EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO) IN PICU – CHW

PRACTICE GUIDELINE ©

DOCUMENT SUMMARY/KEY POINTS

- Extracorporeal Membrane Oxygenation (ECMO) is a supportive therapy for infants and children with cardiorespiratory failure in the Paediatric Intensive Care Unit (PICU)
- This document provides a guideline to enable the safe and effective provision of ECMO for paediatric patients in PICU at CHW
- Initiation and management of ECMO support at CHW requires a multidisciplinary approach with clear communication and roles
- The term "Nurse" in this document refers to a Registered Nurse (RN) employed in PICU at CHW unless otherwise stated
- Documentation of ECMO and patient parameters and management decisions is the responsibility of PICU staff and will be recorded in the eMR

Approved by:	SCHN Policy, Procedure and Guideline Committee	
Date Effective:	1st March 2022	**Review Period**: 3 years
Team Leader:	CNE and Staff Specialist	**Area/Dept**: PICU

Date of Publishing: 25 February 2022 3:32 PM Date of Printing: 25 February 2022

CHANGE SUMMARY

- The changes to this edition of the document relate to the use of different hardware in the provision of the ECMO service
- Multiple changes have been made throughout the entire document
- New ECMO Haemostasis protocol implemented with associated document changes
- All references to ACTs are High Range
- Integrated guidelines into this document: CVVHDF on ECMO & SCUF on ECMO
- Placed 3 appendices as separate documents under Resources in ePolicy. Also added a copy of the ECMO Haemostasis Protocol (bleeding and non-bleeding) as a separate document under Resources.

READ ACKNOWLEDGEMENT

The following staff are to read and acknowledge they understand the contents of this document:

- PICU Intensivists, PICU Fellows, PICU Registrars, PICU ECMO Nursing staff
- Perfusionists
- Cardiothoracic Surgeons
- Cardiac Anaesthetists

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1 Background

Definition

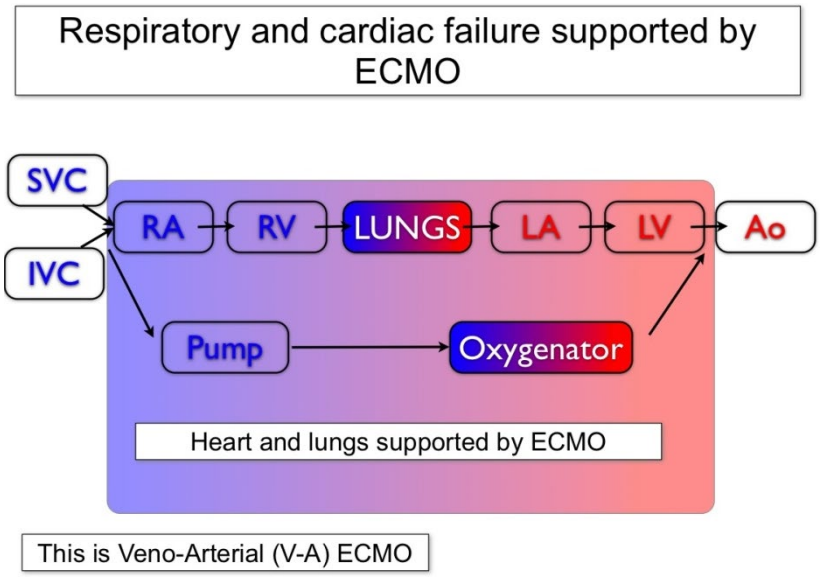
Paediatric extracorporeal membrane oxygenation (ECMO) is defined as the use of a cardiopulmonary bypass circuit for temporary life support for children with potentially reversible cardiac and/or respiratory failure, or as a bridge to transplantation / bridge to decision. ECMO involves the transport of blood through tubing, via a centrifugal pump, to an artificial oxygenator where blood becomes oxygenated and carbon dioxide is removed. The blood is then returned to the patient's circulation.

Aim

The aim of ECMO is to support the failing cardiac and/or respiratory function of the patient until such a time that organ recovery occurs, a suitable transplant is available or cessation of treatment is deemed appropriate (continuation of treatment may be deemed futile). There are two types of ECMO – Veno Arterial (V-A) & Veno Venous (V-V).

2 Veno-Arterial (V-A)

- Applied for the management of cardiac failure or cardio-respiratory failure
- Involves drainage of venous blood from the patient to the ECMO pump by accessing the large central veins or right atrium and returning it to the arterial system after it has passed through the oxygenator
- The decision to commence V-A ECMO may be made in cardiac theatre or in PICU



The ultimate decision to commence ECMO is taken by the PICU Consultant (in PICU) or the Cardiothoracic Surgeon (in Theatre or Cath Lab) and is based on the following Selection & Exclusion criteria with appropriate investigations:

Selection criteria:

- Progressive, intractable pulmonary or cardiac failure
- Failure to separate from cardiopulmonary bypass (CPB) following surgery (post-cardiotomy)
- Cardiac arrest
- Oxygenation Index (OI) > 40 for 4 hr (OI = MAP x FiO_2 x 100 /PaO_2)
- Refractory sepsis

Exclusion Criteria:

Absolute

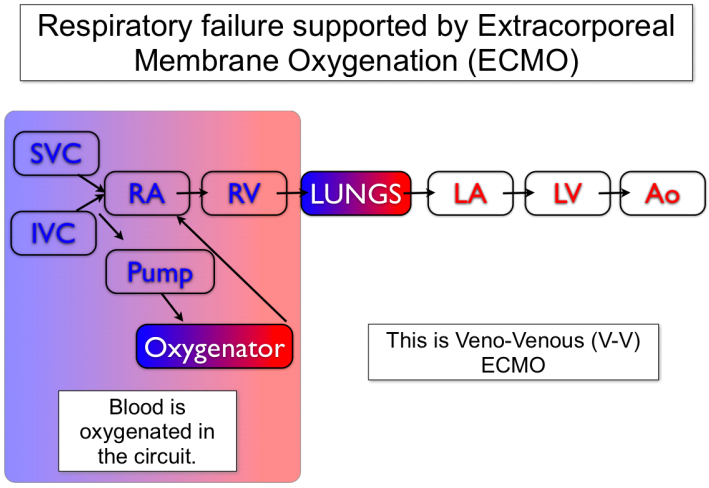
- Weight < 1.8kg (V-A ECMO) or < 2.5kg for V-V ECMO
- Major intracranial haemorrhage (≥Grade III)
- Severe neurologic injury
- Lethal congenital malformation
- Untreatable disease in any organ system
- Active systemic malignancy
- Out of hospital cardiac arrest
- Unwitnessed cardiac arrest

Relative

- Gestation <34 weeks
- Mechanical ventilation >14 days
- Uncontrolled coagulopathy
- IVH Grade I or II
- Genetic Syndrome with poor prognosis
- Overwhelming multi organ failure
- Malignancy

3 Veno-Venous (V-V)

- Applied for management of isolated respiratory failure when cardiac function is deemed adequate for the predicted duration of ECMO
- Preferred modality for isolated respiratory disease - provides oxygenated pulmonary blood flow, maintains systemic pulsatile blood flow and avoids some complications associated with ECMO such as arterial clot
- Option for patients with severe acute respiratory failure when other medical therapies have failed (CMV, HFOV, inhaled nitric oxide, prone positioning etc.)
- Involves drainage of venous blood from the patient to the ECMO pump by accessing the large central veins and returning it back to the venous system near the right atrium after it has passed through the oxygenator
- Facilitates lung rest by avoiding the need for high ventilator requirements minimising ventilator induced lung injury and enabling lung protective strategies
- The decision to commence V-V ECMO is usually made in PICU



Common respiratory diseases supported by VV ECMO

- Acute Respiratory Distress Syndrome (ARDS)
- Acute respiratory failure- non ARDS
- Pneumonia
- Meconium Aspiration Syndrome (MAS)
- Congenital Diaphragmatic Hernia (CDH)
- Persistent Pulmonary Hypertension of the newborn (PPHN)
- Persistent air leak syndrome
- Status asthmaticus
- Pertusiss
- Bridge to lung transplant

Indications

- Oxygen Index >40 for >4hours
- Ventilatory failure: hypercabia with persistant pH <7.0 on high ventilatory support i.e. PIP >35cmH20
- Rapidly deteriorating patient and non-responding to increase support of CMV/HFOV

Advantages of VV over VA

- Return of pump-arterial blood to the right side of the heart
  - If clot or air from the circuit travels into the patient on VV ECMO it is injected into the right atrium & filtered out by the pulmonary circulation (If right to left shunt physiology exists then embolus could still flow directly into the systemic circulation)
  - Returning pump-arterial blood to the right heart means oxygenated blood mixes with the venous, improving oxygen content of the blood returning to the pulmonary circulation and to the left heart - this has the ability to help decrease PVR, right ventricular afterload and also improves coronary artery oxygenation delivery which comes from the left ventricle
- Decreased cardiac afterload
- Normal pulsatile flow is maintained. Pulsatile flow decreases vascular resistance, decreases afterload and improves organ perfusion
- Weaning on VV is easier, safer and requires less interventions and proceduralists

4 Pre ECMO Investigations

- Where appropriate all children should undergo a rigorous pre-ECMO assessment.
- It is acknowledged that in emergency situations this may not be complete.
- Responsibility for organising appropriate investigations is with the PICU Consultant for patients in PICU, or with the Anaesthetist if the patient is in the Operating Theatre.
- Pre ECMO investigations may include, but are not necessarily limited to:
  - Height and weight
  - Chest x-ray (CXR)
  - Arterial Blood Gas (ABG)
  - Central Venous Blood Gas (cVBG)
  - Clotting screen (Coags) including Antithrombin III (AT III)
  - Full Blood Count (FBC)
  - Electrolytes, Urea, Creatinine (EUC)
  - Liver Function Tests (LFT)

- Activated Clotting Time (ACT)
- Thromboelastography (TEG)
- Echocardiography (ECHO)
- 12-lead ECG
- Cranial ultrasound for those infants with open anterior fontanelle

5 ECMO Activation Procedures

ECMO Activation Cue Card

Once decision made to initiate ECMO, the nursing team leader or senior nursing staff member designated by the nursing team leader should use the ECMO ACTIVATION CUE CARD to inform staff (below). Also see ECMO Activation Cue Care and Tiered Calling Card.

ECMO ACTIVATION CUE CARD
Call switch on 2222 & state: 'This is a cardiac emergency' Through switch proceed to call & speak to all individual members listed in Tier 1 & then Tier 2 notifying them of the following information: • Patient Name & Age • Patient weight &/or BSA • Bedspace number
Tier 1 (in this order) via Switch 2222 • PICU Consultant • Perfusionist *(**in hours:** personal page, mobile or pump room #52390)* • *(**after hours:** mobile)* • Cardiothoracic **Consultant** Surgeon – notify them that you HAVE NOT yet spoken to the Cardiothoracic Surgeon Fellow • Theatre Staff (Floor Manager) #52333 or page #6182 • PICU Fellow
Tier 2 (in this order) via Switch 2222 • Blood bank - request urgent x2 unit of PRBCs (Group 0-ve if blood group unknown or nil cross match available) and to prep all other products #52284 or page #6832 • Cardiac Anaesthetist • Cardiothoracic Fellow Surgeon

Blood Product Ordering

- Inform blood bank as per the Tiered ECMO activation contact list
- For initiation of ECMO in PICU, the ECMO nurse holds responsibility to order the following blood products:
  - Further 2 units Packed Red Blood cells (PRBC)
  - 20% Albumin 100mL. (kept in PICU drug fridge)
  - Fresh Frozen Plasma (FFP) 1 unit
  - Cryoprecipitate <15kg 2 unit > 15kg 4 units
  - Platelets 1 adult unit
- Update Blood Bank twice daily, or as required, on the projected requirement for blood products
- If appropriate inform on-call Consultant Haematologist (8am-8pm)

Circuit Choice

CHW has several available circuit sizes for ECMO (see table below), choice is based on desired flow. The ¼ x ¼" circuit is the most commonly used and is pre setup and primed. The 3/8 x 3/8 is set up but not primed.

Circuit	Pump	Oxygenator	Max. Flow
3/16 x 1/4	PediVas	Paragon Neonatal	0-1400mL/min
1/4 x 1/4	CentriMag	Paragon Infant	Max.3000mL/min
3/8 x 3/8	CentriMag	Medos 7000/Paragon	Max.7000mL/min

Flow Calculation

The following calculation methods are to be considered as a guideline. Final flow will be based on individual calculations of oxygen delivery and uptake. Clinical status, including haemoglobin [Hb], and anatomical variance must be taken into consideration.

The following calculations are based on a Haematocrit of 30 – 35%.

The calculations below are a guide for the initial flow on ECMO; assessment of adequacy of oxygen delivery will influence decisions to increase flow where indicated.

V-A Flow calculation

- For V-A ECMO flow will be calculated based on the patient's Cardiac Index (CI) and Body Surface Area (BSA)

BSA M^2 = sq. rt. (Ht. cm x Wt. kg / 3600)

- Flow Rate = Desired Cardiac Index (CI) x Body Surface Area (BSA) with a minimum flow rate in mL/kg/min

- **For all patients the flows are based on desired cardiac index with a minimum flow in mL/kg/min as per table. Final flow will be based on individual patient clinical status and oxygen delivery**
- **Assessment of adequacy of oxygen delivery and end organ function will influence decisions to increase flow where indicated e.g. sepsis patients need much higher flows than usual for adequate oxygen delivery to the tissues**
- Where no height is immediately available the table below also may be used as a guideline for projected flow requirements

Desired Cardiac Index & Minimum Flow based on Weight/BSA

Weight (kg)	BSA (m^2)	Desired Cardiac Index(L/min/m^2)	Minimum Flow (mL/kg/min)
2	0.16	3	120-150
3	0.21	3	120-150
4	0.26	3	120-150
5	0.3	3	120-150
6	0.34	3	120-150
7	0.38	3	120-150
8	0.42	3	120-150
9	0.46	3	120-150
10	0.49	3	120-150
11	0.53	2.8	100
12	0.56	2.8	100
13	0.59	2.8	100
14	0.62	2.8	100
15	0.65	2.8	100
16	0.68	2.6	100
18	0.74	2.6	100
20	0.81	2.6	100
22	0.86	2.6	
24	0.91	2.6	
26	0.96	2.6	
28	1.01	2.6	
30	1.06	2.6	
32	1.1	2.6	
34	1.15	2.6	
36	1.2	2.6	
38	1.25	2.6	
40	1.29	2.6	
>40		2.4	

Minimum Flow:

- 2-10kg 120-150mL/kg/min
- 11-20kg 100mL/kg/min
- >20kg CI only

V-V Flow Calculation

- For V-V ECMO the flow will be calculated based on arterial oxygen and carbon dioxide tensions
- Initially, flow should be started at 50mL/kg/min and increased in increments of 50mL/kg/min depending on the patient's cardiac output state and the resultant arterial oxygen tension
- Final flow may often be as high as 120% of predicted cardiac output
- The preference for cannulation may at times be the dual lumen Avalon Elite Cannula. Patients < 5kg will require discrete double vessel cannulation, most likely R IJ and Femoral Vein

6 Equipment

PICU Bedspace

PICU nursing staff are responsible for PICU bed space availability & preparation

In addition to the standard cardiac PICU set-up, the following must be available:

- Adrenaline infusion
- Sodium Nitroprusside (SNiP) infusion
- Resuscitation Drugs based on patient weight (these must be changed every 48hrs):
  - Adrenaline x 3 doses
  - CaCl 10% x 2 doses
  - NaHCO3 x 1 dose
  - Atropine x 1 dose
- NSA 4% primed ready for attachment to patient
- ACT machine and **High Range ACT** cartridges
- Air eliminating filters
- Attach air/oxygenator gas of ventilator to top gas outlets
- Second primed ECMO circuit (to be made available by perfusion staff once ECMO has been initiated)
- Gas & Power board if required/requested
- ECMO equipment (non-bedside)
  - ECMO Trolley
  - Surgeon's headlight
  - ECMO procedure trolley
  - Chest-opening trolley
  - Emergency resuscitation trolley
  - Diathermy/suction trolley

- 20% Albumin 100mL x1 (kept in PICU drug fridge)
- ECMO drug trolley

- All ECMO equipment is stored inside the alcove at the back doors of PICU (except for resuscitation trolley & chest opening trolley) – does not need to be at the bedside **unless for chest washout +/- wean or emergency crash onto ECMO**

Patient Preparation

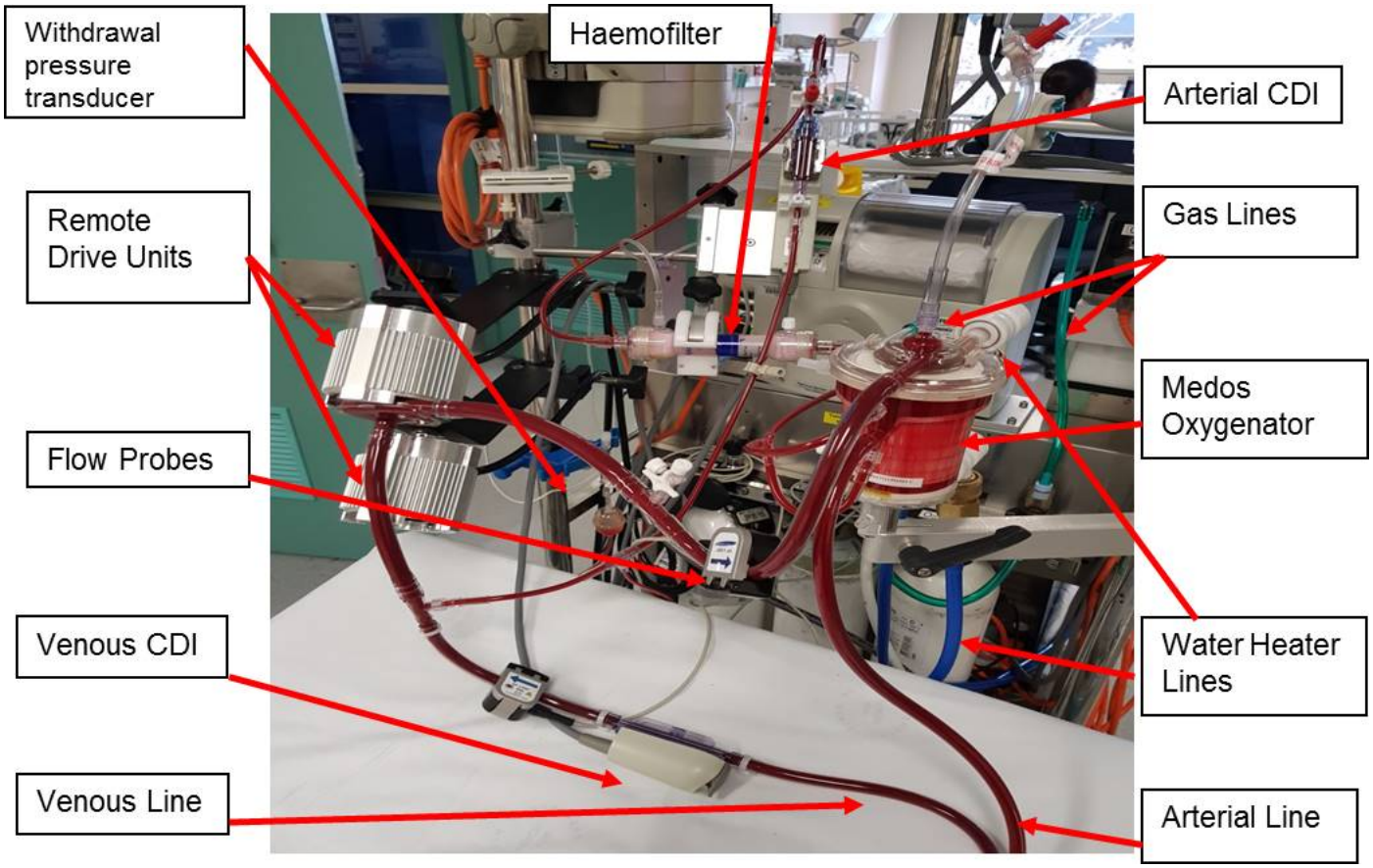
- Insert and secure any invasive access or lines or drains prior to heparinisation and commencement of ECMO
- Insert Nasogastric Tube (NGT) and indwelling urine catheter (IDC) prior to commencing ECMO or Heparin infusion
- Ensure appropriate monitoring of hemodynamic status including cerebral and somatic NIRS (Near Infra-Red Spectroscopy) monitoring prior to cannulation wherever available

