps?
    • not practical
  – Basic PPE and then grab the line
Centrifugal Pump

- Jostra RotaFlow impeller pump
- 32ml priming volume
- The RotaFlow had no stagnant blood zones, no shaft and no seals
# Roller vs. Centrifugal Pump

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<tr>
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<th>Roller Pump</th>
<th>Centrifugal Pump</th>
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<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>Reusable pump with inexpensive disposable parts</td>
<td>No possibility of disruption from excessive line pressure buildup</td>
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<tr>
<td></td>
<td>Ease of sterilization</td>
<td>Decreased blood trauma</td>
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<tr>
<td></td>
<td>Simple flow rate determination</td>
<td>Less risk of massive air emboli</td>
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<tr>
<td></td>
<td>Variable SV for different-sized patients</td>
<td>Less cavitation</td>
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<tr>
<td><strong>Disadvantages</strong></td>
<td>Blood trauma</td>
<td>More expensive non-reusable pump</td>
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<tr>
<td></td>
<td>Possibility of circuit disruption and termination from excessive line pressure</td>
<td>Retrograde flow when pump slows or stops</td>
</tr>
<tr>
<td></td>
<td>Particulate microemboli from tubing spallation</td>
<td>Flowmeter is necessary (poor performance at low flow)</td>
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<tr>
<td></td>
<td>Possibility of massive air emboli</td>
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<td>Occlusion variability affecting flow rate and blood trauma</td>
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Infection

• Risk increases with increasing handling
  – Connection disconnection (CRRT circuit)
  – Blood taking
  – Not adopting aseptic technique
    • Connecting up the circuit
    • Priming
    • Insertion of cannulae
    • Blood taking
  – Patient immunocompromised
  – Multiple foreign materials in body
Hypothermia

- Failure of blood warmer
  - After transport
Temperature Control

• Thermo-controlled water bath necessary
• Avoid a high water bath temperature if possible
  – Bubble formation with heating of blood
  – Not more than 4°C compared with blood
Pharmacokinetics

- If NS for priming
  - Initial hypotension may be related to hypocalcaemia, iCa
- Increase drug sequestration → lower drug levels
  - Esp. benzodiazepine, propofol, opioids, frusemide, phenytoin, phenobarbital
- Increase in vol. of distribution
  - Adjust drug dose, e.g. gentamicin, tobramycin
Risk of Access recirculation

• During insertion
  – Estimate the depth of insertion before cannulation
  – No need to adjust according to X-ray position, but the degree of access recirculation

• Oxygen saturation of drained blood
  – Rotaflow: colour of blood in access cannula
  – Cardiohelp: colour of blood in access cannula + $\text{SvO}_2$

• Note the change in blood colour without and with $\text{O}_2$
Risk of Access recirculation (2)

• Ways to reduce AR
  – Separation of the access and return cannulae
  – Return cannula to RV
  – Insertion of one more access cannula, high-flow ECMO
  – Avalon bi-caval cannula
Risk of further lung damage

• Aims
  – Decrease tidal volume
  – Decrease FiO\textsubscript{2} to an acceptable level (0.3-0.5)
    • Beware of reverse diffusion; FeO\textsubscript{2} > FiO\textsubscript{2}
  – PEEP to keep alveoli open, 10-15cmH\textsubscript{2}O
• Need to be decreased if pneumothorax; BPF
• If not able to do this
  – ECMO is futile
    • (UCH 1\text{st} case)

... On commencement of VV-ECMO, the patient had no other vital organ failure and her oxygenation improved initially. Nonetheless, we failed to wean down the ventilatory support to reduce the risk of VILI....

Hong Kong Med J 2009;15:381-4
In patient with lots of ventilator associated complications

- Pneumothorax – bronchopulmonary fistula
- Ventilator associated pneumonia
- Agitated with sedation AND
- ECMO running is smooth

- Consider wake and extubate with ECMO running
Decreasing/inadequate SpO$_2$/SaO$_2$

- Increase flow$_e$
  - (inc. cannulae size)
  - More access recirculation
  - More chattering
  - More haemolysis
  - Need more fluid
    - Make lung condition worse
- One more access cannula
  - Risk of line complication
  - If insertion failure, difficult to control bleeding
Decreasing/inadequate SpO$_2$/SaO$_2$ (2)

- Decrease O$_2$ consumption
  - If shivering, increase temperature
    - May help in viral clearance
- Increase Hct to 0.4 or Hb to >10g/dl
ECMO

- ECMO
  - Add oxygen to blood **AND**
  - Remove CO2 from blood

- Higher flow needed
  - O2 is carried mainly through Hb, not plasma
  - \[1.36 \times \text{Hb} \times (\text{SaO}_2 - \text{SvO}_2) = \text{O}_2 \text{ ml/l blood}\]
    \[1.36 \times 120 \times (1.00 \text{ to } 0.72) = 46 \text{ ml/l blood}\]
  - One needs ~ 240ml O2 /min \(\rightarrow\) ~ 5 L/min flow
Oxygen content

