QLD Neonatal & Paediatric ECLS Service

CHQ ECLS MANUAL & CLINICAL GUIDELINE

By the CNC ECLS, ECLS Medical Director, ECLS SMOs and Perfusionists

Approved by the CHQ ECLS Board & the CHQ ECLS Management Group

February 2018

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Date	**Version**	**Authors**	**Description of Revision**	**Next Revision**
28 Feb 2018	Final	A Mattke, E Haisz, T Black	Addition of complex cannulation strategies and VAV	Feb 2019

CHQ ECLS Manual & Clinical Guidelines

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An electronic version of this document is available at PICU & ECLS Share Point

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THE QLD NEONATAL & PAEDIATRIC ECLS SERVICE

1 Service History and Current Activity

The QLD Neonatal and Paediatric ECLS service was established in 2008. The service was initially modelled after the service at RCH Melbourne but has since developed its own model of service, equipment and treatment principles. The service has grown significantly over the years, to 35+ ECLS runs annually.

2 Governance Overview

The QLD Neonatal and Paediatric ECLS service is delivered in LCCH PICU by a multidisciplinary team from the Division of Critical Care. The service incorporates a multi-level management approach with a CNC ECLS and ECLS Medical Director, an ECLS Management Group and an ECLS Board.

The CNC ECLS and the Medical Director ECLS coordinate and administer the service, deal with finances and budgetary issues, contribute to the QPCS M&M, carry out data collection, cleaning and reporting to both ELSO and the QPCS M&M, as well as coordinate teaching and training of ECLS SMOs and ECLS Specialists.

The ECLS management group, consisting of the duty ECLS SMOs, Cardiothoracic Surgeons & Fellows, Cardiologists, Perfusionists and the ECLS Nurse Specialists provide advice to Hillside PICU Clinical Leadership Team (Hillside SMO, TL, AH) & clinicians (ECLS Nurse Specialist, Registrars) on patient management

The Board ensures good clinical ECLS practice, serves as a conduit between the ECLS management group and the divisional directorate, and resolves ECLS service issues. The ECMO board oversees strategic matters, provides advice to the divisional director and supervises financial and budgetary affairs.

For emergent discussions or problem solving, an ad hoc ECLS Management group will be arranged consisting of at least 3 of the following designations (as available): ECLS SMO, Hillside PICU SMO, Cardiothoracic Surgeon, Cardiologist, Perfusionist and an ECLS Nurse Specialist.

Research, teaching and innovation are driven by the ECLS management group members, with input from the various subspecialties within the service.

3 History and Principles of ECLS

Our service utilizes centrifugal pumps to provide all modes of extracorporeal life support (ECLS). Centrifugal pumps technology works on the principle of a constrained vortex; the fluid motion in a vortex creates a dynamic pressure that is lowest in the core region, and increases as the fluid moves away from it. The pump motor drives a magnet, which couples with the “disk” inside the pump head housing – thereby creating the constrained vortex. In an ECLS system this translates to the higher the RPM (revolutions per minute) of the magnet, the greater the pressure and flow rates that are generated. Blood flow is dependent on the pressure generated in the pump along with the patient’s pre-load and after-load conditions.

3.1 ECLS Pathophysiology

Please refer to;

QLD Neonatal & Paediatric ECLS Course Material (ECLS Share Point)

ELSO's *ECMO Specialist Training Manual 3rd Edition*

ELSO's *ECMO Extracorporeal Cardiopulmonary Support in Critical Care 5th Edition* (aka "the Red Book")

3.2 Modes of Support

Our service offers 4 modes of ECLS;

- Veno-arterial extracorporeal membrane oxygenation (VA ECMO)
- Veno-venous extracorporeal membrane oxygenation (VV ECMO)
- Complex ECMO cannulation strategies:
    - VA ECMO with additional left atrial (LA) drainage cannula (usually for trans-sternal cannulation)
    - VA ECMO with additional venous drainage cannula
    - Veno-arterial+veno-venous (VVA ECMO or VAV ECMO) cannulation
    - VA cannulation in both groin and neck with two ECMO circuits (rarely used)
    - Right atrium to aorta and pulmonary artery cannulation (RA-Ao+PA), where the arterial/return/outlet line is connected using a Y connector to cannulae in the aortal and pulmonary artery
    - RA to PA cannulation (RVAD with oxygenator in circuit)
- Ventricular assist device (VAD)

When describing modes of ECMO support the location of cannula placement is paramount. We utilize one system with 2 different circuit types to provide the 3 modes of support. We have one ECMO circuit design, and the type of support it provides is entirely dependent on how it is connected to the patient.

It is important to understand that there are many terms used to describe the cannula(s) used to remove and return blood from/to the patient. The terms used to describe these cannulas are directly related to the direction of blood flow through the cannula, and irrespective of the actual cannula location.

The cannula(s) that are used to drain blood from the patient toward the ECLS system are referred to as "venous", "access" and "inlet" cannula. Whereas the cannula(s) used to return the blood from the ECLS system back to the patient are referred to as "arterial", "return", and "outlet" cannula.