ECMO Equipment and Assembly

The Perfusionist will collect and set up pre-primed ECMO circuit (trolley)

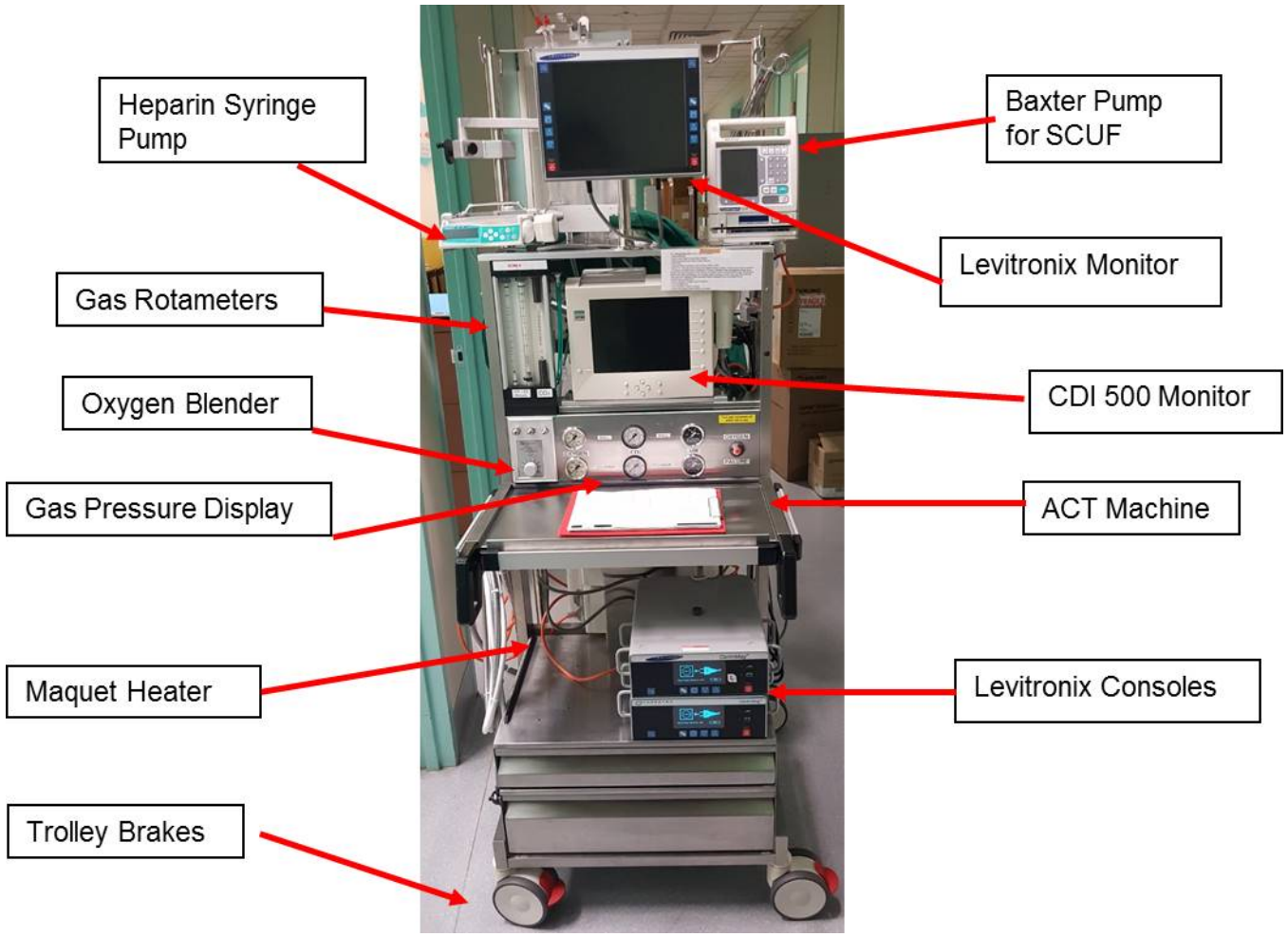
The ECMO circuit trolley contains:

- X2 Levitronix Centrimag consoles
- ECMO heater with connections
- CDI 500 monitor with arterial and venous sensors
- 1 syringe pump
- 1 Baxter Pump (The Perfusion department keep stock of Baxter pumps and infusion lines as these are now not standard stock)
- Air and Oxygen 'wall' gas lines
- X2 Remote pump heads
- Back-up oxygen, air and CO_2 cylinder
- ACT machine
- Tubing clamps x 5
- Clipboard
- Checklist and Initiation forms
- ECMO Water Heater



The ECMO Drug Trolley should contain:

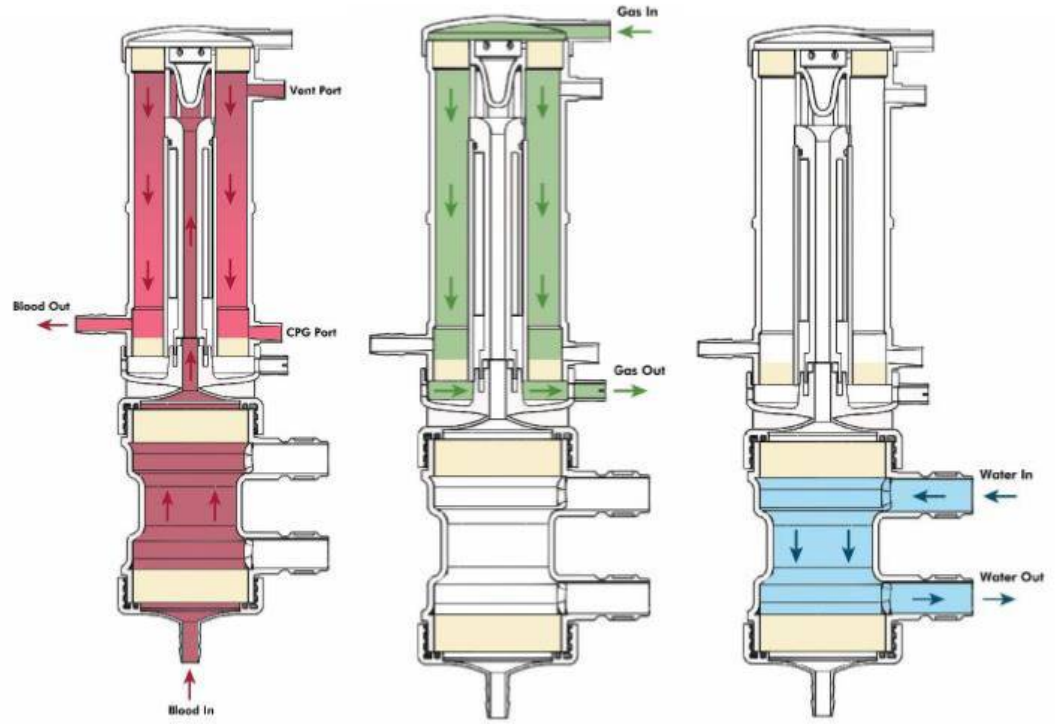
Heparin 5000units/5mL x 1	Drug labels	Drawing up needles
CaCl 1g/10mL x1	Red caps	Alcowipes
$NaHCO_3$ 8.4% 100mmol/100mL x 1	Sterile suction tubing	ECMO task cards
2mL syringe x 1	Sterile scissors	Roll of Velcro
5mL syringe x 1	Yellow sharps container	X1 spare suction meter
20mL syringe x 2	Bottle of unopened betadine	ECMO blood stickers
50mL syringe x 2	1x low flow O2 regulator	



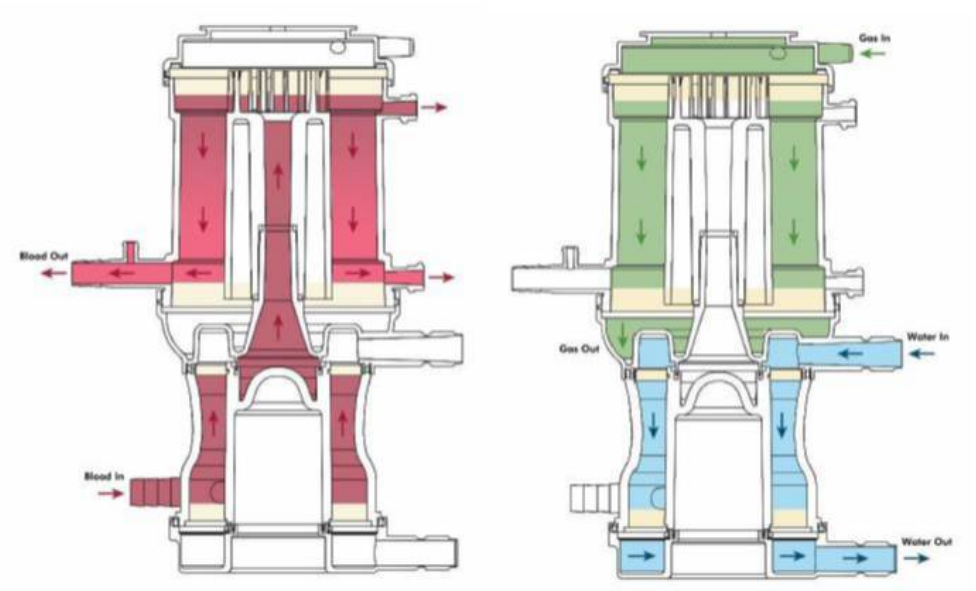
For more specific detailed information on ECMO related equipment see Appendix 1)

Paragon Oxygenator – blood, gas and water flow

Neonatal – Blood, Gas and Water Flow



Paediatric/Infant Blood Gas and Water Flow



7 Circuit Prime

- Stored (¼ x ¼" or 1/4 x 3/16) ECMO circuits available for emergencies at all times have been pre-primed with Plasmalyte 148. - this is the responsibility of Perfusion services & will be changed every month
- Once ECMO is running, a spare pump and circuit will be prepared by the Perfusionist as a back-up
- Prior to initiation of ECMO, the pre-primed circuit requires further additions to improve physiological compatibility and prevent excessive haemodilution
- In extreme situations the pre-primed circuit may be used immediately after the addition of heparin

The following drugs and fluids should be made available:

- 20% Albumin 100mL
- Heparin 5000units/5mL
- CaCl 1g/10mL x 1
- Sodium Bicarbonate 8.4% 100mmol/100mL x 1 (total 50mL in x2 25mL syringes)
- PRBC 1 unit (if blood prime required) (double checked & unspiked)

Crystalloid Prime (Pre-Primed Circuits)

- standard prime for pre-primed circuits at CHW
- designed to fill the circuit with a balanced electrolyte solution (e.g. Plasmalyte) in a bubble free fashion
- Kept in a sterile, ready to go state for up to one month.
- completed ECMO checklist should be displayed

Albumin 20% Prime

- increases the colloid osmotic pressure of the prime
- coats the circuit with albumin in an effort to ameliorate the contact of the patient's blood with the artificial surface of the ECMO circuit
- commenced when confirmation of imminent ECMO requirement has been received

Blood Prime

- Where possible a patient should not be exposed to blood transfusions, unfortunately the large priming volume of an ECMO circuit and relatively small circulating volume of some patients means this is not always possible
- effort to reduce haemodilution of the patient with the prime
- may not be required in large patients or patients whose haematocrit is elevated.

8 ECMO initiation Checks

These checks should be carried out in conjunction with the Perfusionist

- ☐ Ensure blood product availability
- ☐ Power up the ECMO circuit trolley. Ensure all ECMO equipment is plugged into the Uninterruptible Power Supply (the red plugs)
- ☐ Place note above plug stating "DO NOT REMOVE"
- ☐ Ensure pump battery is charged
- ☐ Ensure circuit remains air free
- ☐ Ensure gas lines are connected to wall
- ☐ Ensure gas cylinders are full and are placed in 'open' position. If not using CO2, leave cylinder in off position
- ☐ Turn Gas flow on (FiO_2 0.21) V/Q 0.5 for 1minute. Turn off gas flow to avoid supersaturation of blood
- ☐ Immediately check a prime blood gas)
- ☐ Ensure the ECMO heater lines are connected to the heat exchanger and water flow is confirmed via sight-glass
- ☐ Select the desired blood-flow range on the Levitronix consoles
- ☐ Check blood flow and line pressure alarm limits are appropriate
- ☐ Zero the pump inlet pressure transducer (to be carried out by Perfusionist)

9 Vessel Cannulation

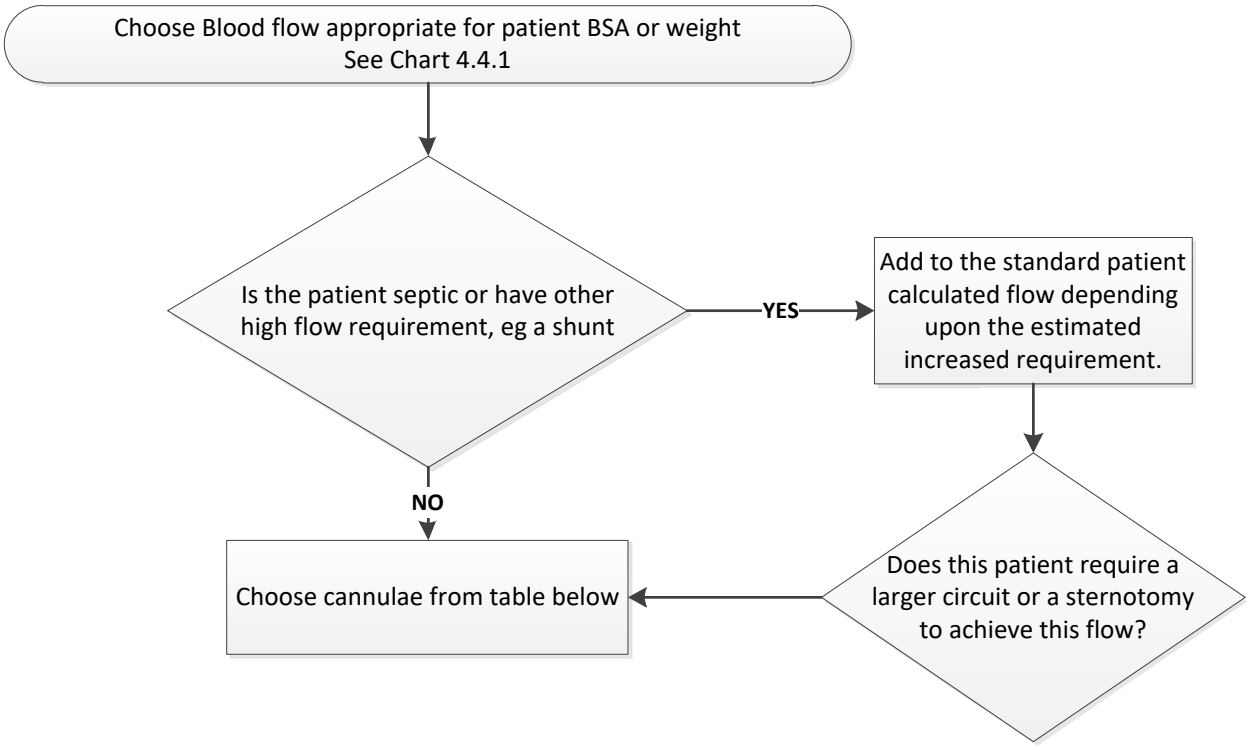
Cannulation Techniques

- Three ways of cannulating major vessels:
  - Surgical Central Cannulation - surgeon attaches the cannulae to the major vessels or cardiac chambers and secures them with sutures
  - Surgical Peripheral Cannulation - surgeon cuts down onto major peripheral vessels (neck or femoral) in order to cannulate them
  - Percutaneous Cannulation - performed using the Seldinger technique which involves serial dilation of peripheral vessels over a guide wire - the skin should form a tight seal around the cannulae
- Chosen method is dependent on the clinical situation and mode of ECMO being employed - currently most post-operative cardiac patients will be cannulated centrally
- Respiratory ECMO will mostly be initiated using the percutaneous Seldinger technique for Avalon cannula insertion or double peripheral venous cannulation - except in neonates and infants as there is currently no suitable size dual lumen Avalon cannula

- Neonates and infants usually require direct open surgical cannulation due to the small size of peripheral veins - surgical reconstruction may be required at decannulation
- The percutaneous Seldinger technique needs to be supplemented by transthoracic or transoesphageal echo to guide cannula positioning in addition to X-ray screening when feasible - for these reasons in planned cases, where the patient is stable for transfer, the procedure may be performed in the operating theatres or the Cardiac Catheterization Lab

Cannulae Selection

- The choice of cannula size is vital to the effectiveness of ECMO
  - If too small a cannula is chosen then sufficient flow will not be obtained and blood haemolysis is likely
  - If too large a cannula is chosen then impedance to the patient's own flow will occur - this is of particular importance during weaning
- Cannula size and type (Single-lumen Vs. Double-lumen) will depend on Surgeon and Perfusionist preference and on size and availability as well the indication for ECMO



VA Cannula Sizes & Flows

Arterial cannulae		Venous cannulae	
FLOW (mL/min)	**SIZE (Fr)**	**FLOW (mL/min)**	**SIZE (Fr)**
0 – 400	8	0 – 350	8-12
400 – 750	10	350 – 500	10-12
700 – 1200	12	500 – 700	12-14
1200 – 1800	14	700 – 1100	14-16
1800 – 2000	16	1100 – 1400	16-18
2000 – 3200	18	1400 – 2000	18-20
3200 – 3800	20	2000 – 2400	22
3800 - 4900	22	2400 – 3200	24
		3200 – 3900	28
		3900 – 5000	32

(Compiled by Dr Chris Harvey, Glenfield Hospital UK - based upon clinical experience and not distributed by the company)

VV Cannula Sizes & Flows - Avalon Elite Cannula

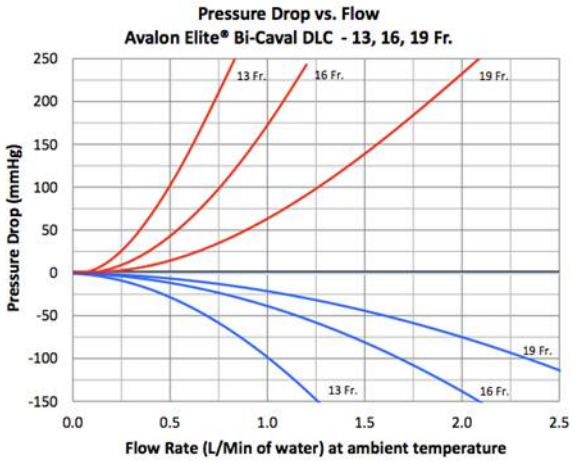
Patient (kg)	Cannulae	Flow (L/min)
5 to 9	16 Fr	0.9
9 to 12	19 Fr	1.2
12 to 15	20 Fr	1.5
15 to 20	23 Fr	2.0
20 to 65	27 Fr	3.5
>65	31 Fr	5

