Symposium

Pediatric Cardiac ECMO: A review

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ABSTRACT :
Patient with congenital or acquired heart disease comprise a major diagnostic category for Pediatric intensive care units across the country, comprising of 30-40% more admission to some of the centres. Over the last 10 years, there has been a dramatic increase in the use of extracorporeal membrane oxygenation (ECMO) in cardiac failure despite absence of encouraging survival statistics. ECMO can be a useful tool in our country in patients who undergo open heart surgery and are in refractory low cardiac output, if instituted electively before a cardiac arrest. Veno-arterial extracorporeal membrane oxygenation (V-A ECMO) is a common modality of circulatory assist used presently in children in our country. This mode can also be used as bridge to heart transplant. This review addresses the following issues for Pediatric Cardiac ECMO: indications and contraindications of V A ECMO, complications, basic ECMO circuit, routine management and management in special circumstances, along with troubleshooting and long term neurological outcome and survival.

Key words: Pediatric Veno-arterial ECMO (VA ECMO), Low cardiac output syndrome (LCOS)

Introduction:
ECMO (Extra Corporeal Membrane Oxygenation) is an adaptation of conventional cardio pulmonary bypass to support the function of the lungs or heart or both for a prolonged period of time.1 Although it was introduced as a form of respiratory support in children with severe lung disease, it has become the most common approach to Pediatric mechanical cardiac support today.2,3 Presently, it can be instituted in cases of reversible cardiorespiratory failure, for a period of days to weeks.4

Extra Corporeal Life Support (ECLS) has its origins in cardiopulmonary bypass for cardiac surgery, a technology pioneered in the 1950s to permit intra-cardiac surgery. Development of improved bypass technologies ensued, to the extent that cardiopulmonary bypass (CPB) is now a routine procedure in cardiac surgery. Today the application of ECLS has almost universal acceptance during the neonatal period and widespread acceptance in the pediatric age group.5

However, despite the increased enthusiasm for cardiac ECMO, the survival to hospital discharge as reported by Extracorporeal life support organisation (ELSO): 39% in neonates and 47% in children, has not increased and remains lower than the survival outcomes reported for respiratory ECMO.6

History:
The phenomenon of transport of oxygen into the blood could occur across a semi-permeable membrane was first recognized in 1944, when Kolff and Berk noted that blood became oxygenated as it passed through the cellophane chambers of an artificial kidney. John Gibbon developed the concept of cardiopulmonary bypass in the early 1950s. Devices used at that time were bubble or disk oxygenators with a direct oxygen-blood interface. In 1956, Clowes developed the first membrane oxygenator. In the next couple of decades, further advances in techniques and research for prolonged pulmonary support took place. Dr Donald Hill, in 1972, successfully treated the first adult patient on ECMO, following polytrauma. In 1975, Dr Robert Bartlett and his team treated a newborn baby with meconium aspiration syndrome on ECMO.7

ECLS was first used for cardiac support in the 1970s by Baffles, but it was not until the 1990s that ECLS became a common therapeutic technique for this patient population.8 Since then, with further innovations leading to the development of more biocompatible membranes, oxygenators and efficient ECMO pumps, the efficiency and outcomes have improved tremendously.

Role of ECMO as cardiac support:
ECMO facilitates ventricular recovery by reducing...
myocardial wall tension, increasing coronary perfusion pressure, and providing adequate systemic perfusion with oxygenated blood. 9, 10, 11

**Indications:**
ECMO can be an effective bridge to recovery, to transplantation, or to prolonged mechanical support. A review of ECMO literature indicates that up to 2–5% of all children undergoing corrective or palliative complex cardiac surgery use mechanical circulatory support with ECMO (Table 1).3

1. Preoperative resuscitation
   Severe low cardiac output states from left sided obstructive lesions (e.g. Critical aortic stenosis), pulmonary hypertension (e.g. Obstructed TAPVC) or severe hypoxemia (e.g. Transposition of great arteries).12,13
2. Early postoperative cardiac failure in the operating room (inability to wean from CPB).
3. Life threatening arrhythmias refractory to maximal conventional therapy.
4. In the Critical care unit (Table.2.): The severity defined by high pressor and inotropic requirement, metabolic acidosis, decreased urine output for 6 hours leading to Low cardiac output syndrome (LCOS) with high inotropic support / vasoactive score is an ideal point to start considering ECMO.

