The Royal Children's Hospital

Melbourne, Australia

Victorian Paediatric Cardiac Surgical Unit

Perfusion Unit:

Extracorporeal Membrane Oxygenation Protocol

EXTRA-CORPOREAL MEMBRANE OXYGENATION - ECMO

CONTENTS

SELECTION CRITERIA

* The acute cardio/pulmonary disease must be reversible.
* Exclusion of a pre-existing major handicap (a handicap associated with the need for dependent care).
* Able to achieve a normal quality of life with no major handicap resulting from the disease.
* Likely to die (predicted 80% mortality).

FOR NEWBORNS

Oxygenation Index > 0.4 for 4 hr $OI = \frac{MAP \times FiO_2}{PaO_2}$

MAP = mean airway pressure
FiO_2 = % oxygen used for ventilation
PaO_2 = oxygen content of arterial blood

Ventilation Index > 90 for 4 hours $VI = \frac{RR \times PIP - PEEP}{1000}$

RR = respiratory rate
PIP = peak inspiratory pressure
PEEP = peak end expiratory pressure
CO_2 = carbon dioxide content of arterial blood

FOR CHILDREN

Ventilation Index > 40 and Oxygenation Index > 0.4 for 4 hours

Other Relative Indications Include

* Failure to respond to maximum inotropic treatment
  Adrenalin > 4 ucg/kg/min
  Dopamine or Dobutamine > 20 ucg/kg/min
* Failure to wean from cardiopulmonary bypass after corrective cardiac surgery
* Cardiac arrest
* Cardiac shock
* Bridge to transplant
* Barotrauma ie. PIE, PT, emphysema, elevated mean airway pressure
* Sepsis

ECMO PRIMING AND FLOW CALCULATIONS

1. SURFACE AREA (Uses the formula of DuBois)

HEIGHT (cm.)
WEIGHT (kg.) > SURFACE AREA (Sq.M)

2. FLOW

a) Patients under 10 kg: Flow = weight x 150 ml/min/kg

Eg. 3.5 kg
55 cm > Surface area = 0.23 Sq.M.

Flow = 3.5 kg x 150 ml/min/kg = 525 ml/min

b) Patients over 10 kg: Flow = 2400 ml/Sq.M./min

Eg. 20 kg
110 cm > Surface area = 0.80 Sq.M.

Flow = 2400 ml/Sq.M/min x 0.80 Sq.M. = 1920 ml/min

3. PATIENT BLOOD VOLUME

This parameter is age dependent and is only approximate.

a)	0	-	6 months	=	100 ml/kg
b)	6 months	-	18 months	=	90 ml/kg
c)	18 months	-	and older	=	80 ml/kg

EQUIPMENT USED

* Biomedicus Bioconsole or Jostra RFC centrifugal pump console
* Jostra RotaFlow RF-32 Pump Head
* Biomedicus Flow Probe when Biomedicus Bioconsole is used.
* PVC Tubing
* Jostra Quadrox D oxygenator
* Cincinnati Sub Zero ECMO Water Bath or Cincinnati Sub Zero Micro-Temp II Heat Therapy Pump
* Sechrist Air Oxygen Blender
* ECMO or Percutaneous Cannula (Biomedicus, Baxter, Jostra or RMI)

OXYGENATOR	BLOOD FLOW	PUMP HEAD
QUADROX	200 - 7000ml	Jostra RF-32

EXTRA-CORPOREAL LIFE SUPPORT - CANNULA SIZES

1. ARTERIAL

Flow (ml/min)			Size (FR)	External Diameter (mm)
0	to	400	8	2.66
400	to	700	10	3.33
700	to	1200	12	4.00
1200	to	1700	14	4.66
1700	to	2000	15	5.00
2000	to	2500	17	5.66
2500	to	3500	19	6.33
3500 ->			21	7.00

2. VENOUS

FLOW (ml/min)			Size (FR)	External Diameter (mm)
0	to	350	8	2.66
350	to	600	10	3.33
600	to	1000	12	4.00
1000	to	1400	14	4.66
750	to	1000	15	5.00
1000	to	1500	17	5.66
1500	to	2000	19	6.33
2000	to	2500	21	7.00
2500	to	000	23	7.66
3000	to	3600	25	8.33
3600	to	4500	27	9.00
4500 ->			29	9.66

Circuit Assembly

The circuit must be assembled in a sterile manner.