Venous and arterial: The "Venous" label is used, as the blood flowing in the cannula is removed from a vein and located pre-oxygenator in the circuit, and "arterial" as oxygenated blood is flowing through this cannula, which is being returned into the patient's arterial (or venous – in VV setup) system.

Access and return: "Access" and "Return" are labels that refer to the patient, and where the blood is accessed from, and where it is returned to.

Inlet and outlet: "Inlet" and "Outlet" refer to the circuit/pump inlet and outlet, and hence the inlet cannula is synonymous with the "venous" or "access" cannula, and the "outlet" is synonymous with the "arterial" or "return" cannula.

3.2.1 Veno-Arterial ECMO

VA ECMO provides support for both heart and lungs. Venous blood is aspirated from the patient's systemic venous circulation. After passing through the pump head and oxygenator the blood returns to the systemic arterial circulation. Peripheral cannulation drains blood via the right internal jugular or femoral vein and returns it via common carotid or femoral artery. Central cannulation drains blood directly from the right atrium and returns it to the ascending aorta.

3.2.2 Veno-Venous ECMO

VV ECMO provides oxygenation and CO_2 removal only. Cardiac output is not supported by VV ECMO and a failing heart is a contraindication for this mode of support. Various cannulation strategies are available, with all having both the venous/access/inlet as well as the arterial/return/outlet cannula placed in a great vein. This can be the inferior vena cava or the femoral vein for the access cannula, and the jugular vein, the right atrium or the pulmonary artery for the return point. In the setup where the return cannula is placed in the pulmonary artery the right heart is – if incompletely – bypassed by the ECMO circuit.

Another cannulation option is a double lumen VV cannula (DLVV, we use the Avalon brand), this is placed in the right internal jugular vein under echo or fluoroscopic guidance, and provides an access as well as a return lumen.

3.2.3 Complex ECMO Cannulation strategies

In specific circumstances more complex cannulation setups may be utilized:

VA ECMO with additional LA drainage cannula:

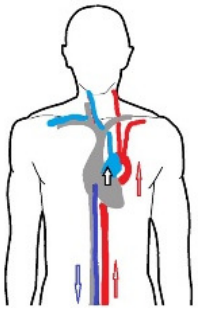
This cannulation strategy can be used to decompress the biventricular heart with severe LV dysfunction and no intra-cardiac connection. Delivery of the oxygenated blood into the patient's arterial circulation increases afterload, which a poorly functioning left ventricle cannot eject against. This progresses to a distended left atrium, which in turn leads to pulmonary oedema. Additionally the high wall tension impedes myocardial recovery. In centrally cannulated patients this can be overcome with placement of a cannula in the LA, which is connected by a Y connector to the RA drainage line. In peripheral cannulation LV decompression is preferentially done via a balloon or blade atrial septostomy (+/- stent). The negative pressure in the right atrium creates an atrial left-to-right shunt, which decompresses the LA and LV. In some cases thoracic access may be required for placement of a drainage cannula in the left atrium even with trans-cervical cannulation.

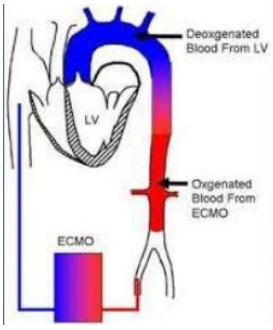
VA ECMO with additional venous drainage cannula:

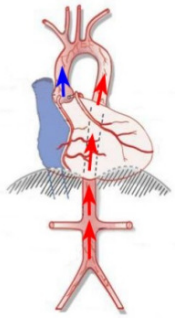
When maximum ECMO blood flow is insufficient to achieve adequate tissue oxygenation, additional flow can be achieved by placing an additional drainage cannula. This problem is typically seen in femoral VA ECMO cannulation for children with sepsis, who need very high blood flows. An additional venous cannula (typically placed in the right internal jugular vein) is only helpful if the return/arterial cannula is large enough to accommodate the respective flow. If the blood flow is already at the maximum that the respective arterial cannula can accommodate an additional venous drainage cannula will not increase the ECMO blood flow.

VVA or VAV ECMO:

Patients who require femoral VA ECMO and have simultaneous respiratory failure are at risk of developing differential hypoxia, potentially resulting in myocardial and cerebral ischemia. Differential hypoxia results from competing blood flow from the patient's native circulation and the ECMO circuit; the LV is ejecting poorly oxygenated (due to poor oxygenation in the pulmonary circuit) blood against the retrograde flow up the aorta from the ECMO circuit. Oxygen delivery to the upper body relies on this retrograde flow, however as cardiac function recovers the mixing zone for these competing blood flows moves beyond the ascending aorta to the right carotid, and potentially the left carotid and subclavian arteries. The potential for differential hypoxia in femoral VA ECMO necessitates continuous monitoring of oxygen saturations in both hands of patients on this mode of support.