There are no clear cut-offs based on evidence to suggest use of ECMO in cardiac indications but elective ECMO before multiorgan function sets in has better results than Rescue ECMO12.

5. In-hospital cardiac arrest and cardio pulmonary resuscitation (To institute Extracorporeal CPR)

7. Cardiac support in systemic disease like refractory septic shock – to allow for restoration of organ function.
8. As a bridge to heart transplant, where facilities for implantation of ventricular assist devices/ Berlin heart is not available immediately.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study Period</th>
<th>Number of patients required following CPB</th>
<th>Survival Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walter III et al.</td>
<td>1984-1994</td>
<td>66 (3.0)</td>
<td>57.6</td>
</tr>
<tr>
<td>Jaggers et al.</td>
<td>1994-1999</td>
<td>35 (3.4)</td>
<td>61</td>
</tr>
<tr>
<td>Kolvos et al.</td>
<td>1995-2000</td>
<td>74 (2.2)</td>
<td>50</td>
</tr>
<tr>
<td>Aharon et al.</td>
<td>1997-2000</td>
<td>50 (4.0)</td>
<td>50</td>
</tr>
<tr>
<td>Chaturvedi et al.</td>
<td>1992-2001</td>
<td>81 (2.5)</td>
<td>49</td>
</tr>
<tr>
<td>Morris et al.</td>
<td>1995-2001</td>
<td>89 (3.4)</td>
<td>40</td>
</tr>
<tr>
<td>Thourani et al.</td>
<td>2002-2004</td>
<td>17 (1.8)</td>
<td>35</td>
</tr>
</tbody>
</table>

Table.1. ECMO following cardiotomy in children with congenital heart disease3

Table.2. Indications for ECMO use in children after cardiac surgery:

**Contraindications:**
1. Age and size: In general, any infant considered old and large enough to undergo cardiac surgery is an appropriate candidate for ECLS.
2. Futility: there is a small likelihood of recovery (severe cardiomyopathy, disseminated malignancy, lethal chromosomal abnormalities, severe irreversible brain injury)
3. CPR ongoing > 15 minutes with no return of spontaneous circulation (ROSC) or severely impaired perfusion.
4. Patient in Fulminant Disseminated intravascular
coagulation states.

**Special patient considerations:**
1. Untreatable underlying diseases and congenital malformations
2. Consider whether the patient is a candidate for heart transplantation on the first day of ECLS. The answer will set the goals and the time limitations for ECLS or other support systems.

**Types of ECMO:**
There are two major types of ECMO.
- Veno-venous or VV
- Veno -arterial ECMO (VA-ECMO): allows gas exchange and haemodynamic support while blood is pumped from the venous to the arterial side. VA ECMO provides both biventricular and pulmonary support.

**Circuit component:**

![Figure 1: Components of ECMO circuit](image1)

The components of an ECLS circuit, although based on the traditional cardiopulmonary bypass circuit, have been developed or adapted for long-term support.

1. Vascular cannulae: the cannula size chosen is dictated by the size and flow requirements of the patient and the size of the vessel(s) available for cannulation.
   - Cannulation is via the neck vessels up to age 2-3 years, beyond age 3 years- the neck or femoral vessels can be used.
2. A small drainage reservoir (bladder) helps to ensure continuous availability of blood for the pump.
3. Blood pump provides the blood flow through the circuit.

<table>
<thead>
<tr>
<th>Single Lumen Cannulation (VA or VA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Size (kg)</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3-6</td>
</tr>
<tr>
<td>6-8</td>
</tr>
<tr>
<td>8-14</td>
</tr>
<tr>
<td>15-20</td>
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<tr>
<td>20-30</td>
</tr>
<tr>
<td>30-40</td>
</tr>
<tr>
<td>&gt;40</td>
</tr>
</tbody>
</table>

Table 3. Selection of cannula sizes as per the weight of patient.

Two types of pumps are currently used for ECMO.
(a) The Roller pump is a traditional pump, a positive displacement pump in which a rotating roller head squeezes a length of blood filled tubing against a backing plate as the roller head rotates.
(b) The centrifugal pump is a non-occlusive pump that generates flow via a rotating impeller and has been used for long term support.

