MONITORING IN ECLS

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Extracorporeal Membrane Oxygenation: A New Therapeutic Modality—Where We are in India

Poonam Malhotra, Venkat Goyal, Pranay Oza

"Courage is fear holding on a minute longer"

–George S Patton

ABSTRACT

Extracorporeal membrane oxygenation (EMCO) is a modality to provide a prolonged but temporary support to the patient suffering from reversible cardiac and/or respiratory failure.
EXTRA CORPOREAL LIFE SUPPORT IS ACHIEVED BY

- Draining venous blood
- Removing CO2
- Adding oxygen
- Returning to circulation
- Through either a vein or artery
ECMO AND ITS IMPORTANCE

- Technique used to provide life support to the critically ill;
- Temporary support for patients with pulmonary or cardiac failure (or both), when no other form of treatment is likely to be successful;
- Expensive therapy, requiring the weighing of its application, instead of other forms of treatment

Are there any positive outcomes of this treatment in critical ill adult patients?

IN WHAT CIRCUMSTANCES CAN ECMO BE USED?

Heart failure
- Heterogenous condition in which the heart is unable to pump out sufficient blood to meet the metabolic needs of the body.

Respiratory insufficiency
- Inadequate supply of oxygen to the cells of the body, and removal of carbon dioxide.

Critical ill patients
- Individuals whose state of disease may lead to eminent death.
A Vicious Circle
GOALS OF TREATMENT REACHED?
## TYPES OF ECMO

<table>
<thead>
<tr>
<th></th>
<th>Bad lung good Heart</th>
<th>Good lung Bad heart</th>
<th>Bad lung Bad heart</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-V</td>
<td>√</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>V-A peripheral</td>
<td>X</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>V-A Central</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>(not required)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## ECMO TYPES

<table>
<thead>
<tr>
<th>Property</th>
<th>VA ECMO</th>
<th>VV ECMO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cannulation site</strong></td>
<td>IJV/FV and RCC/Ax/FA/Ao</td>
<td>IJV alone/ IJV-FV/ FV-FV/Saph-saph/RA</td>
</tr>
<tr>
<td><strong>PaO\textsubscript{2}</strong></td>
<td>60-150 mmHg</td>
<td>45-80 mmHg</td>
</tr>
<tr>
<td><strong>Indicator of O\textsubscript{2} sufficiency</strong></td>
<td>Mixed ven sat or PaO\textsubscript{2}</td>
<td>Combination of SaO\textsubscript{2}, PaO\textsubscript{2}, cerebral ven sat &amp; pre membr sat trend</td>
</tr>
<tr>
<td><strong>Cardiac effect</strong></td>
<td>↓ preload; ↑ afterload; pulse pr ↓; coronary oxyg by LV blood; <code>Cardiac stun</code></td>
<td>Negligible effects; may improve coronary oxyg; may reduce RV afterload</td>
</tr>
<tr>
<td><strong>O\textsubscript{2} delivery capacity</strong></td>
<td>High</td>
<td>Moderate. ↑ cephalad drain</td>
</tr>
<tr>
<td><strong>Circulatory support</strong></td>
<td>Partial to complete</td>
<td>Indirect: ↑ delivery of O\textsubscript{2} to coronary &amp; pulm circ</td>
</tr>
</tbody>
</table>
It is required to:

- Assess the accuracy of the system,
- Monitor patient’s progress
- Efficacy of the system to watch for the safety of the system.
- To rule out complications.
- Monitoring of patient’s parameters helps us to assess the patient progress,
• Success lies with **vigilant monitoring** which helps in early recognition and diagnosis of problems and timely and accurate action.

Monitoring includes:

- Clinical parameters of patient
- Monitoring of accuracy of system and circuit
- Biochemical and Laboratory parameters
- Radiologic monitoring
- Circuit monitoring
- Haemodynamic Monitoring
- ETCO\(_2\) removal
- Anticoagulation monitoring
INTEGRATIVE MODEL FOR CLINICAL MONITORING

• Physical Exam
  – Hypoperfused state
    ■ Cool extremities
    ■ Low urine output
    ■ Increasing CR
    ■ Confusion
    ■ Nausea/Vomiting
    ■ Peripheral edema
    ■ Ascites
    ■ SOB
INTEGRATIVE MODEL FOR CLINICAL MONITORING

Labs

- Increasing BUN/CR ratio
- LFT
- Coagulation abnormalities
- BNP
- Hyponatremia
- Acidosis
WHAT CAN WE USE?

