ECLS – Respiratory and Cardiac ECMO

Ann Karimova & Timothy Thiruchelvam July 2006
Updated by Ann Karimova, May 2009

Associated clinical guidelines/protocols:
- Comprehensive GOSH ECMO guidelines are available in the ECMO office.

Information for Year 1 ITU Training (basic):

<table>
<thead>
<tr>
<th>Year 1 ITU curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic principles of extra-corporeal membrane oxygenation (ECMO)</td>
</tr>
<tr>
<td>Common indications for ECMO</td>
</tr>
<tr>
<td>Common complications of ECMO</td>
</tr>
</tbody>
</table>

Curriculum Notes for Year 1:

1. DEFINITION AND AIMS OF ECMO

ECMO (extracorporeal membrane oxygenation) or ECLS (extracorporeal life support) are terms used for prolonged (days-weeks) but temporary mechanical support used for patients with respiratory or cardio-respiratory failure.

Aims of ECMO:
- To restore adequate oxygen delivery to vital organs in the situations where all appropriate conventional therapies have failed.
- To provide time and optimal conditions for lung and/or heart recovery. In this sense it is vital that patient disease/condition leading to use of ECMO is reversible within the time frame offered by ECMO.

2. HISTORY OF ECMO

The history and evolution of mechanical support is integral to the history of cardiopulmonary bypass. In the 1960’s, it has been demonstrated that extracorporeal devices could be used to support patients for several days outside the operating theatre. In 1972, Hill’s group reported the first adult Extracorporeal Membrane Oxygenation (ECMO) survivor. In 1976, Bartlett et al. reported the first neonatal ECMO survivor, who was appropriately named Esperanza (“Hope”). Following this, there was a proliferation of the use of ECMO for a variety of conditions leading to refractory cardiorespiratory failure.

In 1989, over one hundred ECMO centres from around the world established the Extracorporeal Life Support Organisation (ELSO) as a platform for communication and research in extracorporeal support. Today, there are over 30,000
patients on the registry with an overall survival to hospital discharge rate of 65% (ECMO registry 2006).

Fig 1. Three basic ELSO categories (neonatal, pediatric and adult ECLS) with patient outcomes (ELSO registry, Jan 2009)

### Overall Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Total Patients</th>
<th>Survived ECLS</th>
<th>Survived to DC or Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonatal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>22,867</td>
<td>19,411</td>
<td>85%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>3,609</td>
<td>2,122</td>
<td>59%</td>
</tr>
<tr>
<td>ECPR</td>
<td>444</td>
<td>279</td>
<td>63%</td>
</tr>
<tr>
<td>Pediatric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>3,995</td>
<td>2,570</td>
<td>64%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>4,377</td>
<td>2,694</td>
<td>62%</td>
</tr>
<tr>
<td>ECPR</td>
<td>825</td>
<td>429</td>
<td>52%</td>
</tr>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>1,558</td>
<td>932</td>
<td>60%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>979</td>
<td>473</td>
<td>48%</td>
</tr>
<tr>
<td>ECPR</td>
<td>340</td>
<td>124</td>
<td>36%</td>
</tr>
<tr>
<td>Total</td>
<td>38,994</td>
<td>20,034</td>
<td>74%</td>
</tr>
</tbody>
</table>

3. BASIC PRINCIPLES OF ECMO

In **V-A ECMO** both lungs and heart are by-passed and their function (i.e. both circulation and gas exchange) partially or fully taken over by ECMO.

In **V-V ECMO** only lungs are by-passed (i.e. only gas exchange is provided by ECMO); circulation relies on native heart function.

Four principal parts of ECMO circuit are: 1) venous cannula draining blood from the patient into the venous limb; 2) pump (roller or centrifugal); 3) membrane oxygenator with heater and 4) arterial limb connecting to arterial cannula for return into the patient (for details of the ECMO circuit see Fig 2).

Fig 2: Diagram of ECMO circuit:

**ECMO circuit:**
1. Mixed venous O₂ Sat probe
2. Blood sampling pigtail
3. Heparin infusion/ venous pressure monitoring pigtail
4. Bladder reservoir
5. Roller pump
6. Membrane oxygenator with pre/post-membrane pressure monitoring pigtails / heater
7. Gas blender
8. Pigtail for blood sampling/clotting products and platelets transfusions
9. Bridge (allows recirculation when patient clamped off)
Hemofilter can be added into the circuit to run on pressure gradient from 8. to 4.