![Figure 2: Roller pump and centrifugal pump used in extracorporeal circulation](image2)

4. **An Artificial Lung (membrane oxygenator)**
   - It provides gas exchange, and it also has a heat exchanger which maintains a controlled temperature of re-infused blood.
   - The latest generation of artificial lungs is hollow-fiber oxygenators, constructed with polyethylene, which allows gas but not liquid transfer. Smaller than the old silicone membrane, they may cause less platelet consumption and provide more effective gas exchange. (Fig. 3 & 4)
5. Other circuit components allow for infusion of medications, incorporation of a hemofilter for fluid control, and monitoring systems for blood gas, flow, and pressure.

**Vascular access:**
All cardiac support ECMO circuits require veno-arterial access. There are three ways of achieving veno-arterial access for ECMO.

A. Chest cannulation is usually used when the patient cannot be weaned from cardiopulmonary bypass in the operating room. The right atrial and aortic catheters are used for ECMO access. (Fig. 5.A)

B. Neck cannulation: VA access through the internal jugular vein and carotid is used for children < 10 Kg because of the very small size of the femoral vessels in children who are not walking. (Fig. 5.B)

C. Femoral vessels: The femoral or iliac vessels are usually large enough to permit appropriate vascular access in children over 10-15 Kg of weight. Both the artery and vein will be occluded by the catheter, so provision must be made for perfusion of the leg distally. Venous collaterals are usually adequate to avoid excessive edema and venous congestion. (Fig. 6.A)

**Technical considerations:**
- Blood cannulae and sites of cannulation for good venous return are the life lines for ECMO. The cannulae for vascular insertion are wide bore cannulae, preferably with wire reinforcement. Cannulation can be done by any intensivist or surgeon with prior experience of inserting ECMO cannulae.
- Various techniques such as semi-seldinger, open or ultrasound guided methods can be used for cannulation.

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the vessel or atrial wall (if inadvertent pressure is used/misplacement) resulting in a cardiac tamponade, which should be promptly recognized and treated. Hence, cardiac surgeons should be readily available.

- At the time of cannulation, 75 to 100 units/kg heparin has to be given as a stat dose, depending on the clotting profile of the patient and maintained with hourly heparin infusion to keep ACT (Activated Clotting Time) within desired limits².

Patient specific issues for VA ECMO:

A. Patient unable to come off cardiopulmonary bypass in the operating room: Once it is clear that a patient cannot be weaned from CPB, despite appropriate pharmacologic measures, the decision to go to the ICU with ECMO support should be made sooner rather than later. The longer the patient is on CPB and high dose pressors, the greater the fluid overload, thrombocytopenia, metabolic acidosis, and risk of organ injury. Once the decision for ECLS has been made, the patient should be converted to the ECLS circuit and moved to the ICU (without prolonged attempts to stem bleeding in the operating room).

B. Myocarditis and Cardiomyopathy: The threshold for going on ECLS should be quite low because intractable arrhythmias or diastolic arrest can occur without warning.

C. ECPR in children: ECLS is a valuable adjunct to CPR if it is instituted early. Although CPR > 5 minutes is a general rule for a contraindication (because of the high likelihood of brain damage), if CPR is done successfully with evidence of good perfusion- longer periods of arrest may be considered as an indication.

D. Echocardiography: Following ventricular function by echocardiography is an essential adjunct to ECLS management for cardiac failure. During high flow VA ECLS, the heart will be relatively empty, so it is necessary to turn the flow down until the atria are appropriately filled in order to evaluate ventricular function.

- ECHO is the most valuable method to determine the extent of myocardial recovery. In addition, ECHO can help to identify the position of intravascular catheter, the status of valve and conduit function, and the presence of a clot in the cardiac chambers.

Cardiac Cath lab transport: Cardiac function can be effectively followed by echocardiography, but institutes where transport ECMO is feasible, cardiac catheterization should be done to measure pressures, flows, saturations etc².