- Look at all the variables
- Sv02, urine output, acidosis (lactate)
  - If 2 out of 3 are abnormal likely to be issue with cardiac output
- CO/CI, Filling pressures (PAD, CVP), SVR/SVRI
- PA pressures, oxygenation
- Echocardiography
WHICH PATIENTS NEED THIS TYPE OF MONITORING?

Current guidelines suggest selective use

- Cardiogenic shock
- Acute on chronic heart failure
- Transplant/VAD patients
- Escalating Inotropics support
- Post procedure/MI with heart failure
- At risk for RV/LV failure

Poonam Malhotra, Pranay Oza, Venkat Goyal. Monitoring on Extracorporeal Membrane Oxygenation. Manual of ECMO; Chapter 11; pg 76-80
SEDATION

- should be thoroughly sedated at the time of cannulation and for the first 12 to 24 hours
  - facilitate successful cannulation
  - avoid air embolism in the presence of spontaneous breathing
  - minimize metabolic rate
  - enhance comfort.

- Once the patient is stable on VV-ECMO, sedation should be minimized
CIRCUIT MONITORING

- Circuit blood flow
- Circuit gas flow
- Circuit pressure
- Circuit integrity

These variables should be monitored continuously

Poonam Malhotra, Ritu Airan, Banashree Mandal. Extracorporeal Membrane Oxygenation Circuit and Hardware. Manual of ECMO; Chapter 8; pg 43-64
MONITORING OF ACCURACY OF SYSTEM DURING ECMO

- Circuit check
- Revolution per minute
- Blood flow rate
- Gas flow rate
- ECMO FiO2
- Delta pressure
- Post oxygenator blood gas
<table>
<thead>
<tr>
<th>Increase flow</th>
<th>Decrease flow</th>
</tr>
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<tbody>
<tr>
<td>• Increased RPM</td>
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</tr>
<tr>
<td>• Decreased resistance (afterload)-</td>
<td>• Increased resistance (afterload)</td>
</tr>
<tr>
<td>➢ vasodilation of the patient</td>
<td>➢ Vasoconstriction</td>
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<tr>
<td>➢ Improved arterial cannula positioning</td>
<td>➢ Kinking of tubing</td>
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<td>➢ Bad cannula position</td>
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<tr>
<td>➢ Increased patient filling</td>
<td>➢ Hypertension</td>
</tr>
<tr>
<td>➢ Improved venous cannula position</td>
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MONITORING OF PATIENT SAFETY, WHILE ON ECMO

- ECMO parameters
  - Pre pump pressure
  - Pre oxygenator pressure
  - Post oxygenator pressure
- Coagulative status
  - Activated clotting time (ACT) or partial thromboplastin time (aPPT)
  - Platelet counts
  - Antithrombin III levels
- Hematological parameters
  - CBC – look for hemoglobin and platelet counts
  - Plasma free hemoglobin
- Biochemical parameters
  - Routine like creatine, electrolyte
  - Serum bilirubin and LDH
  - Urinary pH and urine for hemoglobinuria
- Clinical parameters
  - Urine output, urine color for hemolysis and related renal dysfunction
- Radiological parameters
WHAT DO I DO WHEN:

• A sudden increase/decrease in SVO2 occurs?
• A gradual increase/decrease in SVO2 is noted?
• Patient is on full VA ECMO. Monitors show V-fib?
• Perfusionist asks for blood transfusion?
• Patient is on full VA ECMO and EKG monitors show V-fib?
• Perfusionist asks for blood transfusion?
MONITORING OF THE GAS EXCHANGES

• Gas exchanges can be monitored on line like:
  – arterial saturation,
  – mixed or central venous oxygenation
  – end tidal volume carbon dioxide (EtCO$_2$) and
  – the blood gas like PO$_2$, PCO$_2$ and pH.
During VA ECMO it is essential to intermittently monitor right hand saturation,

It will tell you about the right brachiocephalic artery and indirectly coronary circulation (native circulation in case of VA ECMO.)
ScVO$_2$ or SVO$_2$

- It represents the adequacy of tissue perfusion and oxygen extraction.

- Usually ratio O$_2$ consumption depends on extraction.