Circuit Priming.

There are two stages of priming the ECMO circuit, the crystalloid prime and the protein coating. The assembled circuit including the reservoir must be CO2 flushed through the reservoir prior to priming.

The Crystalloid Prime.

The crystalloid prime is designed to fill the circuit with a balanced electrolyte solution in a bubble free fashion. The crystalloid primed circuit is kept in a sterile, ready to go state for up to 4 weeks.

1. Clamp the lines to and from the reservoir and close the tap to the blood bag, stop CO2 flushing and disconnect the gas line from the reservoir.
2. Add 500 ml of Plasmalyte 148 to the reservoir.
3. Take the clamp off the reservoir outlet line and allow the circuit to fill. Remove the clamp from the return line to the reservoir; lower the circuit to a level below that of the reservoir to allow the remainder of the circuit to fill.
4. Shake and hit with the palm of the hand the sides of the oxygenator to dislodge bubbles trapped within it.
5. Once you are convinced that the circuit contains no bubbles you are ready to store the circuit.

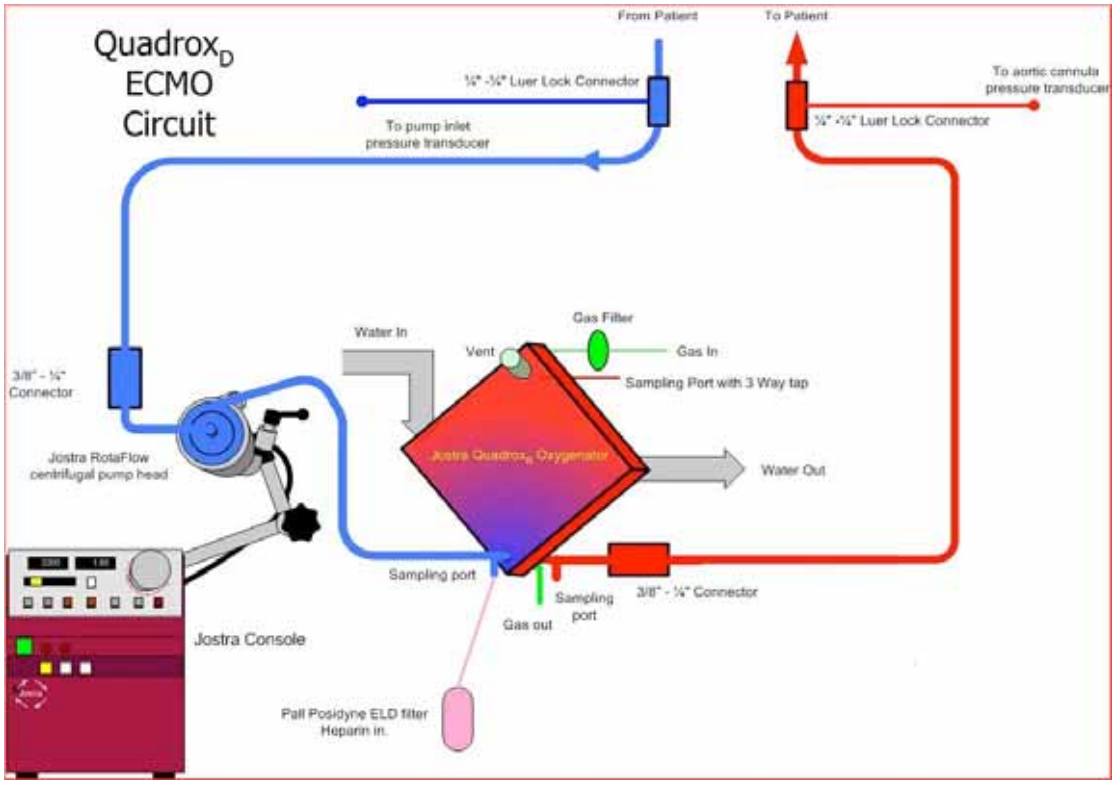
The Protein Coating.