4. NEONATAL RESPIRATORY ECMO

By far the largest and most successful single group of patients supported on ECMO is neonates with acute hypoxemic respiratory failure with an overall survival to hospital discharge rate of 80%. It is also worth noting; that this is the only group of ECMO patients who have been subjected to a rigorous randomized controlled trial (UK ECMO trial, 1996). This conclusively showed a survival and long-term morbidity benefit at 4 years follow-up in babies treated with ECMO (60% survival) compared to those who received conventional treatment (+ 30% survival).

The principal diagnostic categories for neonatal ECMO are show in Fig 3.

Fig 3: (from ELSO registry Jan 2009):

<table>
<thead>
<tr>
<th>Neonatal Respiratory Runs by Diagnosis</th>
<th>Total Runs</th>
<th>Avg Run Time</th>
<th>Longest Run Time</th>
<th>Survived</th>
<th>% Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDH</td>
<td>5,721</td>
<td>246</td>
<td>1235</td>
<td>2,945</td>
<td>51%</td>
</tr>
<tr>
<td>MAS</td>
<td>7,438</td>
<td>130</td>
<td>936</td>
<td>6,965</td>
<td>94%</td>
</tr>
<tr>
<td>PPHN/FHC</td>
<td>3,721</td>
<td>140</td>
<td>1,176</td>
<td>2,860</td>
<td>78%</td>
</tr>
<tr>
<td>RDS</td>
<td>1,470</td>
<td>135</td>
<td>1,003</td>
<td>1,240</td>
<td>84%</td>
</tr>
<tr>
<td>Sepsis</td>
<td>2,580</td>
<td>139</td>
<td>1,200</td>
<td>1,932</td>
<td>75%</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>315</td>
<td>220</td>
<td>936</td>
<td>183</td>
<td>58%</td>
</tr>
<tr>
<td>Air Leak Syndrome</td>
<td>116</td>
<td>167</td>
<td>856</td>
<td>86</td>
<td>74%</td>
</tr>
<tr>
<td>Other</td>
<td>1,804</td>
<td>174</td>
<td>1,131</td>
<td>1,140</td>
<td>63%</td>
</tr>
</tbody>
</table>

Run time in hours. Survived = survival to discharge or transfer based on number of runs

The patient selection criteria for neonatal ECMO are:

a) Newborn > 35 weeks of gestation
b) Severe hypoxic respiratory failure with OI >40 despite maximum conventional treatment (usually including trial of HFOV, surfactant, iNO)
c) Ventilation pre-ECMO <10 days
d) No irreversible organ dysfunction (i.e. severe hypoxic-ischemic encephalopathy)
e) No contraindication to systemic anticoagulation (i.e. intracranial hemorrhage)

Two most frequent indications for neonatal respiratory ECMO (MAS and CHD) will be discussed in the next section:

ECMO & Meconium Aspiration Syndrome
- Patients with MAS are “ideal” candidates for ECMO (i.e. term babies, have reversible lung condition, need lung rest); this is supported by mortality, morbidity and cost effectiveness data from UK ECMO trial.
- ECMO will: a) break the vicious cycle of hypoxia/acidosis - treat pulmonary hypertension; b) allow reduction of the ventilatory settings to “resting settings” (it is the ultimate lung protective strategy…)
- V-V ECMO is the method of choice and inotropes are not contraindication to it
- V-A ECMO only if V-V impossible (failure to cannulate or extreme hemodynamic instability)
- ECMO survival to home discharge for MAS > 90%.
ECMO & Congenital Diaphragmatic Hernia

- Patients with CHD are *controversial candidates* for ECMO (at least in my view) because: a) it is difficult/impossible to identify patients with fatal degree of lung hypoplasia; b) there is no randomized trial supporting the advantage of ECMO use in CHD.

- ECMO will: a) allow time for adaptation of pulmonary circulation; b) allow reduction of the ventilatory settings to “resting settings”

- While criteria by which to predict fatal lung hypoplasia are lacking, our practice is to offer ECMO to patients with OI 25-40 or with severe barotraumas/air leak.

- V-V ECMO (as opposed to V-A) is increasingly used with survival rates comparable to V-A; V-V is the current mode of choice. Note: CHD patients tend to have small neck vessels- cannulation with double lumen V-V may sometimes be difficult.

- Current trend is for delayed CHD repair – in our practice after decannulation (practice varies, in some centers the repair is performed on ECMO).