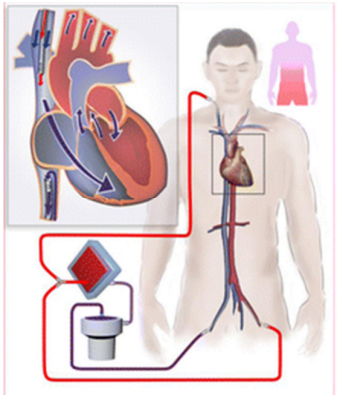






Three options are available to remedy differential hypoxia:

1. The ECMO flow through the femoral VA circuit can be increased, and the mixing zone can be shifted upward/towards the heart in the aorta, due to the increased retrograde flow through the aorta. This option is often restricted by the flow limitations of the cannulae (venous or arterial).
2. Ventilator settings can be increased to improve oxygenation (increase either in FiO2 or PEEP and/or mean airway pressure) of the blood passing through the lungs. This option is often limited by the concerns about oxygen toxicity and pressure injury to the lungs.
3. Addition of an Avalon cannula: by oxygenating the blood before it passes through the lungs the saturation of the cardiac output can be improved, and differential hypoxia can be resolved. Practically we do not run a separate VV circuit, but the access limb of the Avalon cannula is connected to the femoral venous/access limb, and the return limb is split to return oxygenated blood via both the femoral artery and the return limb of the Avalon cannula. It is important to measure the ECMO blood flow of the femoral arterial cannula to know how much ECMO flow is being provided. The total pump flow is not informative as a fraction of this flow will return via the Avalon cannula.



Two VA ECMO circuits: If there is insufficient ECMO blood flow the patient can be connected to two VA circuits – one through the femoral and one through the cervical vessels. The blood can either be run through two ECMO pumps and oxygenators, or the arterial and venous limbs can be Y'd together and run through one pump and oxygenator. This is a very rare setup that we will only use in exceptional circumstances.

Other cannulation options: Other cannulation options include options such as "central VV ECMO", where the cannulation occurs from the right atrium to the pulmonary arteries. This setup is similar to a right ventricular assist device, but differs because of the oxygenator that is included in the circuit.

Ventricular Assist Device (VAD)

At LCCH we only provide centrifugal VAD. Pulsatile VAD (Berlin Heart, Thoratec, etc) is currently not available at LCCH. Centrifugal VAD can only be provided with central cannulation; the access cannula is placed in the left atrium with a return cannula placed in the ascending aorta. A biventricular centrifugal VAD system is theoretically possible, though two ECLS systems are needed to maintain blood flow from the right atrium to the pulmonary artery as well as flow from the left atrium to the aorta.

4 Patient Selection

4.1 General Indication Criteria

The following points list the indication and contraindication criteria for ECLS provision for neonates and children treated at LCCH.

Inclusion criteria

> 34 weeks gestational age

> 2.5 kg body weight (<2.5kg requires individual assessment of cannulation site/vessel size)

As stated in Daily Goals

Exclusion criteria

Major intracranial haemorrhage

Severe neurologic injury

Lethal malformation

Untreatable underlying disease

As stated in PARP or Daily Goals

4.2 Specific Indications ECLS Support

Failure to wean off cardiopulmonary bypass

Neonatal lung disease: PPHN, CDH, (Meconium) Aspiration, HMD

ARDS/ALI

Therapy refractory shock

Bridge to diagnosis or transplant

Intractable arrhythmias

Others

4.3 ECMO assisted CPR

LCCH offers ECMO support for in-hospital witnessed cardiac arrest. Exclusion criteria as listed above apply. Out-of-hospital cardiac arrest is a further exclusion criterion.

ELSO definition; Extracorporeal cardiopulmonary resuscitation (ECPR) is the use of ECLS for patients in cardiac arrest when conventional resuscitative measures have failed. ECPR is defined as ECLS initiated during conventional resuscitation, or when repetitive arrest events occur without return of spontaneous circulation (ROSC) for >20 min.

Refer to CHQ Code ECMO Emergency Response (Document ID 80017) for how to initiate a cardiac surgical emergency response. The document covers the ECPR response for patients in all areas of LCCH, as well as for all emergencies for patients already on ECLS.

CLINICAL MANAGEMENT OF ECLS

1 Circuit Setup and Management

1.1 Circuit Configuration

1.1.1 ECMO

Our service utilizes a standard circuit design which we have available in 2 sizes. Both the 1/4" and 3/8" tubing sets are made from PVC noDOP tubing that has a blue stripe on the inlet limb and a red stripe on the outlet limb.

Maquet circuits contain a Rotaflow pump head and a Quadrox oxygenator. The Quadrox is bioline coated (combined albumin and heparin), and the tubing sets may be coasted with either Bioline or Softline (heparin-free polymer comprised of hydrophilic and hydrophobic areas).

Our circuits are designed as closed-system for infection control purposes; therefore all access points have clave connectors in place (luer lock, straight fluid path). This reduces risk of infection, as well as air entrainment or blood loss (dependent on tap location) if a tap is turned the wrong way.