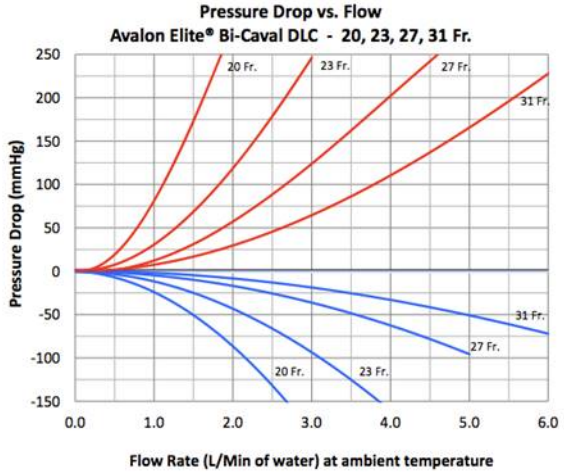
VV ECMO Single Lumen Cannula for <5kg patients

Drainage cannulae (neck)			Return cannulae (groin)	
Weight	**SIZE (Fr)**	**Flows**	**SIZE (Fr)**	**Flows**
<5kg	8-10	400-800mL/min	6-8	400-800mL/min

Avalon Cannula Specifications

		A	B			C		D		E		F		G		H		
Description		Connector Size	Body Diameter			Insertable Length		Proximal Insertable Body to Infusion Port		SVC to Infusion Port Length		Infusion Port to Tip Length (Lead Length)		SVC to Tip Length		Lead Diameter		
	Units	in	Fr.	mm	in	cm	in	cm	in	cm	in	cm	in	cm	in	Fr.	mm	in
Description Size	Order Code																	
13 Fr.	10013	1/4	13	4.3	0.17	10	4.0	8	3.0	1.7	0.7	2.8	1.1	4.5	1.8	11	3.7	0.15
16 Fr.	10016	1/4	16	5.3	0.21	13	5.0	9	3.6	3.1	1.2	4.0	1.6	7.1	2.8	14	4.7	0.19
19 Fr.	10019	1/4	19	6.4	0.25	20	7.75	15	5.8	4.3	1.7	5.7	2.3	10.1	4.0	16	5.3	0.21
20 Fr.	10020	3/8	20	6.6	0.26	29	11.5	21	8.3	5.3	2.1	9.4	3.7	14.7	5.8	17	5.7	0.22
23 Fr.	10023	3/8	23	7.7	0.30	29	11.5	21	8.3	5.3	2.1	9.4	3.7	14.7	5.8	20	6.7	0.26
27 Fr.	10027	3/8	27	9.0	0.35	29	11.5	21	8.3	5.3	2.1	9.4	3.7	14.7	5.8	24	8.0	0.31
31 Fr.	10031	3/8	31	10.3	0.41	29	11.5	21	8.3	5.3	2.1	9.4	3.7	14.7	5.8	27	9.0	0.35





Additional Cannulas - Left sided decompression/additional venous drainage/Backflow

Additional Venous Drainage Cannula

- With V-V ECMO or peripheral V-A ECMO, venous drainage can be improved by placing a second venous drainage cannula - this would usually include the jugular or the femoral vein
- Caution should be taken when cannulating the femoral vessels in children less than 12 years and weight <40 kg due to the risk of causing limb ischemia

Backflow Cannula

- Patients that have the femoral artery cannulated are at risk of compromised limb perfusion - a small arterial backflow cannula can be added to the arterial inflow, inserted distal to the femoral arterial cannulation site
- A backflow cannula will usually be inserted at time of initial cannulation - the backflow cannula kit is on the ECMO trolley that lives in theatre and will be brought to PICU by OT nursing staff
- A Dacron graft can be also employed as an alternative to preserve distal extremity perfusion
- Indications - Femoral arterial cannulation or poor distal limb perfusion - doppler examination of the flow to the distal limb is indicated in case of deteriorating leg perfusion; alternatively differential NIRS rSO2i monitoring of both limbs may be useful

Left Sided Decompression

- If the systemic ventricle cannot generate enough pressure to eject and stroke volume is compromised the left ventricle will fill until the LV cavity pressure is equal to the arterial pressure at which point myocardial perfusion fails
- If the left side is not decompressed the blood backs up into the lungs resulting in frank pulmonary oedema, subsequent pulmonary capillary rupture and pulmonary haemorrhage
- The patient will also be at high risk of forming clot in the left ventricle
- Consider left sided decompression if the patient has:
  - Pulmonary oedema
  - Diminished pulsatility on arterial line
  - Distended left ventricle on echocardiogram
- Medical/Surgical Interventions for left sided decompression (to allow for adequate myocardial rest and avoid pulmonary-venous congestion):
  - Inotropes and dilators to enhance LV emptying and reduce afterload promoting aortic valve opening
  - Direct placement of a cannula in the left atrium which connects to the venous side of the circuit with a 'Y' connector
  - Option of direct LV venting cannula via thoracotomy
  - If the patient is peripherally cannulated the patient can undergo an atrial septostomy in the Cardiac Catheterisation Lab

10 Cannulation in Theatre

- Surgeons, Anaesthetists, Perfusionist and Theatre Nurses are responsible for the entire procedure including equipment and transferring the patient back to PICU
- A team member will telephone PICU prior to the patient leaving theatre to allow adequate time for preparation

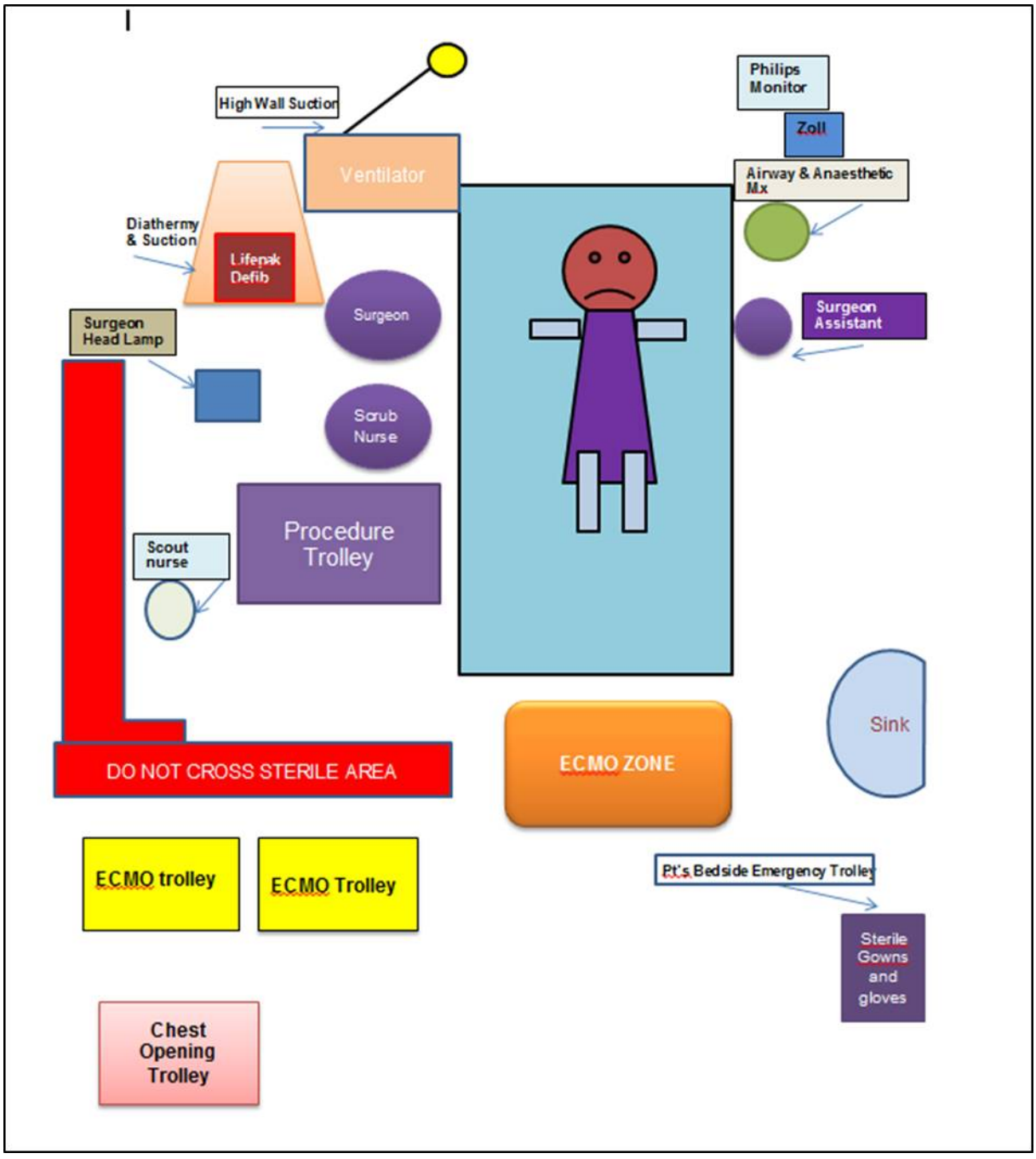
11 Cannulation in PICU

Preparation

- PICU Consultant or Fellow to allocate clear 'team leader' role & establish clear and effective communication between the teams involved
- Clear allocation of vital tasks
- All staff have responsibility for maintaining good aseptic technique and are expected to wear surgical hats and masks at all times during cannulation

For a pictorial representation of appropriate bed space setup see

PICU Bed Space Plan



Predefined roles for staff

Equipment Nurse

Primary responsibility is to organise the chest opening/ECMO equipment

- Bring chest opening trolley with Lifepak defibrillator into room in case internal paddle defibrillation required
- Take out chest opening kit with scalpel (attached to top of kit)
- Zoll defibrillator trolley (if not already in room but should be for patient in ECPR scenario - place under Philips monitor
- Bring large procedure trolley to bedside - set up on patient LEFT side
- Bring ECMO trolley to bedside
- Obtain surgeon head light and plug in on patient RIGHT side
- Bring Diathermy / Suction Trolley and position on patient LEFT side if possible - it can be run from the right side of bed if needed
- Plug the orange power cord from the back of the diathermy power into white power into the bottom panels of the bedspace
- Turn on the diathermy power button
- Plug in the diathermy plate cable into the bottom right of the machine (neonatal diathermy plates have an attached cable & can be used up to 2.7kg; larger diathermy plates require the cable to be clipped on)
- If diathermy trips power (notable by a constant alarm and red light above the writing that says 'mute/fault') - unplug the diathermy and flick the circuit breaker (light should go back to amber and read 'power available') - run the extension cord from the bottom drawer of the diathermy trolley to a power point outside the room if necessary
- Attach diathermy plate to patient
- Hang the suction unit to the side of the trolley and attach to high suction at the bottom left of the panel at the bedspace & turn on suction
- Place the LifePak defibrillator (taken from the chest opening trolley) on top of the diathermy trolley and plug into the wall
- Position patient's bedside emergency trolley next to sink & use to open gowns and gloves for surgeons (one pack contains 3 x gowns and hand towels)
- Place Betadine hand scrub pump pack at the sink
- Put 2 x bath towels on floor under sink
- Place BIG sterile Major pack from the second shelf of the ECMO trolley onto procedure trolley (OT staff will open this)

ECMO Nurse Set Up

Primary responsibility is to help the perfusionist

- Obtain **2 x packed cells** from blood bank (use runner to blood bank)
- Obtain 1 x 100mL 20% Albumin from PICU fridge for CIRCUIT PRIME (or delegate)
- Inform Pathology of ECMO initiation & request preparation of 2 x packed cells, 2x FFP, 2x cryoprecipitate, 1 x platelets - Inform Team leader and anaesthetist when you have done this
- Organise a space for the perfusionist to prime the ECMO circuit
- Draw up & label the following drugs for the Perfusionist:

  20%Albumin - 50mL syringe x 2

  $NaHCO_3$ - 25mL x 2 (in 20mL syringes)

  Heparin (5000 units in 5mL) - 1 x 5mL

  CaCl10% - 1 x 2mL (in 3mL syringe)
- Check the unit of Packed cells and give to perfusionist
- Second unit of packed cells to be given to cardiac anaethetist
- Calculate patient BSA
- Calculate expected ECMO flow for patient
- Remain with perfusionist to assist
- Run **circuit** blood gas if requested - MRN will be 001 - **Once printed ensure this gas is handed back to the perfusionist and not read as 'patient' blood gas**

Perfusionist

- Ascertain patient size & BSA
- Bring ECMO trolley/circuit from ECMO Pump store room
- Identify ECMO nurse
- Check drugs drawn up by ECMO nurse - CaCl, Heparin, $NaHCO_3$, Albumin and Blood
- Ensure pump is appropriately primed and air free
- Inform Team Leader and surgeon when circuit is ready for connection
- Establish patient on ECMO and manage until stable
- Perform safety check with ECMO nurse

PICU Medical Team Leader

- Direct acute event
- Liaise with Nursing Team Leader
- Ensure that the intensivist, surgeon, perfusionist, theatre staff and anaesthetist have been informed
- Ascertain current haematological status of patient
- Check with ECMO nurse that there is a valid X-match and blood product availability

PICU Nursing Team Leader

- Activate or delegate ECMO activation as per tiered calling card
- Allocate and direct nursing staff as required
- Ensure all roles are allocated with role allocation stickers if ECPR
- Maintain update of situation
- Liaise with Medical Team Leader - Cross check that intensivist, surgeon, theatre staff and perfusionist have been informed
- Ensure all non- essential staff leave the room
- Surgical Attire for all staff (caps, masks)
- Provide privacy for patient and family
- Notify Social worker to support family

Surgeon

- Elicit patient update
- Scrub and gown
- Instruct medical and nursing staff on desired patient position to cannulate
- Prep and Drape
- Request cannula sizes suitable for patient
- Clearly instruct when Heparin bolus for patient is to be administered
- Cannulate the patient and obtain haemostasis
- Secure cannulas

Theatre Scrub Nurse

- Bring additional ECMO equipment trolleys from OT including ECMO cannulation trolley
- Receive handover from equipment nurse
- Scrub Nurse to scrub and set up instruments
- Assist with skin prep and draping
- Count with Scout nurse

OT Scout Nurse

- Set up Diathermy/suction trolley to high Suction and power if not already
- Attach Diathermy plate to patient
- Assist with medical head lamp
- Write up MR 18 count sheet and perform count with Scrub Nurse

Procedure

- Position child in appropriate position for cannulation - this depends on site to be cannulated - Surgeon to advise
- Once vessels are exposed and ready to cannulate, a heparin loading dose of 100 - 200 units/kg is administered ONLY at the time of the surgeon's request
- The patient ACT should be checked to ensure adequate heparinisation: If ACT <200 then further dose of 50 - 100 units/kg heparin to be administered
- The circuit and cannulae must be air-free when connected together
- ECMO initiated
- Check adequate blood flow achieved and no air entrained
- The surgeon will secure cannulae at insertion site
- X-ray should be obtained to confirm cannulae position at discretion of team

12 ECPR - Extracorporeal Cardiopulmonary Resuscitation

Definition & purpose

- When ECMO used as part of initial resuscitation from cardiac arrest (as defined by Extracorporeal Life Support Organisation (ELSO))
- ECMO initiated during CPR can provide blood flow and gas exchange during the low flow phase of CPR potentially resulting in improved end organ function and brain perfusion during CPR
- In conjunction with good quality CPR with minimal interruptions to chest compressions, can reduce end organ injury and improve outcome

Aim:

- ≤30 minutes from arrest time to ECMO flow
- Not achievable after- hours thus duration of CPR alone cannot be used to exclude patients

Patient Selection and Decision Making

The limited time available for decision making during active CPR complicates patient selection for ECPR. Predetermined ECMO status is beneficial although not always decided for every patient in PICU. However any post bypass patient will be an ECMO candidate unless otherwise indicated.

Early decision making is important and at any point of the activation process ECMO can be stood down.

Activation Process

- Resuscitate patient as per ALS algorithm
- Consultant/Fellow to request activation of ECMO
- Nursing T/L to delegate or make calls to activate ECMO as per tiered calling system and fill out activation form in the book at the front desk
- Nursing T/L ensure all nursing rolls in place including nomination of ECMO nurse (use resuscitation allocation stickers)
- Equipment nurse/runner and any additional staff to set up bedspace (Link to 5)
- ECMO nurse to help retrieve ECMO equipment from back door alcove and commence drawing up circuit prime drugs
- ECMO nurse notify perfusion on their arrival that they are the ECMO nurse and hand them drugs and PRBC (unspiked) that has been checked by x2 RNs
- All other roles including surgeon, theatre nursing staff and perfusion required for cannulation and initiation of flow see ***Predefined roles for staff*** section

ECPR for patients outside of PICU/OT/Cath Lab

- Apart from the NICU, any patient in established or imminent cardiac arrest should have a 'Code Blue' called which means attendance from the PICU Outreach Service (See BTF Policy)

Emergency Department:

- Code Blue call & PICOS team arrive
- PICOS team to notify & discuss with PICU Consultant along with ED Consultant to determine if patient is an ECMO candidate - Decision lies with PICU Consultant
- If YES: PICU Consultant to notify Pod 1 Nursing T/L to activate ECMO (give name and weight) and the nursing T/L will activate as per normal process (Link) and allocate staffing for patient and prepare bedspace/equipment
- Before moving from ED if possible ensure:
    1. Airway secure
    2. IV access
    3. Rolls identified for transfer
    4. Notify PICU on route as rapid transferring out of ED
- Continue CPR during transfer
- Use lifts and back door of PICU
- On handover to PICU: PICOS team handover to floor staff
- Rapid transfer to PICU bed so cannulation process can commence

Wards:

- Code Blue call & PICOS team arrive
- PICOS team to notify & discuss with PICU Consultant to determine if patient is an ECMO candidate
- If YES: PICU Consultant to notify Pod 1 Nursing T/L to activate ECMO (give name and weight) and the nursing T/L will activate as per normal process (Link) and allocate staffing for patient and prepare bedspace/equipment
- On moving from ward:

    Rolls identified for transfer

    Notify PICU on route as rapid transfer

    Continue CPR during transfer

    Use shortest route to PICU

    On handover to PICU: PICOS team handover to floor staff

    Rapid transfer to PICU bed if ward bed inappropriate (i.e. cot) so cannulation process can commence

NICU:

- Attend NICU if called for assistance with or without Code Blue
- PICOS team to notify & discuss with PICU Consultant along with NICU Consultant to determine if patient is an ECMO candidate. Decision lies with PICU Consultant.
- If YES: PICU Consultant to notify Pod 1 Nursing T/L to activate ECMO (give name and weight) and the nursing T/L will activate as per normal process (Link) and allocate staffing for patient and prepare bedspace/equipment
- On moving from NICU
  - Rolls identified for transfer
  - Notify PICU on route as rapid transferring out of ED
  - Continue CPR during transfer
  - Use shortest route to PICU
  - On handover to PICU: PICOS team handover to floor staff
  - Rapid transfer to PICU bed so cannulation process can commence