Protein coating is started five to ten minutes before patient cannulation.

1. For each 500ml of Plasmalyte 148 add 100 ml of 20% albumin to the reservoir.
2. Increase the pump speed and allow the fluid to circulate for a few minutes. This allows the albumin to coat the tubing, diminishing the loss (by absorption) of clotting factors and other proteins when the patient is connected to the circuit.
3. Ensure the water bath is connected to the heat exchanger and the temperature is set to 37 degrees C.
4. To calibrate the flow probe ensure that transducer is correctly aligned on the probe and turn the pump off. Clamp both sides of the probe. Adjust the flow zero control behind the top panel of the Biomedicus pump until the display reads zero. To zero the Jostra pump, hold the zero button down for three seconds. It will beep when zeroed. Remove the clamps and turn the pump on.
5. Disconnect the power and move the circuit to a position next to the patient to allow easy transfer of the sterile tubing to the operative field. The sterile wrap is opened and the surgeon takes the sterile tubing and discards the priming reservoir tubing. The sweep gas should be off until you are ready to commence ECMO.

Adding blood to the circuit: For infants and neonates the addition of blood to the prime avoids excessive haemodilution. Packed red cells (PRC) are added when the circuit has been clamped and will not be recirculated. 100-120 ml of leucocyte filtered PRC is syringed into the circuit via the port on the venous side of the oxygenator. The same amount of clear prime will be displaced into either the reservoir bag or, if it is clamped off, into a syringe connected to the port at the top of the arterial side of the oxygenator. In this way the oxygenator will be blood primed.

ECMO Circuit Diagram



CANNULATION

Cannulation in the Intensive Care Unit.

The vessels for ECMO cannulation are normally the right internal jugular vein and right common carotid artery. Once the vessels are exposed and ready to cannulate, a heparin loading dose of 0.5mg/kg (50 units/kg) is administered. The circuit and cannula must be air-free when connected together. ECMO is then instituted and the pump speed is increased until the required flow to the patient is reached.

Cannulation in Theatre

Turn the pump speed down to about 500 RPMs. The surgeon takes the lines onto the table and the vessels or atrium are cannulated. The aortic cannula is connected to the ECMO arterial line and deaired. A venous cannula in the right atrium is connected to the venous (pump head inlet) line and deaired.

Weaning onto ECMO

When ECMO is initiated, the clamp from the venous line is removed first. The pump speed in increased slowly to about 700 RPMs. The clamp from the arterial line is then removed and the pump speed increased until the desired flow is attained, with minimum RPMs. This assesses the total obtainable blood flow. Weaning onto support is done very slowly to allow gradual mixing of the prime with the patient blood as there may be a large difference in volumes between the patient and the ECMO circuit. The gas flow should be started at the of the desired blood flow (1:1). The gas inlet pressure must be monitored. A sudden increase can cause the oxygenator membrane to rupture. An ideal pressure for the gas is < 50 mmHg.

A pump inlet pressure monitoring line is connected to the venous cannula connector as soon as possible after initiation of ECMO. A sterile pressure line is handed off from the operative field from a tap on a blood isolator connected to the pressure transducer on the Biomedicus console or HP Merlin system if the Jostra console is used. This entire line including the isolator must be deaired and flushed with heparinised saline (1 unit/ml) from a 50 ml syringe. Care must be exercised when attaching it to the venous line due to the negative pressure in the venous line. Turn the tap off to the patient to flush and deair the line. Zero the pressure line. Turn the tap to the patient and draw back on the syringe to ensure no air is in the line. Gently flush to the patient and then turn the tap on the isolator to read the pressure. This line must be flushed regularly to prevent it clotting as it monitors cannula position and patient volume status. A continuous infusion of heparinised saline delivered by a syringe may be used.

Management

Once the required flow is reached the patient ventilation is minimised. The ventilator parameters are usually in the order of FiO_2 0.21, PIP 20 cmH_2O, PEEP 8-10 cmH_2O, Set at a rate of 5-10 breathes per minute. The ACT is measured hourly and maintained at 160 - 180 seconds (Hemotech) unless there is excessive bleeding. The platelet count is maintained greater than 100,000 and increased if there has been any surgical procedure or excessive bleeding.