There are 3-way taps located at both the inlet and outlet cannulas which are used for continuous pressure monitoring as well as emergency de-airing procedures. A 3rd pressure line is connected to the pre-oxygenator 3-way tap, and this is used to monitor the oxygenator trans-membrane pressure (TMP).

There is a 3-way tap connection pre-pump head which is used as a return point for the haemofilter shunt. Lastly there is a 3-way tap access point located between the pump head and oxygenator which is used for the heparin infusion and sampling port for circuit blood gases.

1.1.2 VAD

Our VAD circuit is built from either a 1/4" or 3/8" ECMO tubing set. Modifications are made to remove all luer lock connectors, leaving an uninterrupted line of tubing from the patient to and from the pump head.

1.2 Priming

A standard ¼" ECMO circuit will always be setup and available in PICU. The default clear priming solution is Plasmalyte, as this setup is stable and approved for use up to 30 days when stored appropriately.

Note: Emergency ECLS Circuit

- There will be a 1/4" available at all times in PICU (Hillside next to surgical re-open trolleys)
- In emergent situations all age groups & weights will be placed on the 1/4" circuit, and changed to 3/8" if necessary
- Default long term priming solution: Plasmalyte
- Whenever feasible a blood prime will be used. If cross matched PRBC not available circuit will be primed with O negative blood

- See work instruction section for Priming 1/4" and 3/8" Rotaflow ECMO and VAD Circuits

1.3 Flow Rates

The following calculations are a guide only, each patient requires individual assessment

1.3.1 VA ECMO

Patients < 10 kg: 100 – 150 ml/kg/min

Patients > 10kg: 2.5 – 3.5 L/m^2/min

Note:

- Consider higher flow rates in septic patients, parallel circulation (single ventricle physiology) and extra cardiac shunts

1.3.2 VV ECMO

Patients < 10 kg: 70 – 150 ml/kg/min

Patients > 10 kg: 1.8 – 3.5 L/m^2/min

Note: The following may be indicators of recirculation

- Inappropriately high circuit SvO_2
- Circuit SvO_2 is > patient $ScvO_2$
- Circuit SvO_2 is increasing while patient saturations are decreasing

.

1.3.3 VAV ECMO

In this mode the total patient flow is then split between return to venous and arterial system.

Total Patient Flow will be the amount of blood being returned via both the Avalon cannula as well we the femoral arterial limb. To calculate the amount of systemic ECMO flow support the flow needs to be measured in the arterial femoral cannula distal of the "Y"only. If the blood flow is measured proximal to the "Y" then the blood flow for both arterial and venous return is measured.

It is therefore imperative that the Spectrum monitor CI is calculated from the arterial return limb only, and initial guide for this flow rate is the same as VA:

Patients < 10 kg: 70 – 150 ml/kg/min

Patients > 10 kg: 1.8 – 3.5 L/m^2/min

Total Patient Flow is the amount of blood being returned to both the arterial and venous systems, which is why it's important to measure flow on 2 of the 3 sections of the return limb (Aortic cannula limb + either total flow or venous cannula limb).

1.3.4 VAD

Patients < 10 kg: 100 – 150 ml/kg/min

Patients > 10kg: 2.5 – 3.5 L/m2/min

2 Haemostasis & Anticoagulation during ECLS

2.1 Anticoagulation Related Complications

Incidence:

- ELSO database reveals > 2 bleeding or clotting complication per ECLS run
- Neonatal & paediatric ECLS have more complications than adult ECLS
- Rate in neonatal & paediatric ECLS increasing

Possible causes

1. The recommended anticoagulation strategies for ECLS are based on old concepts of haemostasis: Heparin works using the old waterfall or cascade model of haemostasis, but not the modern cell-based model.
2. Unfractionated Heparin is a drug with unpredictable dose response in newborns and children – but it is the only anticoagulant option we currently have for ECLS!
3. We are treating sicker patients with multiorgan dysfunction and pre-existing coagulopathy
4. Abundance of device technologies in use for ECLS around the world – this makes design of streamlined, reliable & reproducible anticoagulation strategies impossible.
5. Measures of concentration of clotting and regulatory factors and of platelet function are all decreased in the newborn, reaching adult levels and function not before 6 – 12 months of age – this makes reliable anticoagulation with Heparin – on or off ECLS – very unreliable.
6. Inadequate anticoagulation monitoring tests: our commonly used heparin monitoring tests have never been properly evaluated in newborns, infants or children; the tests & ranges currently used are based on extrapolation from adult data published in the 1970s.

2.2 Our Pragmatic Anticoagulation Strategy for ECLS

The Test Panel

1. Anti-Factor Xa activity (aka aXa, unfractionated Heparin level, UFH and heparin assay)
2. aPTT
3. aPTT-P
4. PT/INR
5. Platelet count
6. Fibrinogen level (clotted)
7. Antithrombin level
8. TEG 6s: Global citrate cartridge; CK, CKH, CRT MA, CFF MA (for validation purposes only)
9. ACT (only pre and post initiation of support and when Anti Xa unreliable)

Important - as most of our clotting tests are based on chromatography, elevated levels of plasma bilirubin, free plasma haemoglobin and/or triclycerides may provide false results.