*** Preferentially these patients should be transferred to PICU rather than OT in view of larger cohort of resources - If space immediately unavailable nursing T/L to arrange with theatre floor manager for transfer to OT ***

13 ECMO for Sepsis

- Sepsis remains a significant cause of mortality and morbidity worldwide
- Historically regarded as contraindication for ECMO, now a standard indication for extracorporeal support (studies demonstrated VA ECMO as lifesaving in neonatal and paediatric refractory septic shock)
- Aims to promptly reverse shock, restore organ blood flow and adequate tissue oxygenation whilst awaiting recovery supported by antibiotics and other treatments
- Key for good outcome = timely decision making about ECMO support – do not delay decision until patient is in severe multiorgan failure
- Other support modalities commonly required - Continuous renal replacement therapy (CRRT) , plasma exchange and plasmapheresis

Indications

- Refractory shock – despite fluid, inotropes, other pharmacological interventions, ventilation and any disease modifying therapy or if cardiac arrest occurs (the speed of shock progression and physiological decline of the patient can be more important than the absolute amount of inotropic support)
- Strongly consider with 2 or more inotropes at following doses:
  - Noradrenaline >0.2microg/kg/min
  - Adrenaline >0.2microg/k/min
  - Vasopressin > 30milliunits/kg/hr
- Rising lactate, progressive hypotension, multiorgan dysfunction

Relative Contraindications

- Septic oncology patient
- Septic shock with neutropenia
- Septic allogeneic bone marrow transplants

Contraindications

- Standard exclusion criteria as for VA ECMO

Cannulation Strategies and Flows

- Central VA ECMO most advantageous (though multiple cannulation strategy options for different haemodynamic shock patterns
- Central VA ECMO allows for:
  - Largest possible cannulae size
  - High flow rates (which may lead to faster resolution of shock)
  - Minimisation of excessive negative pressures (to avoid haemolysis)
  - Prevents differential cyanosis
  - Complete cardiac and pulmonary support
  - Likely to be associated with better outcomes and survival in children

Flows

- Goal directed aiming for
  - Rapid normalisation of lactate,
  - Improvement of SV02>70%
  - Restoration of age/weight appropriate mean arterial pressures
  - Reversal of multiorgan dysfunction
- Generally need much higher flows aiming for high Cardiac Index 3-5 – may need to consider upsizing cannula or additional venous cannula if unable to generate adequate flows with excessive negative withdrawal pressures

Coagulation

- Coagulation cascade is intricately involved in the inflammatory process – septic patients will commonly have disseminated intravascular coagulation (DIC)
- Use ECMO Haemostasis Management Protocol
- Consider use of nitric oxide (NO) and/or prostacyclin as an alternative to a heparin infusion to control bleeding and prevent clot burden:
  - NO is delivered into the ventilating gas of the oxygenator - contact perfusion & inhalation for set up
  - Prostacyclin infusion connected directly to ECMO circuit – contact perfusion

14 ECMO for COVID-19

- COVID-19 is not a contraindication to ECMO for the neonatal or paediatric population
- Use existing indications and threshold for consideration of ECMO:
  - Refractory hypoxemia and worsening despite lung protective ventilation, prone positioning, high PEEP, iNO and HFOV
  - ARDS
- The ELSO Coronavirus Disease 2019 Interim Guidelines published in 2020 have been developed to assist in existing ECMO centres to prepare and plan provision of ECMO during the pandemic
- All suspected or confirmed COVID-19 patients should have their ECMO status established proactively by the PICU team on admission and daily rounds.
- ECPR may be offered to patients that have arrested but will be a case-by-case discussion with consideration of patient co-morbities.

Please refer to the PICU COVID-19-CHW SOP for guidance on initiation, cannulation strategies, team composition and PPE

15 ECMO Initiation

The Perfusionist takes responsibility for commencing flows during initiation of ECMO. Clear communication with the surgeon and intensive care team is crucial to ensure the following:

- Where possible ensure patient ACT > 200
- When ECMO is initiated the clamp from the venous line is removed first
- The pump speed is increased to about 1000 RPMs
- The clamp from the arterial line is then removed and the pump speed increased until the desired flow is attained
- Flow should be increased at a rate that allows 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
- Gas (sweep) flow should be started once blood flow is established. Required gas flow will vary depending on the desired blood flow (start at 0.5 - 1 L/min gas flow: 1 L/min Blood flow)
- For detailed information for commencement of heparin infusion see Haemostasis management section
- Ventilation should be turned down to prescribed resting parameters once desired oxygenation is achieved - Usually PC with PEEP 10, PIP 20, Ti 1.0- 2.0 secs, Rate 10/min and FiO2 30%-40% ("Rest ventilation settings") - Check compliance and CXR findings and adjust ventilation individually after discussion with the PICU team

- Blood pressure should be monitored closely during commencement and inotropes and pressors weaned as ordered by the Intensivist - An intravenous vasodilator (e.g. Sodium Nitroprusside (SNiP)) will often be required to improve systemic blood flow
- A SNiP infusion should always be made up available for the patient (does not need to be attached to the patient), as hypertension on ECMO is considered an emergency and frequent in the eCPR setting given the previous administration of resuscitation drugs
- Inadequate flows should NOT be accepted upon initiation as this may reflect poor cannulae position
- Bridge flow is commenced only once adequate blood flow is established. Bridge flow is then restricted to minimum 150mL/min
- Full hand-over should be given to the ECMO specialist nurse by the Perfusionist with both parties being in agreement with current status
- The Perfusionist should write a note on ECMO initiation in the patient's EMR along with the details written on the 'ECMO Initiation' paper form
- A clear blood pressure target needs to be agreed on by the team – for VV ECMO oxygenation and ventilation targets should be discussed

16 Securing Cannulae

- Secure ECMO cannulae are vital to the safety of the child and therefore effectiveness of the therapy
- Centrally inserted cannulae - secured by sutures and Ioban
- Neck cannulation - directed around the head before passage down the body to the oxygenator - secured using a Velcro head band
- Femoral cannulation - secured to the patient's leg at the site and then distally to the insertion site

17 Securing ECMO Circuit

- Brakes are to be applied to the ECMO trolley and the bed at all times
- The only time the bed and circuit are secured together with straps is on transfer

18 Routine Care of ECMO Patient

- ECMO Risk Assessment Checklist to be completed each shift during the medical round.

Practitioners involved & responsibilities

PICU Consultant	Coordinate all care - provide 24 hour medical coverage with responsibility for all medical decisions involving ECMO whilst the patient is within PICU
Cardiothoracic surgeon	Provide 24 hour advice Attend to surgical procedures and offer input and support for ECMO related issues
ECMO nursing coordinator	Aid in the coordination of the multidisciplinary care team care Communicate with families Clinical resource to staff Responsible for the supervision, training and continuing education of the ECMO nurse specialists in conjunction with the ECMO Medical Lead & Perfusion team Responsible for collecting, storing &evaluating ECMO patient data which includes biannual reporting to ELSO Responsible for coordination & co-chairing of regular ECMO patient review meetings and ECLS Steering Committee meeting (both cover clinical and operational issues, patient outcomes and quality assurance)
ECMO medical lead	Oversees operation of the ECMO program in partnership with the ECMO Nursing Coordinator Responsible for assuring appropriate specialist training, directing quality improvement and providing leadership for the program
ECMO Nurse Specialist	Trained to manage the ECMO circuit and the clinical needs of the patient on ECMO Primary responsibility is to maintain extracorporeal support - troubleshoot alarms and equipment, assess the circuit for clots and management of circuit emergencies until additional assistance is available Collaborate and communicate with patient care nurse (additional PICU RN providing direct patient care) Fully accredited (green) ECMO nurse specialists have been signed off as completely accredited (three accreditations) by the ECMO nursing coordinator and perfusion team - if required and allocated they will have the overarching responsibility of supporting the ECMO patients and nursing staff after hours (night shift, weekends and public holidays) - they can be either allocated as the 'pump' nurse, the 'patient' nurse, ACCESS or team leader and provide clinical resource and trouble shooting

Perfusionist	Provide regular support and 24 hour cover from initiation and weaning of ECMO, priming of circuits, ECMO circuit maintenance, emergency management, provide support and act as a clinical resource to the nursing & PICU team 24 hours after initiation of ECMO if the patient scores satisfactory, low & yes on PICU ECMO Risk Assessment Checklist (and the team agrees) the perfusionist will be on call from home
Cardiologists, Radiologists, Haematologists, Social Workers and Physiotherapists	Provide additional support when appropriate
Primary physician and specialist teams	(For non-cardiac ECMO) provide advice and appropriate input for non ECMO related issues

Shift checks (ECMO Nurse)

- Spare ECMO console present
- Spare remote drive unit present
- Tubing clamps X 5
- Water level in ECMO heater
- Resuscitation drugs within expiry time (48 hours from preparation)
  - Adrenaline 1:10000 X 3
  - CaCl X 2
  - NaHC03 X 1
  - Atropine X1
- Emergency blood products available:
  - 2 x Packed Red Blood cells (PRBC) units and confirm cross match expiry
  - 20% Albumin 100mL (in PICU fridge)
  - 1 x Fresh Frozen Plasma (FFP) unit
  - 2 x Cryoprecipitate units if ≤15 kg or 4 x Cryoprecipitate units if >15kg
  - 1 x Platelets adult unit
- ACT cartridge availability - notify biomedical engineering department projected requirement time (spare cartridge boxes are kept in the fridge in the GNN blood gas lab)
- Validity/currency of crossmatch
- Adrenaline infusion prepared
- Sodium Nitroprusside infusion prepared (24 hour expiry due to stability)

- 4% Albumin or plasmalyte available for emergency volume
- Back up gas supply
- Air-eliminating filters are present on all infusions / lines delivering non cellular products
- Spare 02 tank with low flow regulator and bubble tubing with connector to hang off the side of the ECMO trolley (side where oxygenator sits)

Hourly checks (ECMO Nurse):

- Sweep gas setting
- RPM check
- Flow Check (including bridge flow)
- Circuit pressure check
- FiO2
- ECMO Heater temperature
- Dry connection sites
- Moisture level at gas outlet of oxygenator (consider scavenging or "sighing" of oxygenator gas outlet – appendix 2)
- Wound and cannulation sites
- Circuit clots

Constant circuit checks (ECMO Nurse)

- Air
- Foam
- Blood leaks

Flow Assessment

- Two displayed flows on Levitronix console:
  1. Total Flow - measured by flow probe on the venous withdrawal line immediately proximal to the bridge connector
  2. Patient Flow - passing through the centrimag pump head

Bridge Flow = Total flow – Patient flow

- Flow through the haemofilter bridge should be no less than 150mL/min – adjust gate clamp to obtain desired bridge flow
- Gate clamp should be moved along circuit once per shift to prevent tubing damage and local clot formation (Perfusionist responsibility)
- Flow probes do not require calibration in the Levitronix Centrimag system

Filling Pressures

- Individual patient filling pressure targets should be set by Intensivist – for VA ECMO usually maintained 2 - 10mmHg
- Notify medical team deviation outside target range
- Persistent raised LA pressure is a cause of inadequate LV rest – may be indication to drain blood directly from the LA via an LA vent or atrial septostomy

Circuit pressure check

- Inlet pressure reflects the "sucking" pressure generated by the centrifugal pump and is continuously monitored on the venous side of the circuit
- Changes from baseline pressure may indicate alterations to the patient's filling status, cannulae position, circuit integrity or monitoring error
- Expected inlet pressure values -10 to -30mmHg (but individual per patient)
- Target inlet pressure and management of deviations to be documented in ECMO orders as per Intensivist – notify intensivist and perfusionist of deviations
- Regularly assess pressure monitoring line for clot formation within tubing – notify perfusionist if any suspicion or measured pressure has not changed for a prolonged period of time (the perfusonist will flush the pressure monitoring line once a shift or as required)

Haemostasis management

- Ensure all other sources of heparin are removed - change heparin transducer syringes to 0.9% Sodium Chloride, check if TPN contains heparin
- Do not start Heparin in the bleeding patient unless instructed by the intensivist and cardiothoracic surgeon
- See Haemostasis Management Protocol (also seen in Section 19 (non-bleeding) and Section 20 (bleeding))
- Antithrombin III levels should be checked daily with morning bloods
- Heparin Infusion - 500units/kg in 50mL of 0.9% NaCl

  1mL/hr = 10units/kg/hr

  (do not use NAD/ when new infusion required change syringe and line unless running at 3-way tap between the pump head and oxygenator)

Venous saturation measurement & monitoring

- Venous oxygen saturation (SvO2) measured continuously by CDI 500 attached to the withdrawal line of ECMO circuit
- The CDI 500 requires calibration to arterial blood gas twice per shift or as required by the Perfusionist

- For VV ECMO or if LV vent in situ SvO2 measurement from blood entering the circuit is usually higher than the patient's true SvO2 due to recirculation of oxygenated patient blood into the circuit - knowledge of the patient's true venous and arterial saturations will enable assessment of the extent of recirculation

VA ECMO

- Value is helpful in assessment of oxygen delivery adequacy
- Generally aim to maintain > 70%
- If LV vent in situ SvO2 is not accurate indicator of systemic oxygen delivery adequacy – for accurate assessment, vent should be occluded however this carries high risk of sudden ventricular distension and should only be done under strict instruction of the cardiac surgeon and in the presence of the intensivist and cardiothoracic surgeon/fellow if the information is felt essential to be obtained

VV ECMO

- Value may be affected by recirculation of oxygenated blood from the return cannula
- Values are generally higher therefore may not reflect adequacy of oxygen delivery

SpO2/ ETCO2 Monitoring

- Oxygen saturations should be monitored in all patients however may be unreliable in the absence of pulsatile flow – crosscheck with arterial blood gases
- End tidal CO2 (ETCO2) should be monitored in all patients and cross-checked with arterial blood gases – avoid hypocarbia
- In VA ECMO ETCO2 is the only true reflection of acid/base status of lung tissue

Pathology

Activated Clotting Time (ACT) – high range

Indication & Frequency

- On admission to PICU (if ECMO in theatre)
- Prior to heparinisation of patient (if ECMO in PICU)
- Every 30 minutes until cannulation is complete
- On commencement of ECMO in bleeding patient and then as per Haemostasis Management Bleeding Protocol
- On commencement of ECMO and then as per Haemostasis Management Non Bleeding Protocol - every 30 minutes until Heparin infusion commenced once ACT < 200, then with every blood gas or blood sampling as ordered by medical team or if heparin dose adjusted
- Every 15 minutes during trial off ECMO
- If greatly different from previous ACT (> 20 seconds) and no significant changes have been made - recheck and notify PICU team (consider possible heparin dosing error if change in trend)

Process

- Insert high range cuvette into Haemochron jr
- Take 0.2mL blood from a non-heparinised line (Collect prior to ABG to reduce contamination and erroneous result)
- Insert blood into cuvette when directed to do so
- Press 'start' when directed to do so
- Record result (eMR ECMO page)

NB – Daily ACT quality control will be done by BME

SAMPLE	FREQUENCY
ACT	At initiation 30 minutely until start of heparin infusion at 30units/kg/hr (once <200) With each blood gas
Arterial Blood Gas	Every 15mins during initiation & following changes Hourly for first 12 hours 2-3hourly once stable Venous Blood Gas to be paired with ABG PRN
Anti-Xa	On admission/initiation (all patients) Non-bleeding – 4th hourly for 24 hours then 6th hourly unless Heparin dose changed then 4 hours post Bleeding – 4th hourly
AT III	On admission (all patients) Daily
Blood Culture/PCT/CRP	Daily
Coagulation profile (incl Fibrinogen)	On admission/initiation (all patients) Non-bleeding – 4th hourly for 24 hours then 6th hourly Bleeding – 2nd hourly
Cultures (other)	PRN
EUC, LFTs and CMP	On admission/initiation (all patients) At 4 hours then 6th hourly
FBC	On admission/initiation (all patients) Non-bleeding – 4th hourly for 24 hours then 6th hourly (aim Hb > 100g/L Hct > 30%) Bleeding – 2nd hourly (aim Hb > 110g/L Hct > 35%)
Plasma Free Haemoglobin	Daily (contact Perfusion for POC or send formal to lab) Following any intervention to reduce level Aim <0.5 - if consistently >0.5 with no other signs of haemolysis (rose coloured urine or SCUF) then send off formal levels to pathology

TEG	On admission and PRN Repeat after 15 min if Protamine given
Thyroid Function	PRN
Urine dip-stick	12 hourly

Additional fluid Management

- The haemofilter may be used to ultrafilter fluid from the patient in cases of renal failure or fluid overload or to make room for additional fluid to be given as enteral or parenteral nutrition
- Connection of a CVVH circuit to the ECMO circuit requires presence of perfusionist on call
- See section on CVVH on ECMO below

Imaging

Chest x-ray	Usually daily – see lifting/transfer section below
Head ultrasound	Daily for first three days then Every 48 hours or as indicated
Transthoracic ECHO (TTE) Transoesphageal ECHO (TOE)	As clinically indicated Consider increase of left ventricular preload - intravascular fluid bolus or reduction of ECMO flows Intensivist/Fellow and Perfusionist to be present
CT scan	Requires senior team order & presence – Intensivist/Fellow/, Perfusionist +/- cardiothoracic surgeon (must have knowledge of transport)
Cardiac catheter	Indicated in cases with high likelihood of residual lesion or as diagnosistic tool Requires senior clinician discussion - Cardiologist, Intensivist, Perfusionist and Cardiothoracic Surgeon Will require entire cardiac surgical team (surgeon, perfusionists, surgical fellow, cardiac anaesthetist, operating theatre nursing staff, cardiac catheter lab staff) - significant planning and coordination required

Lifting/ Turning/ Pressure Area Care

- Plan regular turns in consultation with MDT - inform on call Cardiac surgeon of planned lifts
- In rare circumstances where cannula position is difficult to secure, a Surgeon should be consulted and present prior to each turn
- For sternotomy cannulation aim ¼ turn side to side every 4 hrs – maintain head in line with body to avoid disruption of ECMO flow
- Nurse on pressure relieving mattress
- Where possible lifting should only occur between 0800-2000hrs unless urgent
- Use Jordan Frame for patients > 25kg for all lifting (pressure area care & x-ray) –- Cardiac surgeon to be present
- Attend pressure area monitoring during lifting – document in eMR
- Designate experienced ECMO nurse to ensure no tension is transmitted to cannula and no line kinking occurs - awareness of flow alteration and cannulae security is essential, monitor for alterations in inflow and outflow pressures or entrainment of air into the circuit

Circuit access

- NO FLUID OR INFUSIONS (except heparin infusion or prostacyclin infusion) may be added to the circuit
- In the case of dire lack of IV access for infusions – discuss with senior MDT (nursing, medical and perfusion) potential for running non vasoactive drugs through ECMO circuit
- Any medications or infusions added to the ECMO circuit must be delivered between the pump and the oxygenator
- Inotropes should never be infused directly into the circuit in-case of circuit problems affecting delivery
- ONLY Perfusion staff are permitted to add anything to the ECMO circuit

IV Antibiotic prophylaxis

- Routine for first 48 hours if centrally cannulated
- If percutaneously or peripherally cannulated then give a stat dose on cannulation – intensivist/Fellow will direct agent choice
- Daily blood cultures from arterial line plus additional cultures with any instability (including temperature instability)

Handover

Thorough handover between ECMO nurses to include:

- History of patient
- Course on ECMO
- Cannula Positions
- Check of ECMO circuit together – use bright light to check for clots, discuss functional status of all circuit components (in particular the oxygenator) and anticipate the need for planned changes
- Verify most recent set of documented ECMO observations
- Assess the patient's current condition