- Usually oxygen delivery is five times that tissue oxygen extraction.
Cerebral saturation

- Neurological outcome and complications are the major concern in ECMO. In severely critical patient even with high ECMO support sometimes the borderline hemodynamics and oxygenation parameters are accepted.
- Moreover VA ECMO is a retrograde flow and with compromised hemodynamics whether the cerebral circulation is adequate or not that always remains as a question.
- The usual trend is to monitor clinically by through neurological examination and sedation break period.
- Many of the times this parameters are not accurate so it is essential to monitor cerebral saturation.
- It gives us the clue of adequate cerebral perfusion.
End Carbon dioxide (EtCO$_2$)

- Measurement of end tidal CO$_2$ at the airway is another helpful monitor of native lung function.

- During the initial days of an ECLS run, end tidal CO$_2$ may be $\leq$ 5mmHg. As functioning units resume ventilation or as pulmonary blood flow to ventilated units increases, end tidal CO$_2$ will increase.

- When end tidal CO$_2$ is near normal (>35 mmHg), a trial of weaning off ECMO should be considered.

- Patient on ECMO has tachycardia but it usually settles once the hypoxia and perfusion improves.
## FACTORS AFFECTING BLOOD FLOW

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RADIOLOGICAL MONITORING
ECMO Anatomy
VENO-ARTERIAL CANNULATION

Venous Cannula
Arterial Cannula
Patient selection
Monitoring during support
Insertion and correct placement of cannulas
Detecting complications
Decision making: cardiac recovery, weaning, bridge to..
PATIENT SELECTION REVERSIBLE CAUSES OF HEMODYNAMIC INSTABILITY V-A ECMO

CONTRAINDICATIONS

- Aortic dissection
- Absolute contraindications

- Aortic valve regurgitation
- Severe Arterial vascular disease

- Central vs peripheral
- Surgical vs percutaneous
VENOUS TO VENOUS
PATIENT SELECTION

CHIARI’S NETWORK

PATIENT SELECTION

Atrial septal defect (ASD) Patent foramen ovale (PFO)
Patient selection

Insertion and correct placement of Cannulas

Monitoring during support

Detecting complications

Decision making: cardiac recovery, weaning, bridge to..
INSERTION AND CORRECT PLACEMENT OF CANNULAS

ECMO Connect to return Cannula
VENOUS ACCESS CANNULA THROUGH RCFV INTO RA RETURN ARTERIAL CANNULA RCFA INTO ABDOMINAL AORTA
INSERTION AND CORRECT PLACEMENT OF CANNULAS (3D Echo)
ECMO’s hemostatic abnormalities relate to:
- Clinical conditions: post-surgical bleeding, sepsis, hypothermia, hemodilution
- Constant transfusion blood products
- Continuous heparin infusion
- Neonate/infant immature coagulation system

Low AT-III levels

Pharmacokinetics heparin different with neonates vs. adults
Anticoagulation During ECMO
How to Measure It?

Tests available:
- ACT
- anti Xa
- ATIII
- aPTT
- HMS
- TEG
Common Coagulation Tests

- **Laboratory**
  - PT
  - aPTT
  - TT
  - Fib
  - Anti Xa
  - Anti IIa
  - Factor Assays

- **Point of Care**
  - ACT
    - Celite®
    - Kaolin
    - Glass beads
    - Silica
    - thromboplastin
Anticoagulation During ECMO

- **ACT standard POC device for all institutions with ECMO program**
  - **Ranges**: 160-200, rate initiated at 25 Units/kg/hr, mostly trending

- **Pros**: Easily used bedside POC device, cost, availability, comfort level?

- **Cons**: user variability, analyzer variability, poor correlation between ACT & actual Heparin level
Risk of haemolysis

- Minimize
  - Larger cannulae size
  - Lower flow
    - 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

Poonam Malhotra, Ritu Airan, Banashree Mandal. Extracorporeal Membrane Oxygenation Circuit and Hardware. Manual of ECMO; Chapter 8; pg 43-64
Haemoglobinuria
**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
HIT TYPE II COMPLICATIONS
Extracorporeal Carbon Dioxide Removal (ECCO$_2$R)
What’s it?