	Anti Xa	Antithrombin
Total bilirubin	> 340 micromol/L	> 684 micromol/L
Plasma Free Hb	> 2000 mg/L	> 5000 mg/L
Triglycerides	> 3.6 g/L	> 23 g/L

Table 1: Serum levels which effect coagulation test results

Monitoring of coagulation status

- Initial Test Panel after commencing ECLS support is used to assess patients coagulation state (looking factor deficiency, coagulopathy, etc)
- Timing of the initial Test Panel is determined using patient weight:
  - <10 kg: Administer 5 ml/kg of cryoprecipitate, and then send full test panel 30 min post completion of infusion.
  - >10 kg: send full Test Panel 30 minutes after going on support. Administer blood products as required by patient bleeding status and coagulation tests results.
- Subsequent Test Panels are done q 4-6 hrs and PRN while on ECLS.
- Adjusting heparin infusion dose to Anti Xa range begins with a Test Panel sent 4 hrs after commencing the heparin infusion
- If a patient is being managed with a set heparin infusion dose, or no heparin infusion then the Test Panel should be repeated 6 hrly.

Principles

- ACT is at initiation of support, and q 30 min until it falls <300 seconds – when the heparin infusion is commenced.
  - Apart from initiation of support, ACT is not used as a routine test to guide anticoagulation management at LCCH PICU.
  - It may be used for further delineation of the clotting cascade in clinical circumstances such as during procedures, sepsis, hyper-fibrinolysis, transport, or when elevated levels of Bilirubin, plasma HB, and/or Triglycerides are present.
- The anti-Factor Xa assay (labelled “UFH” by Auslab/Auscare and “unfractionated heparin” in ieMR) is the primary monitoring tool for Heparin – Heparin dose adjustments are made based on the anti-Factor Xa level.
- The standard platelet count is the primary monitoring tool for platelets – the decision to transfuse platelets is based on the platelet count as well as the bleeding status of the patient.
- The standard fibrinogen level is the primary monitoring tool for fibrinogen – the decision to transfuse cryoprecipitate is based on the fibrinogen level and the bleeding status of the patient
- The platelet count, the fibrinogen level and the aPPT-P (aPTT after neutralisation of Heparin with protamine) are the primary monitoring tool for underlying haemostasis.
- Antithrombin level
  - Our anti-FXa assay is dependent on the patients AT level; a result below the desired therapeutic range can therefore be caused by patient AT deficiency or insufficient UFH dose
  - Normal AT levels in critically ill children have not been established
  - There is no evidence available to determine whether bleeding and/or clotting complication are more related to the heparin dose or Antithrombin level
  - AT levels <80% are acceptable if:
    - anti-FXa activity is within the desired/target range and the heparin dose is less than 35U/kg/hr
    - In the patient who is bleeding and on a minimum heparin dose

2.3 TEG®6s

Global Hemostasis Assay

Citrate Cartridge

Use ONLY Citrated Sample 3.2% Tube/Syringe

R = time to first measurable clot formation
MA (mm) = Maximum clot strength, reflects platelets and fibrinogen function
LY30 = lysis 30 minutes after MA reached

R

Citrated Kaolin (CK)
- Thrombin activated-global nature including heparin

Citrated Kaolin Heparinase (CKH)
- Counteracts effect of Heparin
- Shows factor deficiency

MA

Citrated RapidTEG (CRT)
- Shows Platelet and Fibrinogen Function

Citrated Functional Fibrinogen (CFF)
- Shows Fibrinogen Function

TEST	Parameter	Normal Ref Range	Measures	Consider transfusing
CK & CKH	R	CKR vs CKHR <5 min difference =? inadequate heparinization		
CRT	MA	52-70 mm	Platelet and fibrin strength	Platelets or cryo (If both CRT and CFF MA low give cryo, if only CRT low but CFF normal give PLTs)
CFF	MA	15-32 mm	Fibrin clot strength	Cryoprecipitate
CRT	LY30	0-2.2%	Anti-fibrinolytic activity	Tranexamic Acid

Table 2: TEG 6s Parameters

Important – Thromboelastometry

- The TEG 6s is still in validation phase, do not use any of the results alone to adjust anticoagulation or treat coagulopathy (see paragraph on TEG 6s)

2.4 Heparin infusion management

Setting up the Heparin infusion:

- Mandatory use of data set provided with the Braun® smart infusion pumps.
  - < 10 kg: Heparin 5,000 Units in 50 ml NaCl 0.9%
  - > 10 kg: Heparin Strong 25,000 Units in 50 ml NaCl 0.9%

Heparin infusion delivery

- ECMO: attached to distal clave at the pre-oxygenator port
- VAD: attached to a patient IV line (CVL preferred)
- Commence infusion as soon as the patient's ACT < 300 seconds or the Anti-Xa level is back – whichever is first.
- Heparin Infusion starting dose (unless otherwise ordered by ECLS SMO, Perfusionist and Cardiac Surgeon):
  - Neonates: 28 U/kg/hr
  - All others: 20 units/kg/hr
- Any further dose adjustments are based on the anti-Xa level.
- Usually the minimum heparin infusion rate should be maintained at 10 U/kg/hr, unless otherwise ordered.
- Occasionally patients may not need any heparin, particularly when they are bleeding. The ECLS SMO, Perfusionist and Cardiac Surgeon are to be consulted prior to running a heparin free circuit.
- Make no changes to Heparin infusion rate – or deliver a Heparin bolus – in the 3-4 hours before the next coagulation testing time – unless clinically indicated.