F. Non-functioning ventricles: Because of left side venting, inotropes, pulsatility and clots in the heart, the left ventricle function is inadequate to open the aortic valve. In this case, left ventricular diastolic pressure and left atrial pressure will gradually increase during VA support because the left side of the heart fills with bronchial venous flow, thebesian flow and any right to left shunt. This will cause a gradual increase in left atrial pressure. When the left atrial pressure reaches >25 mm Hg, pulmonary edema will ensue. If the left ventricle is not emptying through the aortic valve the left side of the heart must be vented into the venous drainage of the ECLS circuit within a few hours.

G. Pulsatile flow: Pulsatility during VA perfusion is not important as long as the total perfusion is adequate (3 L/m2/min or higher, venous saturation > 75%).

Anticoagulation and Hemostasis:

1. Maintaining appropriate anti coagulation while on ECMO is one of the most crucial problems and bleeding and thrombosis (patient or circuit) events are very common.

2. Unfractionated heparin (UFH) is most commonly used for anticoagulation. Heparin acts by inhibiting anti-thrombin 3 and is the most commonly used drug for anti-coagulation on ECMO.

   a) Bolus heparin 50-100 unit/kg (maximum 5000 units) for cannulation as indicated.

   -Patients who are bleeding may require a smaller dose.

   b) Titrate heparin infusion to maintain desired
range as per institutional guidelines and per institutional specific assay for maintaining anticoagulation (10-30 units/kg/hr).

3. Common anticoagulation assays/levels used
   a) Activated Clotting Time (ACT): it is the assessment of whole blood clotting
      - Normal Values: 80-160 seconds
      - ECMO Values: 180-240 seconds
   b) Activated Partial Thromboplastin Time (aPTT): It is the assessment of intrinsic pathway.
      - Normal Values: 30-40sec
      - ECMO Values: 1.5 x normal
   c) Anti-Xa level- It is the assessment of clotting activity.
      - ECMO Values: 0.35-0.71 units/ml

4. Heparin Induced thrombocytopenia (HIT) is a rare but serious complication, a drop in platelet count by more than 50% of the highest previous values should raise suspicion of HIT and needs investigations.

**Monitoring on Cardiac ECMO:**

Figure 7. Veno-arterial access via the femoral vessels-
Extracorporeal blood flow in the aorta is retrograde and mixes with native blood flow in the proximal aorta. FiO2: fraction of inspired oxygen; P Plata-plateau pressure; PEEP: positive end-expiration pressure; P: pressure, V: volume; Vo2: oxygen uptake, Vco2: carbon dioxide uptake, Do2: oxygen delivery, SVR: systemic vascular resistance, PVR: pulmonary vascular resistance; BP: blood pressure; PAP: pulmonary arterial pressure; CO2: carbon dioxide; SvO2: mixed venous oxygen saturation; SaO2: oxygen saturation.

1. ECMO Flow:

<table>
<thead>
<tr>
<th>Age group</th>
<th>Flow</th>
<th>Target MAP and SvO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>100-120 ml/kg/min</td>
<td>MAP 45-60 and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SvO2&gt;65%</td>
</tr>
<tr>
<td>Infant</td>
<td>80-100 ml/kg/min</td>
<td>MAP 50-65 and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SvO2&gt;65%</td>
</tr>
<tr>
<td>Pediatric</td>
<td>60-80 ml/kg/min</td>
<td>MAP 60-80 and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SvO2&gt;65%</td>
</tr>
</tbody>
</table>

-Flow is usually ordered at 100ml/kg/min but titrate to normalize lactate, mean arterial pressure, capillary refill time.

2. ECMO Gases:
   - Sweep gas titrated as per arterial blood gas results to normalize pH/pCO2 in coordination with ventilator changes as appropriate.
   - The ECMO Sweep Gas is never to be turned off on VA ECMO.

3. ECMO membrane efficacy monitoring:
   - Post membrane O2
   - CO2 removal gradient
   - Pre-post filter blood flow pressure

4. Vasoactive agent:
   - Low dose epinephrine and dobutamine in order to facilitate aortic valve opening and prevent stasis of blood in systemic ventricle and aortic root.

5. Mechanical ventilator support: Minimal ventilator support to keep lungs open but not overdistended with the use of PEEP and low ventilator rate.