- **ECCO\(_2\)R**
  - Lower flow need
    - CO\(_2\) mainly carried by plasma (dissolved bicarbonate)
    - Linear kinetics without saturation
    - 1 L blood carry > 500 ml CO\(_2\)
      - CO\(_2\) removal rate < 1 L/min blood flow
    - CO\(_2\) diffuses more readily than O\(_2\) across extracorporeal membrane
AV-ECCO$_2$R (Novalung iLA)
Hattler catheter
(Alung Technologies, Pittsburgh, USA)

- ~ IVOX catheter
  - Hollow fibres bundle ~ 1,000
- + IABP (helium filled balloon)
  - Active mixing
  - IVC
  - 300 beats / min
- Efficient CO2 removal
THROMBOELASTOGRAPHY

Refinements to Technique

TEG accelerants / activators / modifiers

• **Celite / Kaolin / TF** accelerates initial coagulation

• **Reopro (abciximab)** blocks platelet component of coagulation

• **Platelet mapping reagents** modify TEG to allow analysis of Aspirin / Clopidigrol effects

Heparinase cups

• Reverse residual heparin in sample
• Use of paired plain / heparinase cups allows identification of inadequate heparin reversal or sample contamination
CLINICAL PRACTICE: A CONSTANT STRUGGLE......
ANALYTICAL SOFTWARE
GRAPHICAL REPRESENTATION
TEG Parameters: LY30
Clot Breakdown

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clot time</th>
<th>Clot rate</th>
<th>Maximum clot strength</th>
<th>Clot stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemostatic Activity</td>
<td>Ila generation</td>
<td>Fibrin X-linking</td>
<td>Platelet – fibrinogen (ogen) interactions</td>
<td>Reduction in clot strength</td>
</tr>
<tr>
<td></td>
<td>Fibrin formation</td>
<td>FibrinPlatelet</td>
<td></td>
<td>Fibrinolysis</td>
</tr>
<tr>
<td>Hemostatic Component</td>
<td>Coagulation pathways</td>
<td>Coag pathways platelets</td>
<td>Platelets (~80%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fibrinogen (~20%)</td>
<td></td>
</tr>
</tbody>
</table>

Dysfunction

<table>
<thead>
<tr>
<th>Hypocoagulable</th>
<th>LY30</th>
<th>EPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypocoagulable</td>
<td>↑ R (min)</td>
<td>↓ MA</td>
</tr>
<tr>
<td></td>
<td>↓ K (min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>↓ α (deg)</td>
<td></td>
</tr>
<tr>
<td>Hypercoagulable</td>
<td>↓ R (min)</td>
<td>↑ MA</td>
</tr>
<tr>
<td></td>
<td>↓ K (min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>↑ α (deg)</td>
<td></td>
</tr>
</tbody>
</table>
VARIOUS INTERPRETATION ACCORDING TO GRAPH

**Figure 4a.**

*Normal*
- $R$; $K$; $MA$; Angle = Normal

**Figure 4b.**

*Anticoagulants/hemophilia*
- Factor Deficiency
- $R$; $K$ = Prolonged;
- $MA$; Angle = Decreased

**Figure 4c.**

*Platelet Blockers*
- Thrombocytopenia/
- Thrombocytopeny
- $R$ - Normal; $K$ = Prolonged;
- $MA$ = Decreased

**Figure 4d.**

*Fibrinolysis (UK, SK, or t-PA)*
- Presence of t-PA
- $R$ - Normal:
  - $MA$ = Continuous decrease
  - Ly30 $> 7.5\%$; WBCLI $< 97.5\%$;
  - Ly60 $> 15.0\%$; WBCLI60 $< 85\%$

**Figure 4e.**

*Hypercoagulation*
- $R$; $K$ = Decreased
- $MA$; Angle - Increased
HEMOSTASIS MONITORING WITH THE TEG SYSTEM

Measures entire clotting process

Measures: ΔClot strength / time (min)

Rate of clot formation
- Strength of clot
- Stability of clot

Σ Hemostatic status
If it is a low flow venous-venous ECMO, then SVV can be used as a hemodynamic monitoring factor.