Heparinisation target range in ECMO

anti-Xa Level U/ml	Rate Change	Bolus	Repeat Panel
< 0.3	Increase by 20%	20 U/kg	After 4 hours
0.3 – 0.39	Increase by 10%	10 U/kg	After 4 hours
0.4 – 0.6	NA	NA	6 hourly
0.61 – 0.7	Decrease by 10%	NA	After 4 hours
> 0.7	Decrease by 20%	NA	After 4 hours

Table 3: Heparinisation target range for ECMO patients

NB target range may be altered depending on presence of bleeding or clotting complications

Heparinisation target range in centrifugal VAD

anti-Xa Level U/ml	Rate Change	Bolus	Repeat Panel
< 0.2	Increase by 20%	20 U/kg	After 4 hours
0.2 – 0.29	Increase by 10%	10 U/kg	After 4 hours
0.3 – 0.5	NA	NA	6 hourly
0.51 – 0.6	Decrease by 10%	NA	After 4 hours
> 0.6	Decrease by 20%	NA	After 4 hours

Table 4: Heparinisation target range for VAD patients

NB target range may be altered depending on presence of bleeding or clotting complications.

Heparinisation at initiation of ECLS support

- At the time of cannulation a bolus of 50 units/kg of heparin should be administered. The timing of this bolus is determined between the cardiac surgeon and the intensivist. In special circumstances this can be omitted after discussion between cardiac surgeon, perfusionist, and intensivist.
- Heparin is added to the circuit during priming (100 units into the 1/4" and 1000 units into the 3/8").
- Heparin infusion pump in standby mode attached to circuit (ECMO) or patient CVL (VAD).
- Ideally sample for a Test Panel will be taken prior to cannulation - or minimally an ACT.
- ACT every 30 minutes after the initial Heparin bolus.
- Initial Test Panel after commencing on support:
  - <10 kg: Administer 5 ml/kg of cryoprecipitate, and then send full test panel 30 min post infusion completion.
  - >10 kg: send full Test Panel 30 minutes after going on support. Administer blood products as required by patient bleeding status and coagulation tests results.
- AT (aka Antithrombin, Thrombotrol®) should only be administered following measurement of levels. AT replacement dose is based on patient's heparin infusion requirement, AT level, aXa level and bleeding status (see below for details).

Important – Antithrombin (Thrombotrol®)

Write down generic & brand name on Pathology order form

Do not confuse with Prothrombin concentrate (Prothrombinex®)!

2.5 Clotting target ranges

		aPTT-P seconds	Fibrinogen mg/L	Platelets X 10^{-9}/L
Target Range	**Not bleeding**	< 50	> 1.0	> 80
	Bleeding	< 50	> 1.5 (or higher depending on clinical requirements)	> 150 if bleeding

Table 5: Clotting target ranges

	Antithrombin (%)
Target Range	Heparin infusion < 35 U/kg/hr: maintain >40% Heparin infusion > 35 U/kg/hr: maintain >80%
Treatment	*Reduce heparin infusion by 30% with AT administration* AT dose = (100 – actual AT level) x patient weight (kg) ** MAX DOSE = 1 vial (1000 U) and no reduction of heparin infusion if giving less than calculated dose**

Important - Generally valid for VA ECMO, VV ECMO & VAD

2.6 Blood Products & Haemostatic Drugs during ECLS

2.6.1 Packed Red Blood Cells (PRBC)

Usually, give 15 ml/kg over **3** hours; monitor Hb level on Spectrum and ABG. If Hb not in target range, give another 5-10 ml/kg as required. Unless patients are 22q11 positive PRBCs do not have to be irradiated.

2.6.2 Platelets

Usual dose is 15-20 ml/kg. Give over 30 to 60 minutes.

2.6.3 Fresh Frozen Plasma

- Contains only low concentration of clotting factors
- Contains little essential clotting factors (Prothrombin or Fibrinogen)
- Proven not to correct any coagulopathy unless given in massive dose
- Blood product with highest incidence of adverse effects
- Probably only indicated in massive plasma leaks (chylothorax or –peritoneum). In patients with chylothorax or chyloperitoneum losses are replaced 1:1 or 1:2 with albumin and/or FFP, depending on coagulation status.