Haemofiltration is used on ECMO for managing oliguria and anuria (if resistant to high dose diuretics) oedema, electrolyte levels and blood borne toxins, and poor nutrition. Ideally the ECMO circuit should not be accessed for haemofiltration.

If the desired flow range cannot be reached check the following;

1. Is the pump inlet (venous) cannula pressure more negative than -60 mmHg? This could be due to hypovolaemia or bad cannula position.
2. Is the patient adequately filled? The patient will require some volume replacement, due to loss from cannulation and compliance of the circuit.
3. Inadequate venous return due to the size or position of the cannula. Check the cannula position. After the chest is closed (not wired together) the position may be checked with chest radiography or echocardiography.

As soon as possible an ACT, blood glucose, Hb and arterial blood gas should be checked.

The ECMO flow must be sufficient to completely support and adequately perfuse the patient. The arterial pressure trace normally has a distinctive pattern, peaking each time the ventricle ejects. On ECMO this trace will begin to flatten as the circuit flow is increased as it does in conventional bypass. When the trace has flattened and there are no peaks 70% - 80% of the cardiac output is being passed through the circuit.

The ECG should remain normal. The coronary arteries are directly perfused with fully saturated blood from the ECMO circuit ensuring a normal oxygen supply to the myocardium.

Inotropic drugs can be weaned quickly and then stopped when adequate flows have been established. Maintain a dopamine infusion at 2.5 - 5 ug/kg/min to optimise splanchnic flow and renal perfusion.

The goal is to maintain adequate flow. Adequate flow is best defined as the amount of flow that allows for a normal pH, mixed venous pO2 and all other organs to function normally. Flow through the poorly functioning lungs acts as a right to left shunt. Increasing pump flow will allow less blood through the lungs, sending more to the oxygenator. Once the patient has been stabilised the pump flow may be decreased to keep the paO2 in the 85 - 100 mmHg range.

The patient must have an adequate circulating blood volume to obtain good flow rates. Blood sampling may average 50 ml per day in the neonate on ECMO. Blood may also be lost from the cannulation sites. Therefore a careful and complete fluid balance, monitored hourly, is essential. Decisions on volume replacement are made depending on the Hb, blood protein levels or plasma levels. Packed red cells are given if the Hb drops below 9 gm/dl. FFP, or albumin if the Hb is above 9 gm/dl and platelets if the platelet count is less than 50,000.

Sodium citrate preservative in donor blood binds with ionised calcium; therefore calcium gluconate or calcium chloride is usually administered with each 100 ml of blood or FFP. Total serum and ionised calcium levels should be monitored 8 hourly.

The size of the arterial cannula contributes to the resistance in the circuit as it does in CBP. Haemolysis can occur with high flow through narrow orifices so the larger the cannula the less haemolysis will occur. This is more critical than with conventional CPB because of the time period on support.

Indications for Haemofiltration

1. Over hydration, resistant to high doses of diuretics.
2. Parenteral nutrition restricted due to fluid limitations
3. Prevention of hyperkalemia or azotemia
4. Impaired pulmonary diffusion with circulatory failure.
5. Hypernatremia, resistant to natriuretic drugs.

The Jostra QuadroxD has a very low pressure drop across the membrane and is not suited to having a haemofilter operated in parallel with oxygenator in the circuit. Haemofiltration must be set up separately if possible, however, if it is required the safest option is to withdraw blood from the arterial side of the circuit and return it to the venous side through the port at the bottom of the oxygenator.

Trouble Shooting.

Cause and management.

1. Air in Circuit.

a) Air in venous line or pump head only.

1. Air infused into right atrium through I.V. lines.
2. Venous cannula position.
3. Connector from cannula to circuit.
4. Tap open on venous pressure line.

Management

Small amounts of air entering the venous side of the oxygenator will be vented across the membrane at the top of the venous side of the oxygenator.