- ECMO survival to home discharge for patients with CHD is 50-60% with significant late morbidity and mortality (neurodevelopmental delay, respiratory and gastrointestinal problems).

5. PEDIATRIC RESPIRATORY ECMO

As shown below, there is large spectrum of diagnosis leading to acute hypoxic respiratory failure in children.

Fig 4: Pediatric respiratory ECMO (ELSO Jan 2009)

<table>
<thead>
<tr>
<th>Pediatric Respiratory Runs by Diagnosis</th>
<th>Total Runs</th>
<th>Av. Run Time</th>
<th>Longest Run Time</th>
<th>Survived</th>
<th>% Survived</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viral pneumonia</td>
<td>908</td>
<td>321</td>
<td>1372</td>
<td>576</td>
<td>63%</td>
</tr>
<tr>
<td>Bacterial pneumonia</td>
<td>452</td>
<td>273</td>
<td>1332</td>
<td>255</td>
<td>56%</td>
</tr>
<tr>
<td>Pneumocystis pneumonia</td>
<td>28</td>
<td>378</td>
<td>1144</td>
<td>13</td>
<td>46%</td>
</tr>
<tr>
<td>Aspiration pneumonia</td>
<td>194</td>
<td>271</td>
<td>2437</td>
<td>127</td>
<td>65%</td>
</tr>
<tr>
<td>ARDS, postop/trauma</td>
<td>98</td>
<td>233</td>
<td>871</td>
<td>59</td>
<td>60%</td>
</tr>
<tr>
<td>ARDS, not postop/trauma</td>
<td>394</td>
<td>303</td>
<td>1987</td>
<td>194</td>
<td>53%</td>
</tr>
<tr>
<td>Acute resp failure, non-ARDS</td>
<td>720</td>
<td>245</td>
<td>1483</td>
<td>358</td>
<td>50%</td>
</tr>
<tr>
<td>Other</td>
<td>1,301</td>
<td>202</td>
<td>2230</td>
<td>665</td>
<td>51%</td>
</tr>
</tbody>
</table>

Run time in hours. Survived = survival to discharge or transfer based on number of runs. The average survival for this ECMO category is between 50 to 60%.

The general principles of patient selection are similar as for other ECMO patients: the pathology must be regarded as *reversible* and the patient must not have suffered from any complication that would be a contraindication to continuation of intensive care.

As in neonates, V-V ECMO is increasingly being used in children.

6. CARDIAC ECMO

Infants and children with intractable cardiac failure are presently the fastest growing group of patients, supported on mechanical assist devices.

As in respiratory ECMO the *primary aim of cardiac mechanical support* is to restore adequate oxygen delivery to vital organs. *Secondary aim* is to provide time and conditions for myocardial recovery: it is important, that the affected ventricle is off loaded, with reduced ventricular wall stress, reduced myocardial oxygen consumption and adequate coronary perfusion. In circumstances where there is
failure of myocardial recovery over an expected time course of days to weeks, the aim of mechanical support may change from recovery to a bridge to heart transplantation. Mechanical support as a destination therapy is currently not available for children.

**Device choice for cardiac ECMO:**
This part will focus on ECMO as the main mode of cardiac support, although a variety of other mechanical assist devices are available for cardiac mechanical support. **Selection of the appropriate mechanical assist device is determined by the a) size of the patient, b) the indication for support, c) the pathophysiology of the underlying disease, d) the predicted length of time for which the support will be needed (bridge to recovery or transplantation) and e) the availability of different devices in various institutions. The two most common modes of short-term cardiac support used in infants and children are ECMO and centrifugal VADs.**

ECMO remains the mainstay of mechanical cardiac support. The advantage of ECMO over other assist devices is that it can be used to support patients with biventricular failure as well as patients with associated respiratory failure and refractory pulmonary hypertension. The limitation of ECMO is that it can support patients only for several weeks (in our experience maximum 4-6 weeks); the incidence of complications, particularly infection, increases with time. Survival to discharge rates of patients treated with ECMO for short-term cardiac support range from 40% (post-cardiotomy ECMO) to 70% (ECMO for myocarditis) depending on the patient’s diagnosis and underlying pathophysiology.