6. Evaluate for tissue perfusion and end organ dysfunction:
   a. Assess vital signs and hemodynamic status
   b. Assess laboratory studies:
      - ABG
      - Lactate
      - ScvO2
      - Hepatic function
      - Renal function
      - Hematologic studies (CBC, platelet, PT, PTT, fibrinogen, ATIII)
### Table 4. Systemic monitoring on ECMO:

<table>
<thead>
<tr>
<th>System</th>
<th>Monitoring</th>
</tr>
</thead>
</table>
| Neurological    | - Monitor pupil size and equality as well as pupillary response to light, level of consciousness (LOC) by using Glasgow coma scale  
                  - For neonates and infants, monitor anterior fontanel for size and fullness  
                  - Watch for any signs of seizure, electroencephalogram (EEG) monitoring if indicated, cerebral function monitoring (CFM), cranial ultrasonography, CT scan of the brain,  
                  - Near Infrared Spectroscopy (NIRS) are helpful                                                                                                        |
| Cardiovascular  | - Continuous cardiac monitoring  
                  - Frequent assessment of electrocardiogram (ECG) for rhythm, capillary refill time, peripheral pulses, central and peripheral color  
                  - Look for signs of edema                                                                                                                                  |
| Renal           | - Monitor strict input output balance  
                  - Oliguria and acute tubular necrosis (ATN) are common during the first 24 to 48 hours associated with capillary leak and intravascular volume depletion related to an acute inflammatory reaction from ECMO  
                  - Diuretic phase usually begins within 48 hours and is one of the earliest signs of recovery.  
                  - Hemofiltration or hemodialysis may be added to ECMO circuit if renal failure does not improve                                                               |
| Infection       | - CBC with differential count, CRP and Surveillance cultures  
                  - Usually indicators of sepsis are unreliable on ECMO since platelets are routinely destroyed by the circuit and temperature is controlled by the heat exchanger  
                  - Assess for signs of incisional and/or central access site infection  
                  - Antibiotics and fungal prophylaxis as per protocol  
                  - Early recognition of infection and treating with appropriate antibiotics is important.  
                  - Prevention of ventilator associated pneumonia is very important to minimize the duration spent on ECMO.  
                  - Consider early tracheostomy if prolonged ECMO is predicted.                                                                                              |
| Pain and Sedation| - Provide analgesia and sedation as appropriate to promote comfort & minimize stress (morphine/Fentanyl, benzodiazepines)  
                  - Avoid excessive movement which may result in cannula dislodgement or bleeding at the cannula site.  
                  - Minimize use of muscle relaxants to assess neurological status and promote spontaneous respiratory effort                                                                 |
| Family Education: | - Assess family’s level of education, readiness to learn and provide information as appropriate  
                  - Utilize resources for support including social work, child life, psychiatry and chaplaincy as appropriate                                                                 |
| Integument and Immobility | - Gentle change in position every 2 hours and prn as tolerated  
                  - Utilize pressure reducing surfaces as indicated (i.e. gel pads under infant’s head) & monitor for pressure ulcers  
                  - Utilize appropriate resources to manage cannulae and circuit during patient position changes  
                  - Maintain body alignment as indicated (and avoid neuropathy with femoral cannulation)                                                                 |
### Table 5: Complications and Troubleshooting on ECMO:

<table>
<thead>
<tr>
<th>Patient related Complications</th>
<th>Troubleshooting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannulation trauma</td>
<td>- Ultrasoundography should be used to monitor vessel size prior to percutaneous cannulation to aid in selecting appropriately sized cannulas and identifying abnormal venous anatomy prior to insertion.  - Fluoroscopy can help to identify aberrant guide wire placement and reduce the chance of vascular injury.</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>- ACT too high  - Heparin infusion too high  - Platelet count too low  - DIC, Infection, Trauma, Past invasive procedure</td>
</tr>
<tr>
<td>Hemolysis</td>
<td>- Plasma free hemoglobin &gt; 1000 mg/L.  - DIC  - Clot in circuit- check D-Dimer level  - High RPM, to achieve calculated flow  - Cannula too small for calculated flow  - Excessive negative pressures  - Raised PF(plasma free) HGB alone, change only Rotaflow  - Raised PF HGB and consuming coagulation factors (i.e. low fibrinogen level) change out whole circuit</td>
</tr>
<tr>
<td>Infection</td>
<td>- surveillance culture and optimize antibiotics</td>
</tr>
<tr>
<td>Ischemia of distal Limb</td>
<td>- Watch for loss of pulses, cyanosis and coolness of limb  - In the case of femoral cannulations, a dorsalis pedis (DP) or posterior tibial (PT) distal perfusion cannula can be placed to promote perfusion to the lower extremity</td>
</tr>
<tr>
<td>Accidental Decannulation</td>
<td>- Clamp lines immediately and notify physician  - Patient will need volume  - Infuse via venous manifold  - Re-establish ECMO ASAP</td>
</tr>
<tr>
<td>Renal failure</td>
<td>- Hypovolemia, Ischemic kidney damage, Low CO and/or pump flow, PDA, Excessive hemolysis leading to renal damage  - Dialysis (CRRT) can be integrated into the circuit</td>
</tr>
<tr>
<td>Hepatic/GI impairment</td>
<td>- supportive treatment</td>
</tr>
</tbody>
</table>