However, if it involves a right to left shunt, i.e. venous to arterial then SVV should not be used as a monitoring parameter.
ROLE OF BNP AS A PROGNOSTIC MARKER IN PATIENTS UNDERGOING TETRALOGY OF FALLOT IN CYANOTIC CARDIAC SURGERY

Dr. Poonam Malhotra Kapoor; Dr. Arun Subramanian*, Dr. Sameer Goel, Dr. V. Devagourou, Prof. Usha Kiran, Prof. Balram Airan Mch

The authors concluded that:

- In the future, physicians may be able to use these quantitative cut-off values in their decision to delay heart surgery in order to further “tune up” the patient.
- This might be through preoperative optimization with inotropes, vasodilators and diuretics in which case the BNP level could be quickly, inexpensively, and quantitatively followed until it reaches more reassuring levels.
- Even if this optimization does delay surgery, the physician may be preventing postoperative morbidity and premature mortality.
- Alternatively, if the patients’ euvolemic BNP is high, the higher patient risk might be weighed into the decision on whether or not to proceed with open-heart surgery.
- In all, the BNP levels can be used to an extent as a prognostic marker in patients undergoing corrective surgery for congenital heart disease.

(Annals of Cardiac Anaesthesia 2013)
Changes in myocardial lactate, pyruvate and lactate-pyruvate ratio during cardiopulmonary bypass on ECMO: early marker of morbidity

PM Kapoor, B Mandal, UK Chowdhury, SP Singh, U Kiran
Departments of Cardiac Anaesthesia and CTVS, CN Centre, All India Institute of Medical Sciences, New Delhi, India

The authors concluded that:

- The sampling of CS blood via cannula in CS is a simple, cheap, easy technique and can be performed routinely.

- Myocardial markers like lactate, pyruvate and LP ratio may be effective in predicting postoperative outcomes e.g., need for inotropes, postoperative myocardial dysfunction, prolonged postoperative ventilation, ICU stay.

- Pre-CPB myocardial lactate value of 2.9 mmol/l and myocardial pyruvate value of 0.07 mmol/l can predict inotropic requirement post-CPB with good sensitivity and specificity.

(Journal of Anaesthesiology and Clinical Pharmacology 2011; 27:225-232)
Authors concluded that:

- Strong correlation between central venous and mixed venous oxygen saturation was found as shown by Pearson correlation (91%).

- Good agreement was seen between central venous and mixed venous oxygen saturation by Pearson correlation, Regression coefficient and Intraclass Correlation (0.91, 0.99, 0.91 respectively, p<0.001).

- *Central venous oxygen saturation was found to be a reliable surrogate marker for mixed venous oxygen saturation in patients undergoing open heart surgery.*

Poonam Malhotra et al concluded that:

- EGDT may be a useful strategy in patients with risk factors for adverse outcome.
- Although a few benefits were observed in the EGDT group, this study did not conclusively show beneficial effects.
- Including more number of subjects in the study may clarify the issue.

(Annals of Cardiac Anaesthesia 2008; 11(1):27-34)
DECISION TREE FOR HEMODYNAMIC / VOLUMETRIC MONITORING**

GDT IN ECMO

Cl (l/min/m²)

<3.0

>3.0

GEDI (ml/l2) or ITBI (ml/m²)

<700 <850

>700 >850

<700 <850

>700 >850

<10 >10

<10 >10

<10 >10

<10 >10

V+

V+!

Cat

Cat

V-

V+!

V-

V-

ELWI (ml/kg)

<10 >10

<10 >10

<10 >10

<10 >10

GEDI (ml/l²) or ITBI (ml/m²)

>700 >850

700 - 800 850 - 1000

700 - 800 850 - 1000

700 - 800 850 - 1000

>4.5 >25

>5.5 >30

>4.5 >25

>5.5 >30

1. Optimise to SVV (%) +

<10 <10 <10 <10

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

2. Optimise to SVV (%) +

<10 <10 <10 <10

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

Optimise to SVV (%)

<10 <10 <10 <10

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

>700 >850 700 - 800 850 - 1000

V+ = volume loading (! = cautiously)

V- = volume contraction

Cat = catecholamine / cardiovascular agents

SVV only applicable in ventilated patients without cardiac arrhythmia

(Annals of Cardiac Anaesthesia 2016; 19 (2):31-37)
• Accuracy, adequacy and safety are in general a key to success.
• To maintain this constantly one required to have vigilant monitoring.
• Proper monitoring of the system functionality can prevent life threatening complications.
• Thorough check of the ECMO system along with the vital parameter and laboratory value will lead to safe and successful ECMO.
Thank you...