The other device that can be used for short-term circulatory support is non-pulsatile centrifugal ventricular assist device (VAD). The advantage of using nonpulsatile VADs over ECMO is the simplicity of the circuit, better decompression of the supported ventricle, no need for the oxygenator, lower level of anticoagulation required and probably also lower staff-patient ratios. VAD is unsuitable for patients with refractory respiratory failure (no oxygenator in VAD circuit), with large intracardiac shunt and with pulmonary hypertension. This type of support would be typically used for patients with uni-ventricular failure: left ventricular failure following repair of anomalous origin of left coronary artery from the pulmonary artery or late arterial switch operation and right ventricular failure secondary to pulmonary hypertension post heart transplantation.

**Fig 5: Diagram of extracorporeal VAD circuit**

VAD circuit:

1. Blood sampling pigtail/venous pressure monitoring
2. Pump
3. Bridge (allows recirculation when patient clamped off)
For longer term mechanical support there are a variety of devices ranging from paracorporeal devices (Berlin Heart Excor, Medos HIA,) to implantable impeller pumps (DeBakey pump). The device that is used most commonly in infants and children is Berlin Heart Excor VAD. Bh Excor is paracorporeal, pneumatically driven pulsatile device that can provide right, left or biventricular support. The system consists of: a) air driven blood pump, b) cannulae which connect the pump device to the heart chambers and great vessels and c) mobile driving unit.

Fig 6: Berlin Heart Excor Bi-VAD set up:

Fig 7: Berlin Heart Excor pump:

The advantages of VAD compared to ECMO:

a) BH Excor L-Vad offers full decompression of the LV (left sided decompression is sometimes difficult on ECMO).
b) BH Excor offers much longer support time (months), therefore suitable for bridging to transplantation.
c) Patient on BH Excor can be extubated, de-intensified, mobilised and discharged to cardiology ward.

The disadvantages of BH Excor VAD compared to ECMO:
a) BH Excor requires implantation in the operating room with cardiopulmonary bypass. Therefore cannot be deployed at emergency on CICU.
b) BH Excor is not suitable for patients with severe lung disease.
GOSH BH experience is: 18 patients bridged to transplantation to date (Feb 2009); with survival to transplant 78% (4 died).

**Indications for cardiac ECMO.**

**A) Patients with cardiac failure following open-heart surgery**
- It is vital to identify any potentially correctable residual anatomical lesion as the contributory cause of patient’s circulatory failure!!!
- In terms of univentricular versus biventricular anatomy as an indication for mechanical support, there is increasing evidence that patient’s outcome is related more to the potential reversibility of myocardial dysfunction rather than the underlying cardiac anatomy. Thus, patients with single ventricle physiology and other complex heart lesions are now readily supported, provided the cardiac lesions are deemed operable.

**B) Medical patients with cardiac failure due to spectrum of diseases** including myocarditis, cardiomyopathy, pulmonary hypertension, arrhythmias, events related to cardiac catheterization and infants who decompensate prior to surgery.

**When to go on**
Unfortunately, there is no easy formula for predicting severity of illness and patient’s outcome as there is for respiratory ECMO using the oxygenation index. When choosing the optimal time to initiate mechanical support, one has to balance the risks of waiting too long and the patient suffering severe end-organ injury versus the risks inherent in an invasive treatment such as ECMO. Practice varies widely between different institutions in terms of the optimal timing of starting mechanical support.