### Equipment related complications

| Power Failure                   | Equipment not plugged into wall or power source  - Emergency power not functioning |
| Pre-Membrane Pressure Increasing| Changes within membrane oxygenator  - suspect clot formation  - Inspect membrane with flashlight |
| Pre Membrane/ Post Membrane Pressure Increasing (Gradient Unchanged) | - Check circuit distal to membrane oxygenator  - Increased patient blood pressure  - Tubing kinked  - Check arterial cannula and cannulation site |
| Circuit Temperature Continually Reading Higher Than Set Point | - Ensure temperature probe isn’t broken  - Ensure external blower is ON |
| Inaccurate Flow Reading (Flow Has Drifted) | - Flow probe needs to be zeroed, if possible, daily  - check Flow probe is in the proper direction |
Decrease In Flow (Flow Rate Continues To Fall)

Check for:
- Hypovolemia
- Increased resistance in circuit
- Malpositioned cannula
- High HCT
- High patient pressure

Air In The Circuit

Air in membrane:
- air introduced during blood product/drug administration
- Air distal to membrane oxygenator:
  - this is an EMERGENCY, immediately clamp arterial line
  - take patient off ECMO and ventilate
  - Establish the source – air from membrane, cracked or broken stopcock, and loose connector

Oxygenator Failure “Falling arterial PaO2” “Rising arterial PaCO2”

- Rule out other sources (i.e. loose gas line, gas filter in proper direction, check circuit for kinks)
- Pre/post membrane pressure gradient narrows, could be clot formation
- WET lung
- If required to change oxygenator- call the Perfusionist

Table 6. Special Considerations:

**ECMO & Single Ventricle (SV) physiology:**

ECMO support for Norwood with modified Blalock Taussig Shunt (MBTS): Manage Qp:Qs
- Potential aortic run-off via BTS to pulmonary bed causing pulmonary over-circulation and inadequate systemic perfusion.

Manage by
- Maintain adequate systemic flow
- Minimize SVR
- Avoid excessive hypothermia
- Minimize high dose inotrope and vasoconstrictor agents
- Increase ECMO flow (>150 ml/kg/hour) as indicated
- Restriction of flow via MBTS with surgical clip(s) to MBTS as indicated.

ECMO support for Norwood with RV-PA conduit (“Sano” modification):
- Maintain adequate systemic flow
- Adequate decompression of ventricle
- Monitor for conduit patency (? thrombus or ischemia)

**ECMO support for cavo-pulmonary shunted patients:**

(A) Bidirectional Glenn (BDG):
- 2 venous cannulae required to maintain adequate flow and venous decompression
- Superior vena cava (SVC) decompression to avoid prolonged cerebral venous hypertension
- Inferior vena cava (IVC) decompression to avoid systemic venous hypertension
- Higher ECMO flow as indicated in the presence of aortopulmonary collaterals (APCs)

(B) Fontan:
- May require SVC and IVC cannulation for adequate flow and decompression of the venous system
- ECMO flow as indicated in presence of APCs

**Weaning:**

Return of pulsatile arterial flow as evidenced by an increase in pulse pressure is a sign of ventricular recovery. Once the decision to wean has been made, patient is fully ventilated and extra-corporeal flow is gradually reduced at discreet intervals over 4-8 hours with serial assessment of perfusion, myocardial function and gases until a terminal flow of 25% of full support is achieved.