Important –

Not for treatment of mild-moderate coagulopathy or bleeding

Correct use in ECLS:

1. plasma replacement in massive bleeding
2. plasma leaking situation (large PD loses, etc)
3. Always give FFP as part of a MTP

2.6.4 Cryoprecipitate

- Contains Fibrinogen, Factors VIII & XIII, vWF and Fibronectin.
- At LCCH we receive Apheresis cryoprecipitate units from our blood bank, which are more concentrated at contain a higher volume per bag.
- The fibrinogen concentration is 13.2 mg/ml in the apheresis product rather than 9.7 mg/ml in the whole blood cryoprecipitate
- Made by Commonwealth Serum Laboratories (CSL) Behring Australia by thawing of fresh frozen plasma derived from whole blood or collected via apheresis, and distributed by Australian Red Cross Blood Service. The precipitate of the thawing process is recovered and refrozen.
- Indications:
  - Fibrinogen deficiency or dysfibrinogenaemia in association with clinical bleeding, invasive procedure, trauma or DIC
  - ECLS: if Fibrinogen level < 1.5 mg/L, or < 2 mg/L in the bleeding patient
- Dose: 5 ml/kg over 1 hour

2.6.5 Antithrombin (Thrombotrol®)

- Contains antithrombin (AT, an alpha2-glycoprotein of molecular weight 58'000 daltons)
- It also contains low levels of Factor IX, Platelet Factor 4, Heparin, Na, Cl, and Citrate
- Made by Commonwealth Serum Laboratories (CSL) Behring Australia from pooled human plasma and freeze-dried, distributed by Australian Red Cross Blood Service
- Actions: major physiologic thrombin (Factor II) antagonist; makes Heparin more effective
- Indications: AT deficiency. AT is one of the cornerstones of reliable anticoagulation, though at which levels an "effective" antithrombin level is reached remains unclear. At LCCH PICU high AT levels have been maintained, which may have resulted in fewer anticoagulation related complications. We will continue to monitor the AT levels and how they correlate to clotting and bleeding complications, but we will adjust the target AT levels down to 40% for all patients, and 80% for those patients that require a heparin dose exceeding 35 units/kg/hr.
- Dose calculation: required IU = [(100% – actual level (in %)] x weight (kg)
- Max dose = 1 vial; given as intravenous push at maximum rate of 3 ml/min
- Reduce heparin infusion by 30% prior to administration of AT
- Contraindications: to date, the safe use of Thrombotrol has not been established in the paediatric population
- Adverse effects: anaphylaxis

2.6.6 Prothrombin Complex Concentrate (Prothrombinex®)

- Contains Factors II, IX and X, low levels of other human plasma proteins incl Factors V and VII.
- Specifically, it also contains low levels of Antithrombin, Heparin, Na, Cl, Citrate and Phosphate.
- Made by Commonwealth Serum Laboratories (CSL) Behring Australia from pooled human plasma and freeze-dried, distributed by Australian Red Cross Blood Service.
- Effects: promotes clot formation through activation of Factor II (thrombin).
- Indications:
  - Treatment of perioperative prophylaxis of bleeding from oral anticoagulation therapy (eg Vit K Antagonists).
  - Factor II, IX (Haemophilia B) or X deficiency.
  - Cardiothoracic surgery.
- Contraindications: to date, the safe use of Prothrombinex® has not been established in the paediatric population.
  - DVT
  - DIC
  - Relative: ECLS – main problem: mix up with Antithrombin (Thrombotrol®)
- Adverse effects: hypercoagulability, anaphylaxis

2.6.7 Recombinant activated Factor VII (rFVIIa; NovoSeven®)

- Made by Novo Nordisk; the gene for human Factor VII is cloned and expressed in baby hamster kidney cells; distributed as white lyophilized powder
- Contains rFVIIa, Na, Ca, Cl, Mannitol
- Effects: 'clot-booster' by generation of Thrombin and activation of platelets
- Indications:
  - Indicated & licenced for treatment of bleeding episodes in haemophilia (A & B) patients with inhibiting antibodies to Factors VIII and IX (multiple doses of 90 mcg/kg), and in patients with congenital FVII deficiency.
  - Any other use is 'off label', especially in the paediatric population
    - Cardiothoracic surgery.
    - Intractable bleeding on ECLS.
      - Requires discussion & approval by ECLS SMO, Perfusionist, Cardiac Surgeon & Haematologist.
      - Requires adequate level of functioning platelets – always transfuse platelets prior to rFVIIa.
      - Only given with a Perfusionist present at patient bedside.
      - Dose 30 mcg/kg administered IV, into a patient line (never the circuit) over 5 minutes, HLT 2 hours. Dose can be repeated in 30-60 minutes up to a maximum total dose of 90 mcg/kg.
    - NB rFVIIa is not part of any Massive Transfusion Protocol (MPT)!
- Contraindications: DIC, DVT
- Adverse effects: DVT, anaphylaxis