**Fig 5: Comparison between ECMO and nonpulsatile centrifugal VAD and pulsatile VAD.**

<table>
<thead>
<tr>
<th></th>
<th>ECMO</th>
<th>Centrifugal VAD (Biomedicus)</th>
<th>Pulsatile VAD (Berlin Heart or Thoratec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygenator</td>
<td>Yes</td>
<td>No (can be inserted)</td>
<td>No</td>
</tr>
<tr>
<td>Circuit</td>
<td>Longer, with reservoir</td>
<td>Simple, short, no reservoir</td>
<td>Simple, short, no reservoir</td>
</tr>
<tr>
<td>Anticoagulation</td>
<td>ACT 180-200</td>
<td>ACT160-180</td>
<td>APTT twice normal Plat function tests Aspirin/Warfarin/LMWH</td>
</tr>
<tr>
<td>Potential for Air Embolus</td>
<td>Low (air trapped in circuit)</td>
<td>Higher, particularly with L-VAD</td>
<td>Higher, particularly with L-VAD</td>
</tr>
<tr>
<td>Type of Support</td>
<td>Cardiorespiratory</td>
<td>Uni/bi-ventricular, respiratory possible</td>
<td>Uni/bi-ventricular: no respiratory</td>
</tr>
<tr>
<td>Ventricular Decompression</td>
<td>Sometimes difficult (May need atrial septostomy/ LA vent)</td>
<td>Usually via direct drainage cannula in LA or LV apex</td>
<td>Usually via direct drainage cannula in LV apex</td>
</tr>
<tr>
<td>Length of support</td>
<td>Days to several weeks</td>
<td>Days to several weeks</td>
<td>Several weeks to months</td>
</tr>
<tr>
<td>Cannulation</td>
<td>Trans-thoracic or neck</td>
<td>Always trans-thoracic</td>
<td>Always trans-thoracic</td>
</tr>
</tbody>
</table>
In most centers post-operative mechanical support is initiated in patients with *worsening signs of inadequate oxygen delivery* (rising lactate, falling mixed venous oxygen saturation, wide core-peripheral temperature gap, poor urine output and other signs of end-organ ischaemia) despite appropriate vasoactive medical management. Because of the concerns of myocardial damage associated with high doses of epinephrine and to avoid organ damage from periods of low cardiac output there is a trend towards a pre-emptive, earlier institution of mechanical support in patients not responding to conventional treatment. Our policy is to consider mechanical support in patients who continue to deteriorate with signs of LCOS despite increasing inotropic support (epinephrine dose approaching 0.3mcg/kg/min).

In myocarditis/cardiomyopathy patients the same principles to when to go on ECMO apply as to post-cardiotomy patients. Occurrence of arrhythmias, intolerance of enteral feeding and oliguric renal failure are often ominous signs and a preemptive, semi-elective initiation of mechanical support may be warranted.

Some North American centres advocate an *elective use of ventricular assist support* for all patients after the *Norwood stage 1 operation*. This is based on the premise that ensuring adequate cardiac output and thus cerebral perfusion during the first forty-eight hours after surgery will protect these patients against the known long term high risks of neurological morbidity. Preliminary reports have suggested an 80% survival to discharge in this group of patients, which is in fact comparable to centres not using mechanical support after the Norwood stage1 operation. Whilst there does not appear to be a short-term survival benefit using this strategy, the results of long-term neurological follow-up are awaited.

The *general contraindications* to ECMO initiation for cardiac patients are the same as for respiratory ECMO:
- a) no irreversible organ dysfunction (i.e. severe hypoxic-ischaemic encephalopathy)
- b) no contraindication to systemic anticoagulation.

From a practical point of view, it is often impossible in the emergency setting to adequately assess the patient’s cerebral function. In this circumstance the patient is given the benefit of doubt and the neurological function tests are carried out as soon as feasible on mechanical support. The wishes and expectations of the patient’s family should always be taken into consideration.

Controversy exists as to the prognostic significance of the need to place patients on ECMO directly from cardiopulmonary bypass as opposed to the need to initiate ECMO in the intensive care. In our experience there was a survival benefit for those patients who went on ECMO directly from cardiopulmonary bypass (this may be related to the fact that these patients avoided the ill effects of prolonged low cardiac output state prior to the institution of mechanical support). Other centers have reported increased mortality and morbidity (bleeding complications) in those patients who failed to separate from cardiopulmonary bypass.

<table>
<thead>
<tr>
<th>Patient mobility</th>
<th>No</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>High</td>
<td>Lower</td>
<td>V high</td>
</tr>
<tr>
<td>Paediatric Experience</td>
<td>Large</td>
<td>Growing</td>
<td>Limited, though increasing</td>
</tr>
</tbody>
</table>
ECPR
There are now several reports on use of ECMO during or shortly after cardiac arrest. The reported outcomes of these patients are encouraging, with survival rates of around 40%. Several of these patients have suffered prolonged arrests of up to 60 minutes with apparently intact neurological survival.

However, in most circumstances an anticipatory strategy choosing the optimal time to initiate ECMO support is preferable!