Nursing considerations

Neurological

- Hourly neuro observations, pupillary checks and fontanelle assessment
- Adequate analgesia, sedation and muscle relaxation, use scoring tools & document in eMR (See PICU Analgesia and Sedation guideline)
- Head midline and head elevation to facilitate venous drainage - head may be turned side to side if approved by Cardiac Surgeon and no issues with flows
- Observe for signs of seizures - patients on ECMO are at higher risk of seizures for various reasons (as most of these patients are paralysed and heavily sedated, they may not show any motor signs of seizures but they may still be having sub-clinical seizures) - consider EEG if any concern
- Daily break from muscle relaxant unless specifically contraindicated
- Meticulous monitoring of anticoagulation parameters to prevent IVH and emboli
- Eye-care
- If long ECMO run e.g. VV ECMO for ARDS anticipated plan sedation and analgesia goals with MDT and family - for example: aim not to muscle relax, aim comfort but awake with appropriate sleep/wake cycle, anticipate and manage delirium, engage parents and child life therapists with non-pharmacological therapies

Cardiovascular

- Assess circulatory status by warmth, colour of extremities, urine output and capillary refill (quality of peripheral pulses may not be a good indicator of systemic perfusion in V-A ECMO & arterial waveforms will be dampened unless allowing patient to eject)
- Hourly recording of SpO2, HR, ECG, invasive BP, CVP +/- LAP monitoring – consider appropriate preload and afterload management
- NIRS monitoring for all patients: cerebral and somatic
- Hourly circulation limb observations for femoral cannulation – colour, warmth, pulse, swelling, movement, sensation, Doppler (may indicate need for backflow cannula OR

efficiency of backflow cannula), additional NIRS monitoring on calf(s) if concern over peripheral perfusion

- Check cannula placement and stability
- Check air-eliminating filters are present & within 24hrs expiry time (can be done with syringe change if no longer than 48hrs) on all non-cellular intravenous infusions, and drug and fluid bolus lines
- Maintain strict fluid balance observations - include all blood, peritoneal, gastric and insensible losses (be aware that ABG/blood test sampling may average up to 50mL/day = to 20% of a neonate's circulating blood volume)
- Note the presence/absence of oedema

Respiratory

- Maintain lung rest parameters as ordered by Intensivist

  Usually: SIMV (PC) + PS
  PEEP 10
  PC/PS 10 above PEEP
  Ti 1.0 – 2.0 secs
  Rate 10/min
  FiO230- 40%

  (For VV ECMO, ventilation needs to be adjusted on case by case basis with the same overall goal to give rest to the lungs)
- Consider if lungs are still receiving substantial blood flow (e.g. a patent BT shunt, patent ductus arteriosus or MAPCAs) - near full ventilation support is required to optimize lung function and avoid pulmonary congestion and injury for these patients
- Suction ETT at least twice per shift - more frequently if clinical signs indicate - **suction catheter must not be inserted beyond the end of ETT due to risk of trauma in the heparinised patient - NO nasal or oral suction to be performed**
- If re-intubation required it is considered a non-urgent manner while on ECMO (VA and VV) - high risk of bleeding due to anti-coagulation (especially with nasal intubation) - discuss temporarily ceasing heparin with MDT
- If chest x-ray suggestive of significant lung collapse consider early bronchoscopy

Gastrointestinal

- NGT to be inserted prior to ECMO (where possible) – place on free drainage if not being used for enteral feeds
- If NGT or TPT insertion required on ECMO and heparin is running - discuss with Intensivist and Perfusionist (? temporarily stopping heparin) remembering that TPTs have guide wires

- Assess & document abdominal distension, quality of bowel sounds, tolerance of enteral feeding, bowels opened - avoid rectal administration of drugs or enemas
- Dietician involvement for caloric intake - TPN or enteral nutrition should be commenced by Day 2 unless contraindicated
- Gut prophylaxis (ranitidine or omeprazole) should be standard
- Avoid routine mouth care - risk of haemorrhage with anticoagulation

Renal

- Strict fluid balance + hourly documentation in eMR - include SCUF, aim urine output 0.5-1mL/kg/hr
- SCUF volume should be entered into the fluid balance chart (not the ECMO observations) as well as insensible losses for the duration of the ECMO run
- Consider diuretics for poor urine output with evidence of fluid overload
- Perform urinalysis at least once per shift

Family

- Provide communication to family
- Consider family coping mechanisms, strengths and needs ongoing
- Refer to social and pastoral care

NOTE: No change to be made to ECMO management plans without consultation with PICU Intensivist on call

NOTE: No direct connection of infusions or fluids to the ECMO circuit without consultation with the Perfusionist on call

REMEMBER: Anticoagulated state = no insertion or removal of anything without permission from the Intensivist on call - this includes IDC, NGT, TPT, PIVC, IAL, CVL and mouth care

19 Haemostasis management - Non-bleeding patient (<3mL/kg/hr)

Admission to PICU/theatre staff leaves PICU bed space; Established ECMO; Non-Bleeding <3ml/kg/hr

ACTION:

Observe drain output for 4 hours and confirm <3ml/kg/hr

Once observation period finished perform ACT (high range) every 30 min. Once ACT (high range) is **< 200** start Heparin

Starting dose of Heparin (no bolus)
30unit/kg/hr

TESTS:

ACT (high range)
FBC
Coagulation profile
Anti-Xa
Antithrombin III (do not treat)
TEG

ACTION:

4 hours AFTER heparin infusion started perform blood tests

1. Anti-Xa target range:

No clots	0.3 – 0.5
Clot present	0.5 – 0.7 (or higher after discussion with PICU and Haem)

2. Adjust HEPARIN dose by using measured Anti-Xa:

Anti-Xa	Heparin dose adjustment	Anti-Xa	Heparin dose adjustment
<0.1	↑ by 10 unit/kg/hr	<0.1	↑ by 10 unit/kg/hr
0.1 – 0.3	↑ by 5 unit/kg/hr	0.1 – 0.3	↑ by 10 unit/kg/hr
0.3 – 0.5	No change	0.3 – 0.5	↑ by 5 unit/kg/hr
0.5 – 0.7	↓ by 5 unit/kg/hr	0.5 – 0.7	No change
>0.7	↓ by 10 unit/kg/hr	0.7 – 0.9	↓ by 5 unit/kg/hr
		>0.9	↓ by 10 unit/kg/hr

If Anti-Xa >1.5 review heparin bolus time/rate adjustment and/or review dose given of ATIII. Discuss with senior ICU staff

3. Anti-Xa and Antithrombin III (ATIII)
Prior to adjusting ATIII the dose of Heparin should be >40 U/kg/hr

Antithrombin III normal range >50

Circuit clots	*Anti-Xa level*	*AT III*	*Action*
Yes	0.5 – 0.7	<50	repeat Anti-Xa in 4 hrs
Yes	<0.5	<40	give 100-150U/kg ATIII conc
Yes	<0.5	40-50	give 30ml/kg FFP
No	0.3 – 0.5	<50	repeat Anti-Xa in 4 hrs
No	<0.3	<50	↑ Heparin as above

4. Platelets >80
If <80 then give 15 ml/kg

5. Fibrinogen >1.5
If <1.5 then give ≤15 kg 2 bags cryo; >15kg 4 bags cryo

6. Haematocrit >30%
If <30% then give 15 ml/kg PRBC

If output increases to **≥3ml/kg/hr ONCE Heparin established** then "Bleeding protocol" should only be used as a guide. Huddle to occur between Intensivist / Cardiothoracic surgeons / Haematologist to decide patient specific management plan

TESTS:

Every hour
ACT (high range – if the difference is more than **20 seconds** this needs to be discussed with ICU team)
Blood gas

Every 4 hours (for 24 hrs) after heparin started or heparin dose adjusted
FBC
Coagulation profile
Anti-Xa

After 24 hours on ECMO

Hourly	ACT (high range)
8th hourly	Anti-Xa
	FBC
	Coag profile
Daily	AT III

TO NOTE:
Review Anti-Xa **4 hours** after
- FFP bolus
- ATIII concentrated

HAEMOSTASIS ROUND:

Daily "HUDDLE" to occur with
- ICU staff (ECMO nurse and Staff Specialist +/- Fellow)
- Perfusionist
- Haematologist on call

20 Haemostasis management - Bleeding patient (>3mL/kg/hr)

Admission to PICU/theatre staff leaves PICU bed space; Established ECMO; Bleeding ≥3ml/kg/hr
DO NOT start Heparin unless specifically instructed by intensivist and cardiothoracic surgeon

ACTIONS:

Hour 1 – please do the following:
Perform Heparinase TEG
Give in sequence/simultaneously:

If blood loss 3-10ml/kg/hr → Monitor CVP; Consider SCUF, following consultation with intensivist, if concerns arise +/- rise in CVP

1. Cryoprecipitate STAT - 10 min
   - ≤15 kg 2 bags of cryoprecipitate
   - >15 kg 4 bags of cryoprecipitate

   DO NOT wait for Heparinase TEG result
2. Platelets → 30ml/kg if <10kg; 1 adult bag if ≥10kg - 30min
3. FFP → 20 ml/kg - 45 min

Ensure that Haematocrit is ≥ 35%
- 30-34% give 15ml/kg PRBC
- <30% give 25ml/kg PRBC

IF Heparinase TEG shows significant heparin activity
- give 1mg/kg of Protamine

Ensure ionised calcium (Ca^{2+}) >1.2

TESTS:

ACT (high range)
TEG
(If Protamine is given repeat TEG after 15 min)
FBC
(Platelets >150)
Coagulation profile
(Fibrinogen >2.0)
Anti-Xa
Antithrombin III

Hour 2 - Monitor drain losses and Hct/Hb
Complete administration of blood products from 1st hour
Replace with FFP, 4% Albumin or PRBC as clinically directed

Do after all blood products given from 1st hour
FBC → Plts >150
Coagulation profile → Fib >2.0

Hour 3 - if bleeding (≥3ml/kg/hr)
1. Platelets → 30ml/kg if <10kg; 1 adult bag if ≥10kg
2. Tranexamic acid (TXA) – 100mg/kg load then 10mg/kg/hr

Hour 4 - Monitor drain losses and Hct/Hb
Replace with FFP, 4% Albumin or PRBC as clinically directed

FBC → Plts >150
Coagulation profile → Fib >2.0

Hour 5 - if bleeding (≥3ml/kg/hr)
d/w Senior staff (PICU, haematologist and Cardiothoracic)
1. Surgical exploration
2. Use of Factor VIIa – 90 mcg/kg

Hour 6 - Monitor drain losses and Hct/Hb
Replace with FFP, 4% Albumin or PRBC as clinically directed
If **losses** have been **≥3 ml/kg/hr for 6 hours** then return to first hour (ignore Heparinise TEG)

FBC → Plts >150
Coagulation profile → Fib >2.0
Anti-Xa

If <3ml/kg/hr for >4hrs follow Non-Bleeding - ECMO post-op cardiac/sternotomy protocol

21 Ward Rounds & Documentation

A collaborative approach is essential for the care of patients on ECMO.

Routine review of ECMO patients:

- PICU consultant &/or Fellow at ward rounds (morning & evening) & be present for ECMO Risk Assessment
- Perfusionist at morning cardiac rounds, present for ECMO Risk Assessment and before leaving the hospital
- Haemotology team as a part of a weekly huddle with ICU and perfusion - initial huddle at beginning of ECMO run and weekly thereafter unless advice required

Documentation:

- ECMO Risk Assessment Checklist must be completed on each shift on paper form and documentation in eMR by ECMO nurse
- Repeat ECMO Risk Assessment if patient/circuit condition changes & concerned or procedure & or treatment completed which could potentially change level of risk
- Daily ECMO orders and actions to be completed by Intensivist or Fellow
- Discussions of patient care with relevant teams to be documented in eMR by PICU registrar (including objectives for shift)

22 Common Problems

Flow Issues

- The centrifugal pump is sensitive to preload & afterload
- Changes in preload & afterload will alter circuit and patient blood flow and thus oxygen delivery adequacy
- Markers of inadequate patient oxygen delivery:
  - Decreased circuit SvO2
  - Increased arterial blood lactate
  - Decreased arterial pH and increased anion gap
  - Decreased urine output
  - Decreased tissue saturation (NIRS rSo2i)
  - Hypotension – late
- In VV ECMO reduced flow markers:
  - Low patient arterial oxygen saturation
  - Increased arterial CO2

Inadequate flow - increasingly negative venous pump inlet pressure

- Decrease in pump pre-load is most likely cause
- Potential contributing factors:
  - Hypovolaemia
  - Tamponade with compression of the right atrium due to clot
  - Patient head position change
  - Change in venous cannula position
  - Kinking or pressure on pump inlet line
  - Clot in pump inlet line
- Management:
  - Check circuit for inlet line obstruction/clot
  - Correct head position to midline
  - Bolus isotonic intravascular volume - note effect on CVP, inlet pressure and blood pressure
  - If persistent - contact cardiothoracic surgeon on call ?tamponade and changes in venous cannula position
  - Surgical re-exploration is required if adequate flows cannot be reliably maintained despite above measures, particularly if persistent volume boluses are required

Decreasing blood flow - no increasingly negative venous pressure

- Increase in pump afterload is most likely cause
- Potential contributing factors:
  - Increase in vascular resistance
  - Change in arterial cannula position
  - Clot in oxygenator
  - Clot in arterial tubing or cannula
- Management:
  - Check circuit for outlet line obstruction / clot
  - Check oxygenator for large clot(s)
  - Correct head position to midline or best position
  - Consider (increased) vasodilator - unless hypotensive
  - Request perfusionist assess return line pressure
  - If persistent - contact cardiothoracic surgeon on call to check arterial cannula position

Gas exchange issues

- Oxygenation (paO2) mainly determined by FiO2 of sweep gas & blood flow through oxygenator
- Carbon dioxide (paCO2) elimination mainly determined by total sweep gas flow & blood flow through oxygenator
- Depending on mode (VA vs. VV), degree of pulmonary blood flow and lung pathology, ventilation settings may also influence gas exchange (usually set at rest parameters)
- Aims for VA ECMO:
  - paO2 100-150mmHg
  - Sa02 to achieve paO2
  - paCO2 35-55mmHg
- Aims for VV ECMO:
  - Sa02 >80-85%
  - pa02 to achieve Sa02 as above
  - Normal paC02

Interpretation and management of gas exchange on VV ECMO

Arterial Saturation	Venous Saturation	C02	Interpretation	Management
Increasing	Increasing or stable	Stable	Patient is improving	Wean ECMO gas flows
Decreasing	Decreasing or stable	Increasing	Patient is worse	Check cannula/patient position. Increase ECMO Fi02, sweep gas and or pump flow.
Decreasing	Increasing	Increasing	Increased recirculation most likely due to change in cannula positioning	Check cannula/patient positioning. Consider giving volume Consider decreasing ECMO flows as sometimes high flows can cause more recirculation.
			High native cardiac output	Evaluate native cardiac output. If the native cardiac output increases and the ECMO flows remains the same, more blood is going to the lungs and more deoxygenated blood is coming to the left side of the heart. One of the strategies to manage hypoxia secondary to this issue is to decrease the native cardiac output. Consider using beta-blockers (Esmolol).
Increasing (high)	Increasing	Decreasing (low)	Over ventilation PaC02 is decreased	Wean Fi02, wean sweep gas flow.
Decreasing (Low)	Decreasing	Increasing (high)	If acute	Check oxygen tubing connections, wall gas or blender. If blender failure swap to spare gas & flow rotameter
			If slowly worsening & steady increase in Fi02/Sweep Gas	Consider failing oxygenator

Low patient paO2

- Possible causes:
  - low ECMO flow rate
  - decreased pulmonary flow
  - gas tubing leaks
  - build-up of moisture in oxygenator gas phase
  - oxygenator failure
  - sweep gas FiO2 too low
- Management:
- Burp/Sigh oxygenator - Appendix 2
- Increase sweep FiO2 & check for gas leak
- Optimise ECMO blood flow
- Check oxygenator for clots (pre and post oxygenator gas should be checked)
- Increase patient lung FiO2 (temporary solution)
- ECHO to rule out R->L shunt (e.g. PDA)

High patient paCO2

- Possible causes:
  - Inadequate total sweep gas flow
  - Large clots in oxygenator
  - Build-up of moisture in oxygenator gas phase
- If CO2 is being used in gas mix, regularly check flow as it may have changed
- Management:
  - Burp/Sigh oxygenator - Appendix 2
  - Increase total sweep gas flow and check for gas leak
  - Optimise ECMO blood flow
  - Check oxygenator for clots (pre and post oxygenator gas should be checked)
  - Increase patient lung ventilation (temporary solution)

Low patient paCO2

- Possible causes:
  - Excessive sweep flow rate
  - Over-ventilation of lungs

- Management:
  - Decrease total sweep gas flow
  - Reduce patient lung ventilation
  - Consider adding CO2 gas to the sweep gases

Prolonged Acidosis

- Reassess flows
- Reassess fluid status
- Reassess vasodilator therapy
- Suspected infection - Full septic screen & broad spectrum IV antibiotics
- Consider buffering non-anion gap acidosis with bicarbonate to optimise catecholamine sensitivity and myocyte function

Abnormal Bleeding

- All patients are usually anticoagulated & bleeding is common
- Severe bleeding (≥3mL/kg/hr) not related to circuit rupture or decannulation can occur
- Bleeding may be:
  - Visible
  - Concealed
  - Altered observations – hypotension, tachycardia, fontanelle changes (tense or sunken), abdominal distension & firmness - in neonates monitor abdominal girth and anterior fontanelle
  - Drop in Hb
- Tamponade on ECMO features:
  - Rising CVP
  - Increasingly negative withdrawal pressures & inability to achieve required flows
  - constant need to administer volume to maintain flows
  - blocked chest drains
- Suspicion of cardiac tamponade - urgent review by cardiothoracic surgeon on call ? need for chest exploration
- Follow ECMO Haemostasis Management Protocol (also found in Section 19 and 20)
- Factor VIIa requested - MUST have Perfusionist present & pre-primed replacement circuit on standby
- Inform cardiothoracic surgeon on call & prepare for re-exploration of chest if bleeding is persistent and un-responsive
- Cell saver may be required if bleeding remains excessive (12-24hrs)
- For Rare/extreme circumstances of uncontrolled bleeding:
  - ONLY under instruction of Intensivist:

  - Stop Heparin infusion whilst monitoring ACTs
  - Commence prostacyclin infusion 5 - 10ng/kg/min into proximal circuit (post pump) +/-
  - Add nitric oxide 20ppm to the gas phase of the oxygenator (set up by inhalation & perfusion)
- For rare circumstance of bleeding trauma patient on ECMO:
  - Under direction of Intensivist/Cardiothoracic Surgeon/Haemotology
  - See Trauma - Code Crimson and Massive Transfusion Protocol

Clot Formation

- Anticoagulation must be balanced against need for surgical haemostasis
- Hourly circuit clot checks & documentation in eMR (use PICU cold light to assist in clot visualisation)
- Clots tend to form at circuit connectors, haemofilter and oxygenator
- Document & hand over all clot formation
- Clot formation (small) pre-oxygenator:
  - Monitor
  - Unlikely to cause significant patient issues)
- Clot formation post oxygenator management:
  - Increase target Anti-Xa levels to 0.5-0.7
  - Immediately inform Intensivist and Perfusionist
  - Assess indication for circuit change or component cut out (See Section 27)