Echocardiography allows serial non-invasive assessment of ventricular contractility and can assess the response to changes in ventricular loading that are associated with reduction in flow.
Terminal discontinuation/premature weaning from ECMO:
1. Excessive uncontrollable bleeding from multiple sites inspite of blood products
2. Massive Intracranial bleed (Neuroimaging if possible to transport or clinical diagnosis if not possible)
3. Brain death
4. Irreversible hepatic or renal failure
5. Futility of care- no change in cardiac function or deteriorating function in spite of a long run of ECMO-(3-4 weeks) with no possibility of a destination therapy (cardiac transplant or Ventricular assist devices) after counselling relatives. A systematic trial off ECMO can be attempted with high inotrope and ventilator support.

Decannulation:
Decannulation of venoarterial ECMO is a surgical procedure. Surgically placed cannulae are removed after partially withdrawing cannulae, proximally ligating the vessels and removing the cannulas. Removal of percutaneous arterial cannulae up to ~16 Fr can often be managed non-operatively, but larger cannulas may require arterial repair. There is a possibility of stricture or pseudo aneurysm formation at the site of arterial cannulation after repair1.

Neurological outcome:
The ELSO registry reported brain death in 7.3% of children above 1 year of age supported for cardiac failure. Seizures either clinically or electroencephalographically determined, were reported in 5.6% of cardiac cases above 1 year of age. CNS hemorrhage or infarct was reported in 3.5%-6% of cases23. Study examining long term outcomes has reported severe disability rates at 4%24. The result of neurological outcome at an advanced cardiac ECMO centre showed normal to mild neurological impairment in 81% of the surviving patients at the latest follow-up nearly 2 years after ECMO support, while 19% showed significant neurological impairment (including death). (Table 7) -The most significant parameters that appeared to increase risk for poor neurological outcome were presence of CPR, cerebral infarction or hemorrhage, and the use of plasma exchange.

Table 7: Neurodevelopmental outcomes25 in cases on Cardiac ECMO

<table>
<thead>
<tr>
<th>POPC scale at hospital discharge</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval time from ECMO, days</td>
<td>35 (18, 47)</td>
</tr>
<tr>
<td>Good, n (%)</td>
<td>39 (57)</td>
</tr>
<tr>
<td>Mild disability, n (%)</td>
<td>13 (19)</td>
</tr>
<tr>
<td>Mod disability, n (%)</td>
<td>12 (17)</td>
</tr>
<tr>
<td>Severe disability, n (%)</td>
<td>4 (6)</td>
</tr>
<tr>
<td>Coma or vegetative, n (%)</td>
<td>1 (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POPC scale at latest follow-up</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval time from ECMO, years</td>
<td>1.7 (1, 4)</td>
</tr>
<tr>
<td>Good, n (%)</td>
<td>42 (61)</td>
</tr>
<tr>
<td>Mild disability, n (%)</td>
<td>14 (20)</td>
</tr>
<tr>
<td>Mod disability, n (%)</td>
<td>6 (9)</td>
</tr>
<tr>
<td>Severe disability, n (%)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Coma, n (%)</td>
<td>0</td>
</tr>
<tr>
<td>Death, n (%)</td>
<td>6 (9)</td>
</tr>
</tbody>
</table>

The Pediatric Over-all Performance Category (POPC) scale which assess cognitive impairment and functional (general adaptive or physical) morbidity after critical illness or injury, respectively25.

Survival:
Approximately 17,000 patients from neonatal and Pediatric age group who have undergone extracorporeal life support have been reported to the ELSO registry as of January 2017 (Table.10.).Survival in Neonatal ECLS for cardiac failure is 64% with 40% surviving to hospital discharge, while Survival in Pediatric cardiac failure is 68% with 50% surviving to hospital discharge. ECPR has equal survival rate of around 40% and 41% respectively26. Single ventricular physiology has lower outcome in comparison to biventricular physiology on ECMO. (Table.8 and Table.10)
Table 8: ECMO survival of congenital heart disease in infants and children with corrective surgery

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Total reported</th>
<th>Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anomalous venous return repair (Age&lt;30days)</td>
<td>286</td>
<td>48</td>
</tr>
<tr>
<td>Common atrio-ventricular canal repair</td>
<td>66</td>
<td>41</td>
</tr>
<tr>
<td>BDG operation</td>
<td>95</td>
<td>31</td>
</tr>
<tr>
<td>Fontan operation</td>
<td>876</td>
<td>30</td>
</tr>
<tr>
<td>Stage 1 palliation (Norwood age &lt;30days)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data from Extracorporeal life support organization, International summary 2010.