For gross venous air:

1. Clamp off the ECMO cannulae and shunts.
2. Turn the pump off.
3. Ventilate the patient and maintain cardiac output. Find and fix the site if the leak.
4. Attach a 50 ml Luer lock syringe to the tap on the Luer connector on the venous line.
5. Take the pump head out of the external drive unit.
6. Hold the pump head lower than the venous cannula, shake and tap the circuit to move the air up towards the syringe.
7. Aspirate with the syringe until all the air is removed.
8. Put the pump head back in the external drive unit.
9. Re-institute ECMO. Remove the venous clamp, increase pump speed to 700 RPMs, remove the arterial clamp and increase pump speed to required flows.
10. Re-establish the correct flows through the shunts.

b) Air in oxygenator.

1. Improper priming procedure.
2. Membrane rupture.
3. High gas flow with low pump flow.
4. PO2 in blood too high for P.atmosphere.
5. From pump head or venous line.
6. From connectors on the oxygenator.
7. From sample/drug infusion/haemofitration sites.

Management

Small amounts of air entering the venous side of the oxygenator will be vented across the membrane at the top of the venous side of the oxygenator.

For gross air or air in the arterial side:

1. Clamp ECMO lines between the pump head and the oxygenator and any shunts.
2. Turn the pump off.
3. Ventilate the patient and maintain cardiac output. Find and fix the leak site.
4. Connect a 60 ml Luer lock syringe to a tap on the arterial side of the oxygenator and tilt the oxygenator so that the tap with the syringe is higher than the air in the circuit.
5. Tap and shake the oxygenator to move the air upwards and aspirate the air into the 60 ml syringe until all the air is removed.

6. Re-institute ECMO.

If you suspect that the oxygenator membrane has ruptured the patient must be supported by conventional methods until a new oxygenator is used to replace the ruptured one.

c) Air in the arterial line and patient.

1. Oxygenator rupture (? Gas port obstructed).
2. Loose connector at cannula.
3. Heat exchanger leak.
4. Venous line tap left open and circuit filled with air via shunt line if on low flow.

Management.

1. Clamp arterial, venous and shunt lines. **Turn pump off**.
2. Put patient head down (Trendelenburg position) so that air will move from the lower half of the body.
3. Ventilate the patient and maintain cardiac output. Find and fix the leak.
4. Have plenty of volume available to give and a person to give it.
5. Attach a 50 ml Luer lock syringe to the three way tap on the connector on the arterial cannula and open the tap.
6. If air is seen in the cannula aspirate blood from the arterial cannula to remove the air seen in it. Clamp the cannula once the air has been removed.
7. Remove the clamp from the arterial line and tap the line to move the air to the syringe and aspirate it. Give volume as required.
8. Check the rest of the circuit for air. Tap the oxygenator, if any air appears at the top of the membrane do not re-institute ECMO as the membrane has been ruptured and the oxygenator needs to be replaced.
9. If no more air is seen re-institute ECMO.

2. Oxygenator Failure.

a) Air in the top of the oxygenator.

Cause: 1. Membrane rupture.
Management: Change the oxygenator.

b) Clots in the oxygenator.

Cause: 1. Inadequate anticoagulation.
Management: Increase ACTs.
2. Less than rated blood flow for the oxygenator.
Management: Increase flow to patient or through shunts.

c) Decreasing patient saturation.

d) Decreasing post oxygenator pO2.

Repeat pre and post oxygenator gases, increase FiO2 if possible.

e) Increasing pCO2 .

Increase sweep gas if not at maximum.

f) Blood leaking from gas exhaust port.

Ruptured or holed membrane. Change oxygenator.

3. Pump Head Failure.

If the pump head start to leak, if the volume loss is very small the pump head can be changed as soon as is convenient as long as the volume is replaced. If the leak is large the head must be changed immediately. For this the patient must be taken off ECMO. The method is the same as described in the VAD section.

4. Increasingly negative venous (pump inlet) pressure and decreasing blood flow .

The low flow alarm should sound, the venous pressure will become more negative and as the flow decreases so will the saturation. If the situation is prolonged, ventilate and support the patient. Decreased blood return to the pump may be caused by:
1. Change in patient head position.
2. Change in venous cannula position.
3. Patient hypovolaemia due to increased diuresis or bleeding.
4. Fibrin clot in pump inlet line.