Decreased Urine Output

- Potential causes:
  - Inadequate renal blood flow
  - Renal hypoxia resulting in renal damage
  - Renal tubular damage (e.g. medication, haemoglobinuria)
  - Renal artery / vein thrombosis
  - Abdominal compartment syndrome
  - Sepsis
- Management:
  - Ensure adequate circulation and renal blood flow
  - Check urine for haemoglobinuria
  - Check urea, creatinine and electrolytes
  - Consider renal ultrasound
  - PD, CRRT may be required

Pulsatile Arterial Trace (VA ECMO)

- Usual distinctive arterial pressure trace (with peak each time the ventricle ejects) will begin to flatten as circuit flow is increased and the heart ejects less blood
- Pulsatility on the arterial line trace is rarely a bad thing on ECMO - indicates that the left heart or systemic ventricle is capable of ejecting
- Causes:
  - Systemic to pulmonary flow (e.g. PDA, patent shunt, MAPCAs)
  - Lesions causing systemic arterial valve regurgitation (e.g. aortic or truncal regurgitation)
  - Reduced volume loading (e.g. SCUFing, diuresis) and reduced SVR (vasodilating after the immediate ECMO initiation) can cause ejection to subside
- Concern if ejection goes away that something has changed

Abnormal ECG

- ECMO flow should not change the ECG
- Continuous monitoring of ECG for evidence of arrhythmia and myocardial ischemia
- VA ECMO - the heart does not normally eject & myocardium rest is goal
  - Report ECG changes or abnormalities to Intensivist
  - Treat malignant tachyarrhythmias and fibrillation
  - Maintain coronary perfusion pressure
- VV ECMO - patient circulation is dependent on cardiac output
  - Urgently treat any tachyarrhythmia

Abnormal Neurological Examination

- ECMO patients are prone to neurological sequelae of brain ischemia, thromboembolism and haemorrhage
- Daily muscle relaxant breaks are encouraged to enable thorough neurological assessment
- Intraventricular haemorrhage may manifest with falling Hb – US or CT head
- Document hourly neurological observations including pupillary reaction – inform Intensivist of changes
- Treat seizures promptly – consider early EEG monitoring if suspicious
- Continuous EEG monitoring recommended for initial 48-72 hours of ECMO (especially in patients who received ECPR)

23 Emergency management

- ECMO emergencies are extremely uncommon events that require a rapid response
- Any emergency involving ECMO flow is likely to require CPR - activate arrest bell
- In the event of an emergency – follow the tiered calling card as for ECMO initiation
- ECMO & patient nurse to discuss roles in event of emergency at start of shift after handover - pertinent to discuss with other nurses in room

'Taking Patient off ECMO in an Emergency'

- **ECMO nurse** state "This is an ECMO emergency"
- Patient nurse:
  - Press emergency bell
  - Increase patient ventilation to full settings & FiO_2 to 100%
  - Give 10 – 20mL/kg volume bolus
  - Instigate inotrope therapy + consider further volume
  - Commence chest compressions if required
    - target diastolic BP >25mmHg (if IAL in situ)
    - take care not to displace ECMO cannulae
    - internal massage only by cardiothoracic surgical team
  - Use ZOLL non feedback defib pads (central cannulation)
  - Inform Intensivist, Surgeon and Perfusionist

- ECMO Nurse:
  - Clamp circuit distal to oxygenator (arterial)
  - Clamp circuit proximal to pump head (venous)
  - Stop Pump
  - Turn off sweep flow
  - Turn off heparin infusion to circuit
  - Correct problem before ECMO is reinitiated

Sudden Circuit Flow Cessation

- Flow alarm should sound
- Sudden flow cessation possible causes:
  - Circuit air
  - Pump head malfunction (noisy pump head)
  - Disposable pump head failure
  - Pump head drive unit failure
  - Console failure
- Circuit obstruction possible causes:
  - Large clot burden
  - Torsion
  - Kinking
  - Compression of tubing
  - Loss of circuit integrity
- Patient condition change - hypotensive and/or hypoxaemic and hypercapnic

Flow interruption associated with pump head unable to be diagnosed & corrected immediately requires immediate transfer to alternate remote pump head drive unit

Air in circuit

Venous air

- Potentially infused into right atrium via:
  - IV lines
  - Entrained from atmosphere around venous cannulae (position/ tubing)
  - Stopcock /connector problems
- Potentially transmitted by the pump head through oxygenator and into arterial circulation
- If sufficient amount to de-prime pump head circuit flow will automatically stop due to major circuit disruption pre-pump:
  - **Take patient off ECMO as per 'Taking patient off ECMO in Emergency'**
- If air seen but circuit flow continues unchanged or with only minimal reduction:
  - Prepare to come off ECMO as per 'Taking patient off ECMO in Emergency'
  - Find site of air introduction and seal if possible
  - Check for air in IV infusion lines
  - If venous cannulae suspected as air entrainment cause – inform cardiothoracic surgeon immediately
  - Check venous cannula has not rotated slightly due to torque from the circuit tubing(the right angled venous cannula have dotted lines which should be in line with each other)
  - Small amounts of pump head air will break up and be captured by oxygenator

Arterial air

- Visible air distal to oxygenator potentially:
  - transmitted from venous side of circuit
  - due to oxygenator rupture
- Come off ECMO as per 'Taking patient off ECMO in Emergency'
- Place patient in head down (Trendelenburg) position
- Consider:
  - hypothermia to 34°C (by turning off ECMO heater/active cooling)
  - barbiturates
  - steroids
  - mannitol
  - lignocaine
  - transfer to hyperbaric unit
- Re-institute ECMO with de-aired or new circuit

Air within oxygenator

- Visible air within the oxygenator potentially from:
  - improper priming procedure
  - membrane rupture
  - high gas flow with low blood flow
  - pump head
  - venous line
  - connectors
  - access sites
- On arterial side of oxygenator:
  - Prepare to come off ECMO as per 'Taking patient off ECMO in Emergency'
  - Oxygenator +/- circuit likely to require replacement (Perfusionist only)
  - Observe closely for air into arterial side of circuit
- On venous side of oxygenator:
  - Bubbles visualised on superior aspect
  - Observe for any reversible cause of entrained air and correct
  - Inform Perfusionist immediately
  - Continuous stream of micro air from venous side can be transmitted to arterial side - maintain constant vigilance & prepare to clamp circuit immediately if any air is seen on arterial side manual removal (by Perfusion only) requires clamping of the circuit:

Manual removal of air from venous side of oxygenator

- Prepare resuscitation volume
- Prepare 50mL syringe to connect to venous port 3-way-tap on superior aspect of oxygenator
- Perfusionist will manually aspirate air with the 50mL syringe
- Heparin bolus may be required (due to aspiration of heparin during de-airing procedure) to reprime the pigtail line from the top of the oxygenator
- Gradually increase circuit flow and observe closely for further air entrainment

Pump Failure

Pump Head Decoupling

- Pump flow dependent on magnetic coupling of disposable pump head and remote pump head drive unit
- Mechanical decoupling may present as rattling or grinding noise leading to rapid decrease in flow and sometimes complete cessation of circuit flow
- Check for correct orientation of pump head assembly
- If problem persists:
  - Prepare to come off ECMO as per 'Taking patient off ECMO in an Emergency'
  - Clamp circuit distal to oxygenator
  - Clamp venous line
  - Stop pump and check disposable pump head correctly inserted
  - Unclamp venous line
  - Increase RPM to 1000
  - Unclamp arterial line
  - Increase pump speed controller to previous rpm setting
  - Flow should return to previous levels and noise no longer audible
- If noise persists, but flow achieved:
  - Repeat decoupling procedure
  - Reassess continuing ECMO
  - call Perfusionist
- If noise persists, but flow decreased:
  - Indicates imminent pump head failure
  - Transfer to alternate remote pump head drive unit
  - Call Intensivist and Perfusionist urgently
  - Prepare for component and / or circuit change

Disposable Pump-head Failure

- Manifests as:
  - Blood leaking from pump head
  - Reduction in flow with a noisy pump head
- Component needs to be changed
- Small blood loss or reduction in flow:
  - Change can be planned
  - Replace lost volume
- Large blood loss or significantly reduced flow:
  - Take patient off ECMO as per 'Taking patient off ECMO in an Emergency'
  - Prime new pump head
  - Perfusion to connect to circuit

Remote Pump Head Drive Unit Failure

- Manifests as:
  - Significant reduction or complete cessation in flow
  - With or without noisy pump head
- Sudden and complete cessation of flow without preceding noise likeliest to be electrical fault or disconnection between console and pump head
- For electrical motor failure transfer to alternate remote pump head drive unit (below)
- For electrical mains failure pump will run for the displayed number of hours on the console without mains power

Transfer to Alternate Remote Pump Head Drive Unit

- Press arrest bell
- Clamp circuit distal to oxygenator (arterial)
- Clamp circuit proximal to pump head (venous)
- Pump will already be stopped in pump head failure
- Remove disposable pump head and insert into alternate pump head drive:
  - Unscrew the pin
  - Place fingers around pump head & rotate the pump head in a clockwise direction
  - Pull out pump head – do not pull directly on tubing
- Place pump head into new drive unit - allow magnet to draw it in
- Slightly rotate anti-clockwise to lock

- Check display - 'pump head not inserted' should have disappeared from channel now in use
- Screw in retaining pin
- Remove proximal clamp (venous)
- Increase displayed RPM to minimum of 1000
- Remove distal clamp (arterial)
- Increase RPM till desired flow is achieved – plan for prior flow to be re-established
- Note and inform Intensivist/ Perfusionist of any deviation from prior baseline values

Transfer to Emergency Hand-Crank - Medtronic Bio-console only

- Press arrest bell
- Clamp circuit distal to oxygenator (arterial)
- Clamp circuit proximal to pump head (venous)
- Stop Pump
- Remove disposable pump head & Jostra pump head adaptor together - attach to hand-crank unit
- Crank pump manually in the direction of arrows displayed on hand-crank unit
- Hand-crank rpm will be displayed hand-crank unit – increase to previous rpm
- Remove proximal and then distal clamp
- If console remains operational note flow achieved in circuit

Loss of circuit integrity

- Come off ECMO as per 'Taking patient off ECMO in an Emergency'
- Place additional clamps before and after circuit integrity disruption
- Give volume to replace lost volume as indicated
- Contact Perfusionist urgently for repair, reprime and recommencement of ECMO

Accidental Decannulation

- Come off ECMO as per 'Taking patient off ECMO in an Emergency'
- Apply firm pressure to site of bleeding
- Position patient in head down (Trendelenburg) position
- Notify surgeon and prepare for recannulation in PICU
- Replace blood loss on a volume for volume basis
- Consider activating Code Crimson

Oxygenator Failure

- Manifests as:
  - Decreasing patient saturations
  - Decreasing post oxygenator pO_2
  - Increase in $PaCO_2$ without flow manipulation
- Causes:
  - Moisture build-up within the gas phase (most common)
  - Disruption of gas supply
  - Consider excessive clot formation within oxygenator (unlikely)
- Management:
  - Burp/ Sigh the oxygenator (Appendix 2)
  - Compare pre and post oxygenator blood gases to confirm if rectified or failure of oxygenator
  - Increase oxygenator FiO_2 to 100% and increase sweep gas flow to maximum V:Q ratio 2:1
  - Consider increasing patient lung ventilation
  - Review anticoagulation if excessive clots seen in oxygenator
  - Consult perfusion for planned replacement if declining performance persists
- Suspect membrane rupture if blood leaking from gas exhaust at bottom of oxygenator or air seen at top of oxygenator:
  - Do not burp/sigh oxygenator
  - Temporary cessation of ECMO is required
  - Prepare to come off ECMO as per 'Taking patient off ECMO in an Emergency'
  - Replace volume loss from oxygenator mL for mL
  - Prepare for replacement of oxygenator/circuit by perfusion (circuit clamping)

Oxygen Delivery Failure

Wall gas failure

- Automatic transition to spare oxygen and air tanks on ECMO circuit trolley
- Audible alarm
- Total sweep gas flow reduced (lower gas pressure in cylinders compared to wall) – check rate

Wall & cylinder failure

- No audible alarm (relies on pressure difference)
- Sudden drop in patient saturation

- Sudden increase in ETC02
- Decreased post oxygenator paO_2
- Increased post oxygenator $PaCO_2$ - if running C02 this may now be only gas running

Management:

- Notify patient nurse to start manual hand ventilation
- Press arrest bell
- Check oxygen bubble tubing connections from back of oxygenator blender
- Remove oxygen bubble tubing from nipple at back of blender and attach to spare oxygen tank (with low flow meter) at side of the ECMO trolley (larger patients with higher sweep flows may require normal high flow meter)
- Set the flow at sweep gas flow setting (mindful C02 was running) to deliver 100% oxygen
- Notify perfusionist and troubleshoot on their arrival

Heat Exchanger Failure

- Manifests as:
  - Blood visible in heat exchanger water
  - Sudden unexplained haemolysis
- Management:
  - If patient has no ability to support own circulation turn off heat exchanger and maintain ECMO flows
  - If patient circulation supportable off ECMO come off as per 'Taking patient off ECMO in an Emergency'
  - Turn off heat exchanger (turns off water flow)
  - Use alternate means of patient thermoregulation
  - Prepare for replacement of oxygenator/circuit by perfusion services

Cardiac arrest due to arrhythmia

- Non-perfusing cardiac rhythms can occur whilst on ECMO
- Management on VA ECMO does not require cardiac massage but cause should be urgently sought and reversed
- Management on VV ECMO is urgent and requires cardiac massage

For VA ECMO:

- Causes:
  - Cardiac stunning
  - Coronary artery embolus (air, clot)
  - Cardiac over-distension
  - Electrolyte disturbance (hyperkalaemia, hypocalcaemia)
  - Arrhythmia
- Management:
  - Ensure adequate circuit flow
  - Urgently notify Intensivist and Perfusionist
  - Address and reverse causative factors
  - Consider electrolyte replacement and antiarrhythmics
  - If DC shock required assemble senior team (PICU, Perfusion, Cardiology, Cardiothoracics) – may need to reduce flows just prior to administering shock to help offload heart

For VV ECMO:

- Causes:
  - Tension pneumothorax
  - Hypovolaemia
  - Cardiac tamponade
  - Electrolyte disturbance
  - Arrhythmia
  - Hypoxia (failing oxygenator)
  - Hypothermia
- Management:
  - Press emergency bell
  - Commence CPR as per paediatric advanced life support algorithm (take care not to displace cannulae)
  - Manually hand ventilate with 100% oxygen BUT aim for minimal ventilation as CO_2 should be removed via the ECMO circuit
  - Identify risk factors and treat
  - Urgently notify intensivist and perfusionist if not already present
  - If insufficient flows reduce ECMO flows and give intravenous volume

24 Invasive procedures/surgery on ECMO

- Relatively minor or non-invasive procedures on ECMO are associated with risks:
  - uncontrollable haemorrhage
  - potential air entrainment
  - cannula dislodgement
  - flow interruption (planned or unplanned)
- Intensivist on call holds responsibility to give consent for any procedures (planned or emergency) for any patient on ECMO
- Minor procedures - wound swab, airway suction or change of ETT
- Major - chest re-exploration, insertion of intracardiac and central lines
- Intensivist/Fellow and Perfusionist are required to be present for any procedure likely to cause significant bleeding or where the ECMO circuit requires reduced flow or cessation
- Cardiothoracic surgeon presence is dependent on procedure – consult with Intensivist and Perfusionist
- **Prior** to major procedures:
  - Informed consent from parents/carer
  - Clear and effective communication & coordination between involved teams - surgical, perfusion, anaesthetic, operating theatre and PICU
  - Intensivist/Fellow to delegate clear 'team leader' and allocate vital tasks
  - Team Leader delivers a 'Time Out'
  - Aseptic technique – all staff in room to wear gowns, surgical hats and masks at all times during cannulation
  - PICU Bedspace set up and predefined roles if applicable.
  - Discuss if or when to turn off the heparin infusion
  - If intracardiac access is required (either for venting cannula insertion or central line access) the patient will temporarily come off support when heart is opened/accessed – prepare for support required during circuit clamp (+/- inotropes, fluid, ventilation)
  - If jugular or femoral central venous access required - MDT to agree upon line proceduralist, risks associated, and plan for ECMO flow reduction (with enough positive pressure in venous side of the circuit) OR temporary circuit clamping
  - If no appropriate proceduralist available for intracardiac, jugular or femoral access – consider infusing medicaitons into ECMO circuit ONLY for short term option in consultation with the Perfusionist/Intensivist/Fellow
  - Coordinate timing with theatre nursing team

- Set up PICU ECMO equipment as per ECMO initiation set up section
- Anaesthetic requirements are usually managed by Cardiac Anaesthetist – if unavailable this defaults to Intensivist/Fellow
- Prime and connect an extension line on at least one IV access point for emergency administration of drugs and volume once patient is draped
- Prepare appropriate resuscitation drugs & bolus fluids
- Document baseline observations (including neurological observations)
- Plan blood product requirements with proceduralist and anaesthetist (what needs to be immediately available)
- Check FBC and Coagulation profile
- Plan ACT management with surgeon, Intensivist and Perfusionist (any prescribed alteration to current)
- Plan scribe role allocation & communication – responsibility for documentation into eMR (include fluid balance input/output during procedure)
- Plan for anti-fibrinolytic or Factor VIIa use - pre-primed circuit to be on stand- by

25 Intra-hospital transfer of ECMO patient

- Transfer to other hospital departments may be required for patients on ECMO (may include but not limited to - theatre, CT scan or cardiac catheter laboratory)
- As with all patient transport, a 'Time Out' prior to transfer must occur involving all members of the transporting team – include role allocation, plan to move and emergency management with a clear team leader for the transfer process
- The priority lift key is kept in the key box at front desk (allows override of lift call and door opening held)
- Lift dimensions CHW = Door Width 140cm, Internal Length 275cm - any configuration of patient bed and ECMO circuit cannot exceed these
- Use lifts near PICU back entrance – on entering the lift the ECMO trolley must be moved to left of bed for left hand side lift & right of bed for right hand side lift
- Inform all necessary staff & check availability for assistance - Intensivist, Surgeon, Perfusionist, ECMO Nurse, Anaesthetist as appropriate
- Pre-allocated roles:

  Team Leader = Anaesthetist or Intensivist/Fellow

  Bed moving = 2 people

  ECMO trolley & bed monitoring & safety = Perfusionist (need to be moved at same speed, no tension placed on any components & cannulae visible & secure at all times)

- Important equipment essential for transfer:
  - Adequate sedation & muscle relaxant
  - Continuous monitoring
  - Emergency equipment, volume and resuscitation drugs remain with patient
  - Check primary and back-up console (an integrated part of ECMO hardware) battery is fully charged
  - Separate and spare full O2 cylinder with flow meter
  - ACT machine and cartridges
  - Additional blankets +/- hat – for expected heat loss once ECMO heater is disconnected – Do not cover ECMO tubing (must remain visible at all times) - For the neonatal and infant patients consider increasing patient temperature slightly via the ECMO heater prior to transfer
- Check all equipment will fit through doorways prior to leaving PICU and that planned route is clear
- Always move with the bed following the ECMO trolley - allows ECMO trolley to dictate speed and reduces likelihood of it tipping over
- Switch over to hospital gas and power supplies as soon as destination is reached
- Switch ECMO water heater back on
- For cardiac catheter lab - consider replacing catheter sheath with appropriately sized central line to reduce bleeding risk at the end of the procedure