(Haldane effect: $O_2$ displaces $CO_2$ from Hb)

$\uparrow$ pH
$\downarrow$ DPG
$\downarrow$ Temp

$\downarrow$ pH
$\uparrow$ DPG
$\uparrow$ Temp

(Bohr effect: $\uparrow$ $CO_2$, $\downarrow$ pH)
Mixed blood $O_2$ saturation

- Venous $O_2$ saturation
- ECMO flow as % of total blood flow

Legend:
- 50%
- 60%
- 70%
- 80%
- 85%
- 90%
- 95%
Extracorporeal flow needed for oxygenation

- Remain 60% saturated
- 100% SO2 after passing through extracorporeal circuit
- Overall 90% saturated after mixing

Higher extracorporeal flow needed
Increasing PaCO$_2$/PetCO$_2$

- Easy to be removed by ECMO
  - cf. Novalung® iLA membrane ventilator

- Increase gas flow
  - Keep V/Q 1:1
  - Avoid lung tissue alkalosis
    - Decrease ventilator minute volume
What’s it?

• **ECCO₂R**
  – Lower flow than ECMO needed
    • CO₂ mainly carried by plasma (dissolved bicarbonate)
    • Linear kinetics without saturation
    • 1 L blood carry > 500 ml CO₂
      – CO₂ removal rate < 1 L/min blood flow
    • CO₂ diffuses more readily than O₂ across extracorporeal membrane
Extracorporeal flow needed

Increasing size of cannulae

Separate cannulae needed or Avalon cannula

Regional citrate anticoagulation possible
Carbon dioxide Removal

Carbon Dioxide

![Graph showing CO2 content vs PCO2 (mm.Hg.)](image)

- Mixed Venous: 9.3 ml/100ml
- Normal gas flow: 12.5 ml/100ml
- Double gas flow: 75 ml/100ml
AVCO2R or PECLA

Connects to cannula placed in femoral artery

Connects to cannula placed in femoral vein
AVCO2R or PECLA

- Novalung: interventional Lung Assist (iLA) membrane ventilator
- Medtronic: Affinity NT
- Hemodynamic should be stable, with MAP >60mmHg
- Flowmeter monitoring is needed
- Risk of distal limb ischemia
- Indications
  - LPV for ALI/ARDS or severe asthmaticus
  - Bridge to lung transplantation
Venovenous CO2 Removal

- Move gradually to VV-ECMO
- Novalung: iLA Activve (diagonal pump)
Extracorporeal flow needed for CO$_2$ removal

Patient venous blood not through circuit

+ CO$_2$ after circuit

⇒ Normal CO$_2$ after mixing

lower extracorporeal flow needed
Renal circuit

- Post pump
  - Before and after oxygenator

- CRRT
  - Positive pressure allowed in CRRT
    - Prismaflex
    - Gambro AK 200S Ultra
ECMO and CRRT
Monitoring – Extracorporeal circuit

• Extracorporeal circuit
  – Pump speed, blood flow & pump noise
  – Circuit: blood clots, air bubbles, kinking, recirculation
  – Lines: silent or kicking
  – Check cannula placement & stability
  – Gas flow & FiO₂
Monitoring – Patient

• Patient
  – Oxygen delivery
    • \( \text{SaO}_2, \text{Hb, Haemodynamics} \)
  – Monitor APTT & platelet count
  – Observe for bleeding
  – Assess CNS status (if patient not sedated)
  – Monitor plasma free Hb
  – Chest X rays changes
Weaning

• Gas flow_{e}
  – May decrease to zero (test oxygenation & CO2 removal)

• Flow_{e}
  – Can’t be zero (minimum >1L/min)

• Gas FiO_{2}
  – FiO2 0.21 → no O2 get into blood but CO2 removal continue (test oxygenation only)
# Membrane Lung vs. Natural Lung

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Membrane lung</th>
<th>Natural lung</th>
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<tbody>
<tr>
<td>Surface area (m²)</td>
<td>0.5 - 4</td>
<td>70</td>
</tr>
<tr>
<td>Blood path width (µm)</td>
<td>200</td>
<td>8</td>
</tr>
<tr>
<td>Blood path length (µm)</td>
<td>250,000</td>
<td>200</td>
</tr>
<tr>
<td>Membrane thickness (µm)</td>
<td>150</td>
<td>0.5</td>
</tr>
<tr>
<td>Max $O_2$ transfer (ml/min STP)</td>
<td>400 - 600</td>
<td>2,000</td>
</tr>
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</table>
Learn together through practice
Questions/Comments?