5. Decreasing blood flow (no increasingly negative venous pressure).

The low flow alarm should sound and the arterial cannula pressure will increase, but the venous pressure will remain the same or become more positive. The patient's saturation may fall as the flow decreases. Increased resistance to flow can be caused by:
1. Increased arterial pressure.
2. Change in patient head position.
3. Change in arterial cannula position.
4. Clots in:
   - oxygenator.
   - arterial cannula
   - arterial tubing.

6. Changes to patient pO2 .

Increasing arterial pO2 :

Patient looks generally well:
Improved pulmonary function.
High ECMO flow rate.

Patient looks unwell:
Tension pneumothorax?
Hemothorax?
Pneumopericardium?

Tissue necrosis (ongoing acidosis):
Infection?
Poor perfusion.

Decreasing patient pO2 :

Cyanosis, acidosis.
Pneumothorax or atelectasis
Ventilation malfunction,
patient secretions
Fluid in vent. tubing
ECMO flow to patient too low.

Decreased pulmonary blood flow:
?Patent ductus arteriosus.
Increased pulmonary
hypertension.

Mechanical:
Gas tubing leaks or not connected.
Oxygenator failure.
Sweep gas FiO2 too low.

CNS Injury:
Seizures impairing pulmonary inflation.
Massive intracranial haemorrhage

Patient looks generally well:
Improving pulmonary perfusion.
Improved oxygen extraction.

7. Changes to patient pCO2.

Increasing pCO2:

Patient tachypneic, acidotic:
Gas flow rates too low.
Needs more ventilation support.
Pneumothorax.
Citrate or Bicarbonate overload from transfusions.

Mechanical:
Oxygenator failure.
Endotracheal tube problems.

Decreasing pCO2:

Patient apnoeic, alkalotic:
Gas flow rates too high.
Over ventilated.
Lung compliance improving.

Patient tachypneic, alkalotic:
High pCO2 in post oxygenator gas.
Cerebral dysfunction.

Patient tachypneic, acidotic:
Other organic acid in blood.

8. Changes in urine output.

Decreased urine output:

Hypovolaemia:
Patient hypotensive and mottled.
Give volume.

Pre-ECMO hypoxia:
Ischaemic kidney damage.
Increase pump flow. Increase diuretics
Try haemofiltration.

Capillary leak syndrome:
Oedematous patient. Poor perfusion.
Increase pump flow, start diuretics.
Start or increase inotropes.

Low pump flow:
Increase pump flow.

Patent Ductus Arteriosus?
Do cardiac echo to confirm.

Haemoglobinuria:

Red serum noted.
Check plasma Hb.
Plasma Hb > 1.0 g/L.
Pump failure, clots in circuit or pump.
Change pump head or circuit.
Renal Dysfunction.
Do renal ultrasound.
Pump speed too high.
Reduce pump speed.
Pump inlet pressure < -60 mmHg.
Check cannula & patient position, give volume if required.
Patient has sepsis/DIC. Low platelet count, prolonged PT & APTT. Elevated FDPs.
Culture blood, check PT, APTT & FDPs.

Increased urine output:

Response to improved blood flow.
Post-injury diuresis.
Improving pulmonary status.
"Recovery diuresis" post capillary leak.

9. Patient Bleeding.

Blood pressure decreased, pulse rate increased.

ACT too high?
Reduce heparin infusion rate.

Decreased Hb, visible bleeding.

Due to pre-ECMO procedure.
Investigate wound site.
Heparin dose and ACT too high.
Reduce heparin infusion & check ACT.

Internal bleeding.

Pneumothorax etc.
Check with X-ray.
NEC, Fontanelle tense:
seizures, CNS Changes.
Trauma.
Check with ultrasound.

Platelet count low.

Destruction of platelets by circuit.
Transfuse platelets.
DIC.
Check PT, APTT, FDPs, transfuse Platelets, FFP etc.

Infection/Sepsis.
Culture and treat with appropriate antibiotic.