If any issues or circuit alarms during transfer call out "Stop" and team will pause and troubleshoot

26 Planned Circuit Change

Suggested Criteria

- Circuit with increasing clot formation
- Visible clot post oxygenator
- Failing oxygenator
- Ongoing septicaemia with positive blood cultures unresponsive to IV antibiotics
- Worsening circuit induced consumptive coagulopathy

Preparation

- Contact Perfusionist on call to prepare new circuit
- Notify Cardiothoracic surgeons, Intensivist/Fellow and PICU Nursing T/L
- Plan for procedure - inotrope/increase in ventilation/fluid required

- ECMO nurse to notify blood bank and request 2 units of packed red cells
- Prepare emergency drugs and volume in case of prolonged low cardiac output or cardiac arrest
- ECMO & patient nurse to prepare bed-space and equipment:
  - Sterile gloves, gowns, masks & caps for surgical team
  - Maintain aseptic technique
  - Ensure adequate drapes
  - Open ECMO Emergency Pack (Drawer One of PICU Chest Opening Trolley - Sterile scissors x 2 + scalpel and scalpel holder +sterile tubing clamps x 6 + sponge forceps + gallipot + gauze x 10 squares + needle holder + mosquito forceps x 2
  - Betadine cleaning solution and sterile gauze
  - 20mL syringe & sterile saline
  - Ensure appropriate connectors available (on ECMO Accessory Trolley)

Process

- Surgeon - clean and drape patient /circuit
- Perfusionist - increase blender FiO_2 to 100% to pre-oxygenate patient
- ECMO ceased as per 'Taking patient off ECMO in Emergency'
- Perfusionist – hand surgeon primed circuit and appropriate connectors
- Surgeon - prepare new circuit: cuts, adds connector and de-airs
- PICU medical and nursing staff - prepare for possible CPR
- Surgeon - clamp cannulae, separate existing circuit & connect new circuit ensuring no air - process should take less than 3 mins and not require CPR
- Recommence ECMO
- Consider re-infusion of residual circuit volume, check haemoglobin and haemotcrit
- Document process on eMR

27 Planned Arterial Clot Cut Out

- Significant clot formation in arterial side of circuit concerning - newly formed/ grown in size/ change in colour - notify PICU, Perfusion and & Cardiothoracic Surgeon
- Check anticoagulation - increase AntiXa levels to 0.5-0.7 if appropriate
- PICU, Perfusion and & Cardiothoracic Surgeon decide if clot is to be cut out

Preparation for clot cut out

- PICU ECMO & patient nurse to prepare patient, bed-space and equipment
- PICU ECMO nurse to assist cardiothoracic surgeon with procedure if required
- Perfusionist to manage ECMO circuit & lines
- Prepare emergency drugs and volume in case of prolonged low cardiac output or cardiac arrest
- Confirm with Intensivist - low dose inotrope to commence prior to procedure and or fluid bolus
- Increase Fi02 on ventilator & ECMO circuit to 100%
- Cardiothoracic surgeon & nurse assisting must wear sterile gloves, gown, mask and cap - provide WPP (sterile gown pack) x 2
- Maintain aseptic technique
- Ensure adequate drapes.
- Open onto clear sterile drape covering procedure trolley:
    - ECMO Emergency Pack (on ECMO equipment trolley or first drawer of PICU Chest Opening Trolley) - Sterile scissors x 2 + scalpel and scalpel holder +sterile tubing clamps x 6 + sponge forceps + gallipot + gauze x 10 squares + needle holder + mosquito forceps x 2
    - Pour Betadine cleaning solution into gallipot and open sterile gauze onto trolley
    - 2 x 50mL syringes filled with sterile saline - one to have red drawing up needle attached
    - 2 x appropriate connectors

Process:

- PICU team - prepare to support patient with fluid and inotropes - consider wean or cessation of dilators
- Surgeon - clean and drape on and around the component of the circuit where cut out is to occur
- Perfusion – clamp the circuit & stop the pump as the surgeon clamps either side of the clot

- Surgeon - cut out the section of clotted circuit
- Surgeon - add new connector
- ECMO nurse assisting - use 50mL syringe of saline with attached needle to fill from the bottom of the connector slowly withdrawing needle & syringe as it fills up
- ECMO nurse assisting - pick up second 50mL syringe of saline and continue filling between the connector and the tubing as surgeon connects the tubing to the end of the connector
- Both surgeon & nurse assisting visually inspect for any air
- Surgeon - unclamp
- Perfusion - unclamp and resume blood flow
- Process should ideally take 3-4 mins
- Document process in eMR

28 Use of ECHO

VA ECMO

- Used to assess atrial distension, volume loading degree of mitral regurgitation
- Persistent volume loading of the R or L ventricle may be noted
- ECMO flows may be adjusted to offload the RA, or may be an indication to vent the LA in order to offload the LV

VV ECMO

- Used to assess return cannula jet and to optimise position of return cannula during cannulation (particularly for placement and orientation of Avalon catheter
- Further imaging (usually TOE) recommended to optimise cannula position in cases of suspected increased recirculation

ECHO weaning study

- Preferably done the day prior to planned wean to assess suitability to separate from ECMO in presence of Intensivist/Fellow and Cardiothoracic Surgeon
- Pre- ECHO commence appropriate inotrope infusion at low-dose (ensure reaches patient through the line prior to commencement)
- Increase ventilation
- Commence ECHO to assess ventricular function
- Wean flows gradually and increase inotropic support +/- volume as required as guided by Cardiothoracic and PICU senior team at bedside - assess ventricular function with reduced flow
- Cardiologist will complete the wean study and document findings

- Give intravascular volume load if little evidence of ejection and low atrial pressures
- If any problems arise during procedure immediately return settings to pre-procedure levels
- If ECHO is favourable team should formalise plans for wean and decannulation
- If ECHO suggestive that more time is required for myocardium rest and function recovery function – return settings to pre-procedure and do not reattempt ECHO weaning study for next 48hrs or as per decided amongst the multidisciplinary team

29 Weaning

VA ECMO Wean

Overview

- Team based approach - almost all cases weaned by the Cardiothoracic Surgical Team (surgeon/surgical fellow/anaesthetist/perfusionist +/- cardiologist) in conjunction with PICU medical and nursing team
- Complex process involving continuous assessment of adequacy of patient cardiac output vs circuit output with adjustments of inotropes, filling and ventilation
- Usually requires multiple interventions based on underlying condition – Single ventricle anatomy patients (in particular) have complex issues which may require adjustment of shunts or bands to facilitate weaning
- Flow reductions must be met with increase in pulse pressure and native cardiac output - requires ongoing management at bedside for at least 1-2 hours during the weaning process

Preparation

- Discussion and planning between PICU and Cardiothoracic Surgical Team - suitability & timing + plan for re-commencement of ECMO if patient fails to wean or weans successfully then deteriorates
- Inform parents and seek consent
- Cardiothoracic Surgical Team will organise/contact clinicians - perfusionist, cardiac anaesthetist and theatre nursing staff
- PICU ECMO nurse to notify PICU T/L
- Aim to commence cardiac support drugs at least 4 hours prior to wean (prepare and commence as indicated by medical team Adrenaline and Noradrenaline infusions)
- Attach bolus volume (crystalloid or blood as ordered by medical team) to patient ready to administer during wean
- ECMO nurse to notify blood bank and request required blood products (as ordered by medical team – e.g. 2 units of packed cells, 1 unit FFP and 1 unit platelets)
- Prepare emergency drugs and volume in case of prolonged cardiac arrest

- Prepare heparin bolus (usually 300-400units/kg)
- PICU nurse to prepare bed-space and equipment in conjunction with theatre nurses
- Place diathermy pad
- **For neonates or infants on PICU bed - place bair hugger under patient prior to commencing procedure**

Process

- Weaning is commenced when team is at bedside - Cardiothoracic Surgical Team (surgeon/surgical fellow/anaesthetist/perfusionist +/- cardiologist) + PICU medical and nursing team
- LA vent cannula (if present) will be removed surgically (usually prior to weaning) and clamped at the discretion of the surgeon
- Heparin infusion increase +/- bolus prior to flow reduction – check ACT pre & post
- Flow is gradually reduced – maintain SaO_2 >90%, PaO_2 >80 and SVO_2 >60-70% & monitor NIRS trend (Note parameters are dependent on underlying patient condition, especially in single ventricle anatomy)
- SV02 measurement on CDI becomes increasingly inaccurate as flows are reduced
- ECMO flow is expressed as a percentage of (100%) flow prior to commencement of weaning
- Increase ventilation (Cardiac anaesthetist will communicate recommended ventilator settings to PICU team) and inotropes as flow is reduced
- Give volume fill (crystalloid or blood as pre-planned & ordered) to increase venous capacitance
- Exercise caution with flows <20% as retrograde flow may occur
- Potential for hypothermia at low flow through heat exchanger – consider bair hugger or overhead heater
- TTE or TOE may be requested to assess contractility and output at low flow
- If successful
    - Return line clamped
    - Pump turned off
    - Withdrawal line clamped
    - Gas flow ceased
    - Heparin infusion ceased

Successful wean	• Normal arterial pressure trace • Stable LA/ RA pressures (usually<12 mmHg or as deemed appropriate) • Clinical signs of adequate perfusion & haemodynamic stability without high dose inotrope

- A short period of observation off ECMO is commenced prior to decannulation – blood is circulated through bridge to prevent circuit clot formation (See section below)
- Check Patient ACT>300 and ABG regularly until decannulation
- If prolonged period of observation indicated prior to decannulation (with no flow) Perfusionist will recommence flow intermittently as per surgeon/intensivist instruction to maintain cannulae patency

VV ECMO Wean

Overview

- Significantly different to weaning VA – wean by gas rather than flow
- Process is directed and managed by PICU team led by Intensivist/Fellow

Preparation

- Intensivist/Fellow to liaise with Cardiothoracic Surgical Team (surgeon/surgical fellow/anaesthetist/perfusionist/theatre nursing staff – planning for timing of wean and decannulation- include plan for re-commencement of ECMO if patient fails to wean or weans successfully then deteriorates
- Intensivist/Fellow to inform parents, seek consent, document in eMR

Process

- Increase ventilation settings as FiO_2 and flow-rate of sweep gases reduced and ceased
- Assess lung compliance & gas exchange (notable on ETC02 tracing)
    - Auscultate breath sounds
    - Check chest x-ray – for visible improvement
- Blood flow is not altered, wean is of sweep gas flow and FiO_2
- Monitor patient:
    - SaO_2
    - PaO_2
    - $PaCO_2$
    - Venous saturation
- Suction ETT regularly
- Plan for decannulation if serial gases remain acceptable over next 12-24 hours

30 Decannulation

- Transthoracic cannulae or cannulae inserted by full cut down are placed and removed by the Cardiothoracic Surgeon (and vessel reconstruction if required)
- Percutaneously inserted cannulae are placed and removed by a professional appropriately trained in the technique
- During venous cannula removal - a prolonged inspiration on positive pressure ventilation may be requested to reduce the chance of air embolus
- Drains may be inserted post decannulation at discretion of the surgeon
- Heparin can be reversed with Protamine if ACT remains elevated +/- active bleeding
- For removal of percutaneous cannulae:
  - Check clotting screen
  - Give IV antibiotics 30mins prior to procedure
  - Cease Heparin at least 60mins prior to procedure
  - Clamp circuit
  - Administer muscle relaxant and sedation (as ordered by medical team)
  - Aseptic technique for removal

31 Recirculation through 'the bridge'

- Technique to be used after wean whilst observing if patient is able to separate from ECMO
- Also used (rarely) during trouble shooting procedures which stop ECMO circuit flow
- Process:
  - Clamp withdrawal and return lines to isolate circuit from patient
  - Cease gas flow to prevent air entrainment into oxygenator
  - Fully open clamp on haemofilter bridge
  - Check CDI 500 bridge is open
  - Adjust pump speed for flow 0.2 to 0.3 L/min

32 Haemofilter Management

- A shunt from the arterial side of the oxygenator to the venous side of the circuit just prior to the pump containing a haemofilter (Maquet BC20) and the CDI 500 arterial sensor allows blood to pass from the high pressure arterial side of oxygenator through the haemofilter and shunt (arterial blood) sensor and return to the negative pressure venous side
- To prevent clotting a flow of at least 150-200mL/min must be maintained through the haemofilter shunt - a restrictive clamp can be placed to moderate flow
- Suspect a fibre rupture within the haemofilter if blood is seen in the ultrafiltrate – may require removal and replacement of haemofilter (with pre-primed one) by clamping lines either side of it (done by Perfusion staff)
- The effluent line exiting the side port of the haemofilter passes through a Baxter infusion pump (used to actively control ultrafiltrate volume) which is then connected to urometer to accurately measure and confirm ultrafiltrate volumes
- Consider medication filtration - discuss with PICU Pharmacist (*Pager 6817*)

33 SCUF - Slow Continuous Ultrafiltration

- Useful in setting of fluid overload unresponsive to diuretics
- Intensivist to prescribe volume of fluid to be removed each hour/desired overall hourly patient fluid balance – regular review with patient examination + documented fluid balance
- Use worksheet (below) for accurate calculation of SCUF volume (similar to calculating "machine balance" in CVVH but note two separate worksheets and NOT to be used for CVVH or vice versa)
- Use Baxter volumetric fluid pump to regulate volume removed each hour (Baxter pump and fluid lines are now ordered and supplied by the Perfusion department and kept with their stores)
- Use high-fidelity urometer for accurate hourly measurement of volume out
- Note that volume dialled on pump may not exactly equal effluent per hour (IV pumps are not designed for this purpose and may be inaccurate)
- Monitor serum electrolytes regularly
- Expect sodium and water loss should be expected – inadequate replacement of sodium loss will lead to hyponatraemia
- Responsibility for hourly measurement & documentation in eMR is by PICU patient nurse - drop down box under 'outputs' labelled 'SCUF volume' which then crosses into ECMO observations page (Do not enter SCUF volume in ECMO observations as it will put into the wrong hour on the fluid balance chart)
- Consider medication filtration - discuss with PICU Pharmacist (*Pager 6817*)

Worksheet for Calculating SCUF Flow in ECMO

Enter HOURLY absolute amounts (not /kg) - if variable then estimate daily amount and divide by 24 or just estimate hourly amount

Revise the "Desired fluid off patient per hour" frequently by examining patient and actual fluid balance on eMR

Patient Details:

This is entered as a positive number, although it is a negative fluid balance

Date	Time	Desired + fluid off patient per hour	+ IVs+	TPN	+Feed	+Drugs	+Blood – products (not urgent volume)	- Urine	-Other losses	- Insens = loss	SCUF Flow	SCUF Flow must be at least 10mL/hr If <10 mL/hr then increase IVs or feeds, so that SCUF flow is >10 mL/hr
		Example only		Example only					Example only			
2/08/04	11.00	10+	15+	10 +	0 +	7 +	8	5 –	5 –	12	28	

34 Peritoneal Dialysis on ECMO

- There is no contraindication for Peritoneal Dialysis for a child on ECMO with a PD catheter already in place
- Insertion of a PD catheter on ECMO needs to be carefully assessed and discussed with the senior team due to risk of bleeding - if required then discuss when to temporarily stop Heparin infusion
- Most infants and children with renal dysfunction or fluid overload may be managed with SCUF or CVVH – see sections in this guideline
- For details relating to Peritoneal Dialysis guideline

35 Continuous Renal Replacement Therapy on ECMO

- Continuous Renal Replacement Therapy (CRRT) in form of Continuous veno-venous hemofiltration (CVVH) or Continuous Veno-Venous Hameodiafiltration (CVVHDF) is possible and may be indicated for significant acid-base or electrolyte derangement with oliguric renal failure (in absence of PD catheter)
- Decision to commence CRRT is by the Intensivist
- Increases the complexity of the extracorporeal circuit - requires blood to be drawn and returned via the bridge at a controlled rate by CRRT machine
- Inform Perfusionist of plan to add CVVH to the ECMO Circuit – they are required to be present for commencement of CVVH flows
- Check additional primed ECMO circuit available
- ECMO nurse to check PRBC x2 units available prior to initiation of flow (haemodilution may occur depending on CVVH circuit prime fluid used)
- CRRT safety pause to be completed in conjunction with ECMO Risk Assessment Checklist

Advantages & Disadvantages

Advantages of adding CVVHDF	Disadvantages of adding CVVHDF
Improved urea clearance compared with PD - 0.5-1.0mL/kg/min vs 0.2mL/kg/min maximum	Additional surface area of filter membrane (0.2 m^2 in infants <15 kg, 0.6 m^2 in >15 kg) N.B. this compares with the oxygenator surface area of 2m^2
Ability to regulate plasma chemistry (Na, K, Phosphate, Bicarbonate)	New membrane causes new inflammatory response
Accuracy of fluid balance control (N.B. SCUF can control water overload but cannot regulate chemistry). Using the existing SCUF filter with IV pumps for dialysate/replacement is inaccurate, although effluent can be accurately measured	Extra circuit volume primed with albumin (60mL in <15kg, 93mL in >15kg) dilutes the patient's blood. N.B. this compares with the ECMO circuit volume of 500mL plus the patient's blood volume of 80mL/kg
Better clearance of inflammatory mediators with Polyethersulfone or AN69 membranes	Extra volume either dilutes existing heparinisation or additionally heparin loads the patient
PD cannot be done in many cases	Risk of micro air bubbles entering circuit and passing through oxygenator. N.B. this risk is greater when a separate CVVHDF circuit is used independent of the ECMO circuit if the patient has a common atrium
No need to insert a separate dialysis catheter – high risk in heparinised patient	The Prismaflex circuit "steals" 20mL/min or 3mL/kg/min (whichever is greater) blood flow from the ECMO aortic return and returns it to the input side of the oxygenator - there is no alteration of blood flow to the patient
Ability to be flexible with dosing of drugs such as milrinone by achieving near to normal "renal" clearance	

Connecting CRRT to ECMO circuit (see diagram and photos below)

1. Notify Perfusionist that patient requires CRRT via the ECMO circuit
2. Set up CRRT as per standard policy with addition of Heparin to the Albumin prime (PICU nursing staff responsibility)
3. Add 250 units of Heparin to 500mL 4% albumin used for the final albumin prime – in bleeding patient/deranged coagulation profile consult with Intensivist, cardiothoracic surgeon and perfusionist
4. Inform perfusion once circuit is ready and with perfusionist at bedside:
5. Move Heparin infusion from superior aspect of oxygenator to three way tap between the pump head and the oxygenator (three way tap currently turned off to the ECMO circuit)
6. Prime Heparin back out of the spare lumen of three way tap to eliminate any air
7. Start heparin infusion and allow for build of back pressure (small bolus of Heparin may be required if small element of back flow up Heparin line)
8. Turn three way tap off to the spare port
9. Disconnect CRRT **access** line from Y Line & connect to three way tap superior to oxygenator (tighten to secure)
10. Disconnect CRRT **return** line from collection/effluent bag (ensure fluid primed all the way to top of return line) & connect to remaining port of three way tap between pump head and oxygenator (where Heparin connected) – tighten to secure
11. Disconnect effluent line from Y Line & connect to free port on effluent bag
12. Unclamp effluent, access & return lines
13. Secure all lines into clip closest to patient
14. Turn both three way taps to on position
15. Press start

Notes:

- **The CRRT circuit will always be connected post pump head on the positive phase of the ECMO circuit**
- Perfusionist will modify ECMO circuit for connection of CRRT machine (if not already done)
- SCUF will cease and haemofilter will be left with blood flow through it
- Place a restrictive gate clamp on the CRRT withdrawal line in order to make the pressure <300mmHg
- Move Heparin infusion to the high flow three way tap with the CRRT return line proximal to the oxygenator
- A restrictive gate clamp may be placed on the CVVH withdrawal line in order to make the pressure in the CVVH withdrawal line <300mmHg

- There may be some back flow down the return line but this will resolve
- It is unlikely that the CRRT circuit will require the heater sleeve to be placed as the patient's temperature will be maintained via the ECMO circuit
- If the return pressure of CRRT circuit into the ECMO circuit is >300mmHg the blood will not return (i.e. if patient blood flow is high) – if this occurs:
    - Troubleshoot with the PICU and perfusion team
    - May require turning down the CVVH blood flow rate or reducing the ECMO flow - only to be done in discussion with senior medical team
    - If unable to troubleshoot and unable to return CRRT blood flow then consider need for a vascath
- **No additional anticoagulation** is required – patient is fully anticoagulated with one source of heparin running through ECMO circuit adequate
- Citrate-based replacement fluid is not required – can be used if the citrate is metabolised adequately - bicarbonate-based solution will usually be used
- Intensivist to prescribe hourly patient balance and replacement rate – review desired balance regularly after examining both the patient and the documented fluid balance on eMR.
- Use CRRT worksheet to calculate machine balance

CRRT Worksheet for Patient Fluid Removal

Calculations (Enter HOURLY amounts, if variable- estimate daily amount and **divide by 24)**

Transcribe on to the prescription sheet

This is a Positive number for a negative patient balance

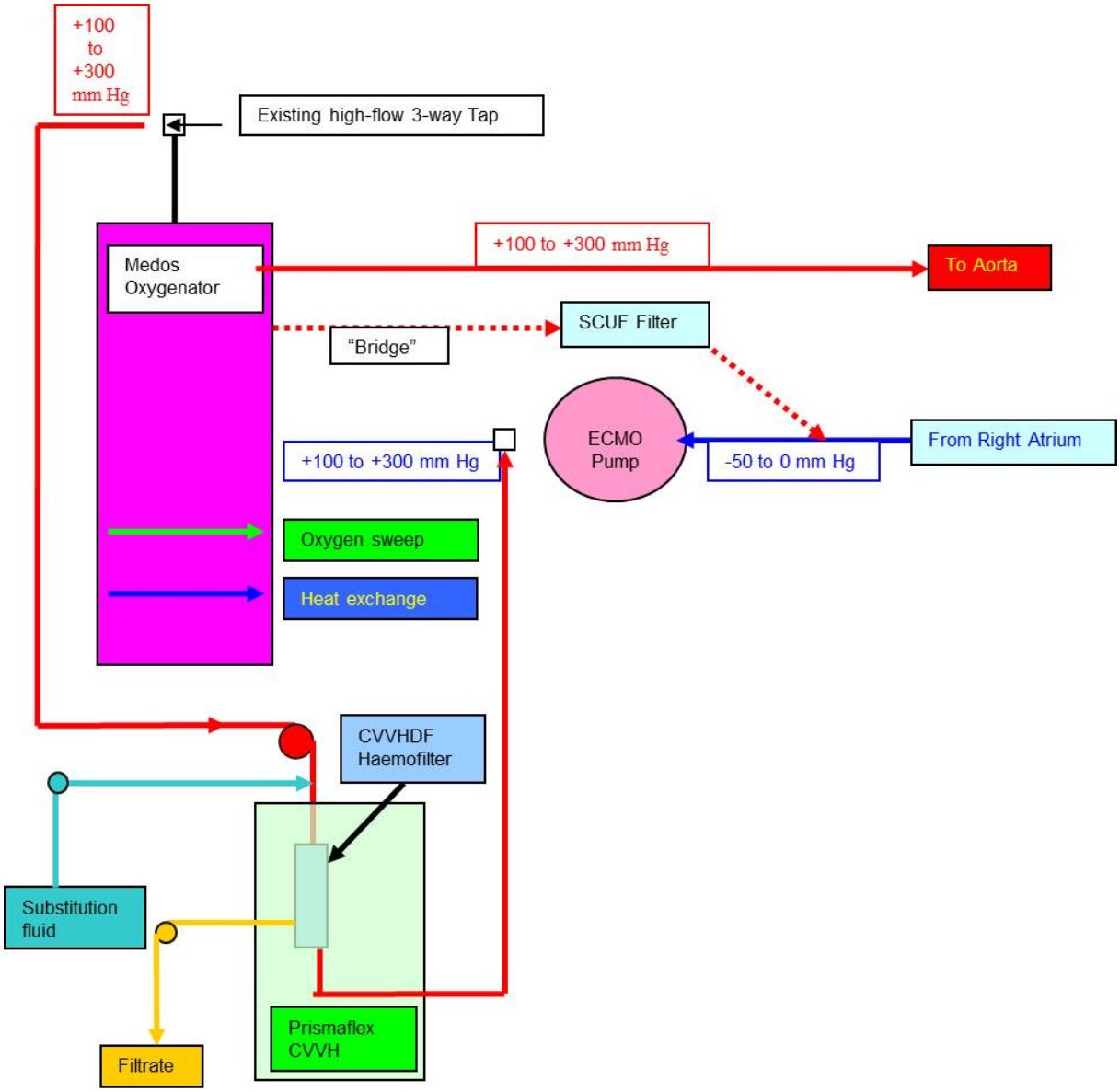
Date	Time	Feeds +	Drugs + (including infusions)	Blood products & colloid (not urgent volume)	+ IV's +	TPN –	Urine –	Other loss -	Insens Loss + +	Desired fluid off =	"Patient Fluid Removal" (usually positive)	Enter the starting Replacement Flow here _____ Filtration flow rate is given by: Diafiltrate (Effluent) = Pre-Blood-Pump (PBP) Replacement fluid flow + Post-Filter Replacement fluid flow + Dialysis fluid flow + "Patient Fluid Removal" e.g. Filtrate = 720 + 600 + 20 + 50 = 1390 "Patient Fluid Removal" used to be known as "Machine Balance" Machine balance used to be entered as a negative number, "Patient Fluid Removal" is entered as a positive number.
2/11/01	11.30	5	5	20	17	23	25	10	15	30	+ 50	
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		
		+	+	+	+	–	–	–	+	=		

Example Only

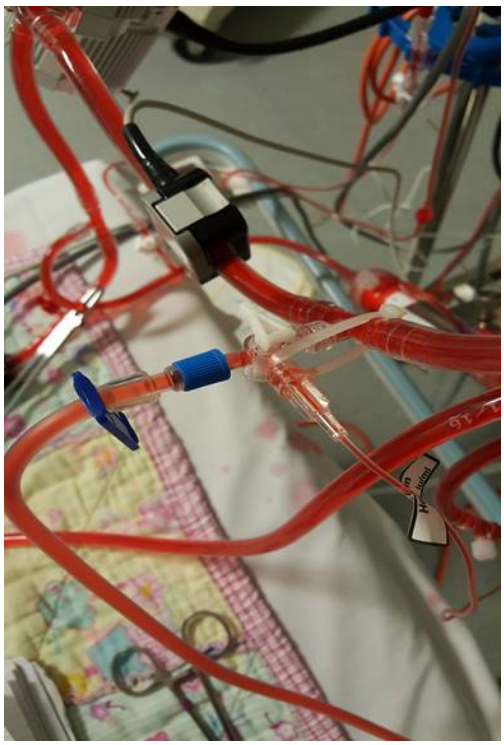
Example Only

Example Only

Diagram & pictures of CRRT to ECMO circuit connection



CVVH withdrawal line



CVVH return line & heparin infusion

CVVH set up

36 Pharmacology

- Drug volume distribution(Vd) changes secondary to haemodilution and sequestration of drugs (generally increased) – especially for water soluble drugs
- Drug clearance is generally decreased
- Impact of haemodilution depends on patient size in relation to circuit volume - a larger effect may be seen in infants vs. teenagers
- Redistribution of fluid into tissues and protein losses into circuit may affect protein bound medications impacting their overall Vd
- Fluid shifts from the ECMO circuit will influence highly protein bound and hydrophilic medications more than others
- Consider potential array of pathophysiological changes in these patients (AKI, derangement of liver function, variations in cardiac output) leading to changes in drug clearance
- Sequestration of drugs to the circuit occurs however the binding of drugs to components of the circuit will depend on the chemical characteristics of the drug, oxygenator design and type of priming fluid
- Review of drug doses & monitored drug levels with PICU Pharmacist (*Pager 6817*) is recommended
- Analgesia & sedation dosing for patient comfort on ECMO is important – use scoring tools (see PICU sedation & analgesia guideline)
- Morphine is opioid of choice due to moderate Vd comparative to other opioids
- Muscle relaxant always used at ECMO initiation but continuous infusion may not be required ongoing
- If on continuous muscle relaxant aim for once per day "holiday" allowing for movement to be seen prior to recommencement facilitating neurological assessment (not for patients undergoing temperature control for cerebral protection or arrhythmias, or for patients with unstable cannula)
- Volume should be used as first line support in any patient unexpectedly coming off ECMO
- An adrenaline infusion is to be available & connected for emergency management
- Low-dose Adrenaline (or other inotropes/pressors) may be required - restrict or limit to planned or unplanned time off ECMO (can significantly increase afterload making recommencement of ECMO more difficult)
- Sodium Nitroprusside (SNiP) infusion prepared for potential hypertensive emergencies
- Volatile anaesthetic agents can NOT be used with oxygenator
- Ranitidine or Omeprazole should be prescribed prophylactically for gut protection

Analgesia & Sedation Recommendations

Drug	Recommendations
Morphine	• Routinely used as the opiate of choice • Moderate Vd • Sequesters in the circuit ->higher doses required • Will accumulate if the patient has AKI.
Hydromorphone	• Limited data exists on use during ECMO • Clearance does not occur via the kidneys.
Fentanyl	• Highly lipophilic • High Vd • Affinity for circuit components • Not recommended
Midazolam	• Will accumulate due to decreased clearance • Decrease in drug concentration over 24hr period • Likely 10-20% increase of dosing for ECLS patients
Dexmedetomidine	• Highly lipophilic • Significant loss to circuit
Propofol	• Lipophilic • Dosing challenging related to sequestration • Up to 90% of propofol may adhere to circuit

*When possible switch to enteral sedation

37 ECMO Duration

- Depends on indication for ECMO support
- ECMO is not curative - allows time for resolution of the underlying pulmonary or cardiac pathology and a return of the patient's cardiorespiratory function or in some cases as a bridge to diagnosis or decision
- ECMO may be used as a bridge to VAD and transplant
- Progress and potential for weaning and separation from ECMO are discussed daily
- Most children wean from VA ECMO by day 10 or sooner - if separation not imminent by day 7 have a multidisciplinary meeting to plan further management, review expected disease pathophysiology, likelihood of any residual reversible lesions and need for further diagnostic investigations
- VV ECMO runs are expected to be significantly longer than VA (depending on how long the underlying pathological process takes to resolve
- Plan intermittent multidisciplinary meetings to discuss management- the PICU CNC should be allocated for care coordination

38 Family

- The equipment involved in maintaining a child on ECMO is both invasive and daunting-adequate description of the equipment is required
- Encourage families to spend time at the bedside and touch their child
- Siblings should be closely supervised at all times whilst at the bedside
- Maintain regular contact with family to inform/update them
- Social work and/or religious support should be offered to the family
- Consider weekly meetings +/- additional meetings following MDT planning for families with a child on ECMO > 1week
- Where possible prepare & consent in advance for any procedures (including transfusion of blood products)
- Prior to ECMO weaning it is advisable to inform family that the first wean may not be successful - parents are generally excluded from the room during weaning, unless a one-way weaning plan has been agreed
- In the case of one-way wean: an experienced PICU RN should be allocated to support the family with prior discussion of a clear plan involving the surgical team, intensivist, ECMO nurse and perfusionist

39 Follow up

- All patients successfully separating from ECMO are to have a careful neurological examination by ICU senior medical staff
- Where necessary refer to Neurology for consult with appropriate investigations where indicated
- All infants <1 year old at time of initiation of ECMO are planned to be seen in the Neurodevelopmental Follow-Up Clinic (held weekly in Grace Ward) up until 3years of age after discharge from PICU
- Routine investigations, including neuroimaging should not be ordered unless clinically indicated prior to discharge
- A completed Discharge Summary detailing the PICU admission (with specific reference to any complications of ECMO therapy) is made available to CHW Co-Consultant, Referring Paediatrician (if known) and General Practitioner (including details of Follow-Up plans)

40 ELSO

In 1989 the Extra-Corporeal Life Support Organisation (ELSO) was set up to maintain an international registry of ECMO patients to organise and standardise approaches to care and to stimulate multi-institutional research. The registry is based in the USA.

CHW are committed to data submission to ELSO. Currently the PICU ECMO Co-ordinator collects and submits data to ELSO.

41 References

1. ELSO, Extracorporeal Life Support Organisation, Ann Arbor Michigan.
2. GOSH, ECLS Protocol, Great Ormond Street Hospital for Sick Children, London.
3. Greenlane ECLS Manual, Greenlane Hospital, Auckland.
4. RCH ECMO Policy, The Royal Children's Hospital, Melbourne.
5. The Alfred ECMO Policy, The Alfred Hospital, Bayside Health, Melbourne.
6. The Royal Hospital For Sick Children ECMO Manual, Yorkhill NHS Trust, Glasgow.
7. UCSF Children's Hospital ECMO Policy, University of California San Francisco Medical Center.

Appendix 1 – Additional ECMO Equipment

PICU does not store all of the necessary equipment to initiate ECMO. Perfusion services are responsible for providing the pump and primed circuit. They should be contacted as early as possible in order to set up for ECMO. Out of hours please contact the on-call Perfusionist for cardiac via switch board.

Centrimag Pump Head

The pump head used is a centrifugal device manufactured by Abbott. This device contains impeller blades which push through the blood, creating turbulence in areas of positive pressure (leading edge) and negative pressure (trailing edge). The priming volume of this device is 14mL (31mL for 3/8 inch pump head).

Remote Pump Head Drive Unit

This remote drive unit weighs 1.7kg and transmits power to the disposable pump head permitting blood flow through the circuit. Two remote pump heads should be present at all times.

Console

The Console has an on/off switch at the rear. Flow probe, transducer, and remote drive unit attach at the rear. The internal battery charge is displayed on the front of the device. Two consoles should be present at all times.

Flow Probes

Transonic flow probes are clipped onto the outside of the circuit tubing. ¼ inch probes are used for ¼ inch circuits and 3/8 inch probes are used for 3/8 inch circuits. These probes do not require calibration.

Medos Oxygenator

The Medos diffusion membrane oxygenator is a true membrane device with integral heat-exchanger. This device relies solely on concentration gradients for gas diffusion. Due to the nature of the true membrane this device cannot be used with volatile anaesthetic gases. For blood flows up to 800mL/min the Medos 800LT will be selected (prime vol. 55mLm max. gas flow rate 1.6L/min, surface area 0.32m^2) for blood flows up to 2.4L/min the Medos 2400LT device will be selected (prime vol. 95mL, max. gas flow rate 4.8L/min, ¼ inch connectors, surface area 0.65m^2), and for blood flows > 2.4L/min the Medos 7000 will be selected (prime vol. 275mL, max blood flow rate 7 L/min, surface area 1.9m^2)

Paragon Oxygenator

(See Section 6 for photo diagram and Section 5 for blood flow rates & priming volumes)

The Paragon oxygenators are hollow fibre membrane oxygenators with integrated heat exchangers that facilitate the gas exchange and the regulation of blood temperature during Extracorporeal Life Support. They come in five different sizes: Neonatal, Infant, Paediatric, Adult Midi and Adult Maxi. They are a single use disposable product.

The gas exchange section of the Paragon PMP Oxygenators are formed from plasma tight hollow fibre membranes. Gas flow takes places through the internal lumen of the fibres. Blood in contact with the outside of the fibres allows oxygen to diffuse in to the venous blood and carbon dioxide to be removed.

The heat exchanging part of the oxygenators is made of non-porous hollow fibre membranes. In the Paragon Paediatric and Infant sizes, water flows through the inner lumen of the fibres, so that blood temperature flowing outside the fibres is regulated. In the Paragon Neonatal, water flows through the outside of the fibres, so blood flowing through the internal lumen of the fibres is temperature regulated.

Heat Exchanger

a.) Maquet: This device requires mains power and does not contain an internal battery. Filtered tap water should be used in this device. This unit does not actively cool blood. If a lower temperature is selected the device will not commence heating until the temperature drops to this level.

b.) Medos: This device requires mains power and does not contain an internal battery. Filtered tap water should be used in this device. It can be used for efficient heating and cooling of the ECMO patient. Sorin 3T: Kept in theatres. This device has the ability to actively heat and cool the patient. For use when no Maquet available. CAUTION: This device has the ability to cool a patient to 18 degrees Celsius.

Jostra Rotaflow Pump Head (not routinely used)

The pump head used is a centrifugal device manufactured by Jostra. This device contains impeller blades which push through the blood, creating turbulence in areas of positive pressure (leading edge) and negative pressure (trailing edge).The priming volume of this device is 32mL.

Medtronic External Drive Unit (not routinely used)

This Bio-console device weighs 6 LBS and has a cord length of 8 feet. It attaches the Jostra magnet adaptor to allow the use of the Jostra pump head.

Bio-console (not routinely used)

The Bio-console has an on/off switch at the front. Flow probe, automatic clamp, air detector and transducer attach at the rear. The internal battery when fully charged

Will last approx.100mins at near maximal settings (4530 rpm, flow 2730 L/min, and pressure 400 mmHg).

Emergency Handcrank (not routinely used)

The emergency handcrank should be attached to the main pole at all times to allow for simple transition from external drive unit to handcrank. This device has a ratio of 24:1. The handcrank will deliver forward flow if turned in either direction but has much greater efficiency if turned anti-clockwise (the displayed arrow direction). When turned anti-clockwise the device will also display RPM's.
NOTE: The black Jostra pump head adapter should remain attached to the pump head when being attached to the Bio-console Handcrank.

Disposable flow probe/ Transducer (not routinely used)

The 3/8" flow probe is used in paediatric and adult ECMO circuits. This device does not require the application of any lubricant and contact with alcohol should be avoided. This device uses electromagnetic sensor pins to measure flow. The transducer should be clipped in place ensuring direction of flow arrow points away from pump head.

Appendix 2 – Burp/Sigh of Oxygenator

- Moisture build up can impede gas transfer from the gas to blood phase of the oxygenator – observe for moisture at 'gas out' port, decline in oxygenation, increase in CO_2 (may also manifest as alteration in patient SpO2 and/or NIRS)
- Removal of condensed fluid from gas phase with temporary increase in supplied gas flow rate = burping/sighing oxygenator

Process:

- Increase total sweep gas flow:
  - **Medos** Oxygenator - for NO MORE than 4 seconds to no more than maximum rated gas flow for device in use (800LT = 1.6LPM, 2400LT = 4.8LPM, 700LT = 10LPM)
  - **Paragon** Oxygenator: for 5-6 seconds to 2:1 gas to blood flow (total flow)
- Observe for dripping at oxygenator outlet
  - Reset gas flow to baseline
  - Observe patient vital signs and CDI 500 values
  - If initial deterioration in parameters not rectified - contact Intensivist and Perfusionist

Alternative (By perfusion only)

- Place a suction scavenger tube (containing a moisture trap) on the side port of the gas outlet
- Connect to a low flow suction outlet