Information for Year 2 ITU Training (advanced):

<table>
<thead>
<tr>
<th>Year 2 ITU curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Principles of extra-corporeal membrane oxygenation (ECMO): VV and VA</td>
</tr>
<tr>
<td>- Complications of ECMO</td>
</tr>
<tr>
<td>- Outcome of various patient groups.</td>
</tr>
</tbody>
</table>

Curriculum Notes for Year 2:

PRACTICAL ASPECTS OF ECMO

Cannulation:
Veno-arterial ECMO in children can either be instituted via cannulation of the neck vessels (right common carotid artery and right internal jugular vein + an additional femoral venous cannula) or cannulation via a median sternotomy, usually through the operative site. In patients who fail to wean from cardiopulmonary bypass and are placed directly on ECMO in theatre, cannulation is usually achieved using the bypass cannulae in the aorta and the right atrium with most patients also requiring an additional left atrial vent for decompression. The same would apply for post-cardiotomy patients requiring urgent cannulation in cardiac arrest or near arrest situation in the intensive care unit, as this would be the quickest way to deliver mechanical support. However, if time permits, and there are no contraindications to neck cannulation, then this is probably the preferred site of cannulation as it reduces the risk of bleeding and sepsis.

In cardiac ECMO It is vital to decompress the left heart, particularly where there is marked left ventricular impairment and failure of aortic valve to open. In this circumstance the left atrial pressure is likely to be very high (above 30 mm Hg), causing lung congestion. A high left ventricular end-diastolic pressure is also likely to increase ventricular wall stress and impair coronary perfusion. The decompression of the left heart can be achieved either by creating an atrial communication in catheter lab or by direct placement of left atrial vent.

For the neonatal veno-venous ECMO double lumen venous cannula is inserted (by the surgeon) into internal jugular vein.

Anticoagulation and management of bleeding:
Heparin infusion is used for anticoagulation on ECMO with target ACT (activated clotting time) 180-200.

Excessive bleeding is one of the most common complications of ECMO (mainly post-op cardiac).

The management of post-cardiotomy bleeding in our practice involves:
- Aggressive correction of any coagulopathy (maintaining platelet count >100 000, and fibrinogen >2 g/l)
- Maintaining the activated clotting time (ACT) in the range of 160 to 180 seconds
- Administration of anti-fibrinolytic agents such as Aprotinin
- Chest re-exploration for significant ongoing bleeding (>10 ml/kg/hr) despite correction of the patient’s coagulopathy and the above mentioned manoeuvres
- Conversion of chest to neck cannulation if applicable
- Use of recombinant activated Factor VII
- Using a blood cell-saver
- If the bleeding continues, running the circuit heparin free for a period of 4 to 6 hours until the bleeding is controlled. In this situation a spare primed ECMO circuit should be readily available on stand-by in case of major clotting.

**Determining adequacy of ECMO**

The usual markers of end-organ perfusion should be used to assess the adequacy of extracorporeal support. These include serial measurements of acid base status, lactate and mixed venous oxygen saturation as well as urine output. Although there is insufficient knowledge about optimal ECMO flows (usually between 100-200 ml/kg/min), it seems logical that the lowest ECMO flow, that provides satisfactory oxygen delivery (and ventricular decompression), should be used.

In circumstances where there is deemed to be inadequate systemic oxygen delivery, the haematocrit should be optimised to 40% and the blood leaving the oxygenator should be checked to be fully saturated. The use of ultrasonic measurements of blood flow on the arterial limb of the ECMO circuit distal to the bridge serves as a useful guide to the actual blood flow. In a situation, where one does not have a device to measure the actual flow, it should be always checked that the roller pump occlusion is appropriate and that the bridge is fully clamped. If the patient continues to have signs of inadequate end organ perfusion despite the above manoeuvres then the pump flow should be increased to meet the patient's metabolic demands. In the rare situation, where very high flow, i.e. >200 ml/kg/min, is not able to achieve adequate end organ perfusion, reducing the patient's metabolic demand by cooling the patient to 34 degrees C can be considered. Generous use of vasodilators to optimize perfusion, to control hypertension and to reduce afterload is frequently necessary on ECMO. The afterload reduction and maintenance of optimal volume status (right atrial pressure > 5 mmHg) are of a key importance when centrifugal pump is used.

**Patient management on ECMO**

Patients should be managed in the most physiological manner possible, i.e.: enteral feeding (unless contraindicated because of gut ischaemia), minimally sedated to keep patient comfortable and safe, and parents should be encouraged to participate in their child’s bedside cares.

**Ventilation** on ECMO is usually maintained on “resting” settings of tidal volumes of 5 to 10 ml/kg (max. peak inspiratory pressure 20-25 cm H2O), PEEP 7-10 cm H2O, ventilator rate of 10-20 per min and FiO2 0.21%. In cardiac ECMO the FiO2 on the ventilator is set at 40% in order to avoid pulmonary venous desaturation. Note, that in contrast to ECMO, full ventilation is mandatory in patients on VAD. Although antibiotic cover is not routinely necessary for patients on ECMO, it is common practice to perform daily blood cultures and treat any new infection aggressively.