Table 9: Congenital cardiac diagnosis, age groups and survival for cardiac ECMO

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>0–30days</th>
<th>31days–1year</th>
<th>1–16years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECMO runs (n)</td>
<td>Rate (%)</td>
<td>ECMO runs (n)</td>
</tr>
<tr>
<td>Left to right shunt</td>
<td>147</td>
<td>34</td>
<td>423</td>
</tr>
<tr>
<td>Left-sided obstructive lesions</td>
<td>279</td>
<td>29</td>
<td>153</td>
</tr>
<tr>
<td>Hypoplastic left heart</td>
<td>699</td>
<td>27</td>
<td>173</td>
</tr>
<tr>
<td>Right-sided obstructive lesions</td>
<td>123</td>
<td>42</td>
<td>73</td>
</tr>
<tr>
<td>Cyanotic with ↑↑ pulmonary blood</td>
<td>149</td>
<td>31</td>
<td>43</td>
</tr>
<tr>
<td>Cyanotic with pulmonary congestion</td>
<td>450</td>
<td>43</td>
<td>81</td>
</tr>
<tr>
<td>Cyanotic with ↓↓ pulmonary blood</td>
<td>366</td>
<td>39</td>
<td>152</td>
</tr>
<tr>
<td>Other</td>
<td>761</td>
<td>42</td>
<td>671</td>
</tr>
</tbody>
</table>

Table 10.

<table>
<thead>
<tr>
<th>Overall outcomes</th>
<th>Total runs</th>
<th>Survived ECLS</th>
<th>Survived to DC or transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonatal</td>
<td>29,942</td>
<td>25,205</td>
<td>84%</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>7,169</td>
<td>4,643</td>
<td>64%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>1,532</td>
<td>1,028</td>
<td>67%</td>
</tr>
<tr>
<td>ECPR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pediatric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>8,070</td>
<td>5,424</td>
<td>67%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>9,362</td>
<td>6,404</td>
<td>68%</td>
</tr>
<tr>
<td>ECPR</td>
<td>3,399</td>
<td>1,958</td>
<td>57%</td>
</tr>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>12,346</td>
<td>8,242</td>
<td>66%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>10,982</td>
<td>6,251</td>
<td>56%</td>
</tr>
<tr>
<td>ECPR</td>
<td>3,485</td>
<td>1,382</td>
<td>39%</td>
</tr>
<tr>
<td>Total</td>
<td>86,287</td>
<td>60,537</td>
<td>70%</td>
</tr>
</tbody>
</table>

Data from ECLS international registry, January 2017.
Conclusion / Summary:
ECMO should be considered to be an important and useful therapeutic modality for children with post-cardiotomy myocardial failure unresponsive to conventional medical management. Cardiac intensive care units wishing to offer post cardiac surgery ECMO support should develop standardized protocols that drives the process of ECMO care including anticoagulation management, management of ECMO complications, and ECMO weaning. It is also essential to build teams of well-trained cardiac surgeon, perfusionist, cardiologist and intensivist and dedicated ECMO personnel who are skilled at priming, maintaining and troubleshooting the mechanical aspects of ECMO circuit to improve outcomes for their cardiac ECMO patients. The results of patients who are put on ECMO are bound to improve with time our units will gain more experience in selecting patients and when we have better protocols applicable to our conditions. With the advancement of technology, next generation of equipment and access devices would make ECLS much simpler, safer, less complicated, and easier to manage in any ICU. We expect that the next decade will bring routine application of ECMO to all advanced ICUs where profound respiratory and cardiac failures are treated and also ECMO becomes a more affordable mode of supportive treatment in a developing country like ours.

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Source of Funding: None

References:
2. ELSO Pediatric Cardiac Failure Supplement to the ELSO General Guideline, December 2013-Version 1.3.


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