**Weaning from ECMO**

Difference between V-V and V-A ECMO weaning: On V-V ECMO weaning is achieved by weaning the ECMO blender gases (FiO2 and sweep gas =CO2 clearance). On V-A ECMO weaning is achieved by weaning the ECMO flow; once
minimal flow is achieved, the patient is clamped off ECMO (and the blood left to re-
circulate across the bridge) for trial period of 1-2 hours. If the patient remains stable
during “trial of ECMO period”, decannulation is performed.
Finding the optimal time for weaning the patient of ECMO is one of the greatest
challenges of ECMO management.

In respiratory ECMO the duration of anticipated recovery on mechanical support
depends on the underlying pathophysiology (for instance: it is unlikely that patient
with severe ARDS will come off ECMO in first 7 days). Improvement in lung
compliance and gas exchange together with improvement on CXR are the indicators
of recovery. For trial off ECMO the patient is analgosedated (and paralysed -at least
for the decannulation) and full ventilation started (with or without iNO, inotropes).
After trial period of 1-2 hours the patient can be decannulated.

In cardiac ECMO it is usual practice to rest the patient on full ECMO support for 48-
72 hours. After this time, a “stress test” is performed on an infusion of inotropes
(usually adrenaline or dopamine in combination with milrinone): the left atrial vent (if
present) is clamped off and the ECMO flow is gradually reduced over a period of 1-2
hours until the lowest safe flow is achieved (usually around 100-300 ml/minute). If
flow reduction is successfully achieved without haemodynamic compromise, the
patient is clamped off ECMO support. The echocardiogram is useful in this setting to
assess ventricular function as well as to check for any undiagnosed lesions,
pulmonary hypertension, regional wall dyskinesis, pericardial effusions or any other
complication. If the patient is deemed to have failed the trial off ECMO, as indicated
by unstable haemodynamics and/or signs of inadequate tissue oxygen delivery, then
the patient should be reinstated on full ECMO support. It is advisable to wait a further
48 hours before the next trial of weaning from ECMO to allow a decent period of time
for further ventricular rest and recovery.

When to stop (how long is long enough?)

Respiratory ECMO:
As the scientific information about the necessary time for lung recovery is lacking, it
is our practice to support the respiratory patients with ECMO until the diagnosis of
irreversible/fatal lung disease is made or the patient develops serious/fatal
complication. CT scan on ECMO can be very helpful in obtaining more detail
information about the lungs.
Lung biopsy in patients on ECMO can be of great help when deciding about the
disease stage and reversibility (irreversible lung necrosis pertussis) or even making
the diagnosis (alveolocapillary dysplasia), however the expected benefit must be
judged against the high risk of severe bleeding.

Cardiac ECMO:
In post-cardiotomy patients, where the pathology is essentially post-operative
myocardial stun, some improvement of ventricular function should be evident within
72-96 hours of support and if there are no signs of ventricular recovery by this time,
then these patients should be considered for early listing for transplantation. The
timing for listing will also depend on organ availability. The issue when to stop
mechanical support in patients, who fail to show signs of effective ventricular
recovery and who are not suitable for transplantation, is understandably emotive.
Most survivors are on ECMO for periods of 5-10 days. Recovery is thought to be less
likely beyond 10 days in this patient group. It is our current policy to withdraw
mechanical support if there are no signs of recovery of ventricular function after 14
days of support and the patient is not a candidate for heart transplantation. In
patients with myocarditis one would anticipate adequate ventricular recovery,
sufficient for a trial of weaning from mechanical support within a 10-14 day period. If weaning fails, and the patient remains a candidate for heart transplantation, then mechanical support should be continued as a bridge to transplant for as long as the patient remains a transplant candidate. However, availability of the appropriate mechanical support device for the anticipated long waiting time becomes a limiting factor. Some patients with cardiomyopathy have demonstrated an improvement in ventricular function sufficient to wean off ECMO over a 1-3 week period of support. These patients require very close follow up and often remain listed for transplantation.

**Other sources of information:**

**Websites.**
http://www.ich.ucl.ac.uk/ecmo/
http://www.elso.med.umich.edu/

**References:**
See reading material