2.6.8 Tranexamic Acid (TXA; Cyclokapron®)

- Mechanism of action
  - TXA is a synthetic analog of the amino acid Lysine.
  - Binds irreversibly to Lysine receptor sites on Plasminogen and Plasmin.
  - This prevents Plasmin from binding to and degrading Fibrin.
- Effects: Haemostatic agents e.g. stops bleeding by prevention of fibrinolysis; 8-times more active than Aminocaproic Acid (Amicar®).
- Indications:
  - Prevention and treatment of excessive bleeding including Paediatric Cardiac Surgery.
  - Trauma, surgery, gastrointestinal etc.
  - Is part of the Massive Transfusion Protocol (MTP).
- Dose: 10 - 15 mg/kg 8 hourly (see F. Shann, Drug Doses); 2 hours HLT.
- Adverse effects: clot formation (circuit, DVT), gastrointestinal (vomiting, diarrhoea), potential for CNS toxicity (seizures).
- Should be given once fibrinogen levels are replete (ie give cryoprecipitate before giving TXA).

2.6.9 Epoprostenol Sodium (Prostacyclin, PGX, PGI_2, Flolan, Epoprostenol)

- Epoprostenol is a naturally occurring prostaglandin produced by the vascular endothelium. It is a potent pulmonary and systemic vasodilator, and inhibitor of platelet aggregation.
- Administration:
  - Half-life is approximately 3 minutes. Administered via circuit or CVAD using an infusion with a 0.22 or 0.2 micrometre inline filter.
  - When diluted with provided solution the syringe is stable for 24 hrs at 2-8 ^{o}C (using a cold pouch system), or 12 hrs at room temperature. We allow a syringe to be used for 24 hrs, allowing for some loss of potency.
  - In ECMO the infusion is connected to the clave at the haemofilter return line – to prevent accidental bolus.
  - If claves not present on circuit then Perfusion is responsible for connection to and discontinuation of prostacyclin to the ECLS circuit.
  - If claves present then an ECLS Specialist may connect and discontinue prostacyclin infusion from the ECLS circuit.
- Dosing:
  - Dosing depends on the indication. For platelet inhibition the dose is 5 nanograms/kg/min.
  - When used for pulmonary hypertension the usual starting dose is 5 nanograms/kg/min, adjusted according to response up to 20 nanograms/kg/min. Rarely doses up to 40 nanograms/kg/min are used.
- Adverse effects: hypotension (beware bolusing or rapid infusion rate changes). When weaning and ceasing beware rebound hypertension and monitor coagulation status (platelet function) closely.
  - To prevent any Epoprostenol being left in the line a generous waste must be taken from the clave connector.

2.6.10 Recombinant Fibrinogen Concentrate (RiaSTAP®)

- RiaSTAP® is a freeze-dried fibrinogen concentrate derived from human plasma. It contains 1g of human fibrinogen per vial. It is produced as a sterile white powder for intravenous injection after reconstitution with Water for Injection.
- Each vial contains

Fibrinogen	900 - 1300 mg
Albumin	400 - 700 mg
Arginine hydrochloride	375 – 660 mg
Sodium chloride	200 – 350 mg
Sodium citrate	50 – 100 mg

- Indications: treatment of acute bleeding episodes in patients with fibrinogen deficiency
- Contraindications: hypersensitivity to the active substances.

- Adverse events:

MedDRA System, Organ, Class	Undesirable effects	Frequency
General disorders and administration site conditions	Pyrexia	Very common
Immune system disorders	Allergic or anaphylactic reactions	Uncommon
Vascular disorders	Thromboembolic events*	Common**

  - Allergic/anaphylactic reactions have been uncommonly observed. Events reported include generalised urticarial, rash, dyspneoea, tachycardiac, nausea, vomiting, chills pyrexia, chest pain, cough, blood pressure decrease, and anaphylactic shock.

- Dosing: If the patient's fibrinogen level is unknown the recommended dose is 70 mg/kg body weight, administered IV.
  - In patients with known fibrinogen level the target level is 1 g/L for minor bleeding events, and 1.5 g/L for major bleeding events:

$$\text{Dose of fibrinogen (mg/kg body weight)} = \frac{\text{[Target level (g/L) – measured level (g/L]}}{\text{0.017 (g/L per mg/kg body weight)}}$$

- Administration: reconstitute as per package insert. Do not mix RiaSTAP® with other medications or IV solutions – it should be administered on its own at room temperature by slow intravenous injections at a rate not to exceed 5 ml/min.

2.6.11 LCCH anticoagulation flow sheets

See chapter 8.4

3 Cardiovascular Care & Haemodynamics during ECLS

3.1 Myocardial Protection

General consideration: coronary arteries may get supplied by blood from the lung, and this blood may well be deoxygenated if there is significant lung disease. It is therefore important to keep ventilating and oxygenating blood that passes through the lungs at a minimal & defined level. Observe the ECG (ST changes) at all times, and obtain an echocardiography at defined times or criteria.

3.2 Myocardial distension

- At risk are patients on VA ECMO with myocardial dysfunction and absence of left-to-right shunt.
- In a patient with poor ventricular function increased ventricular afterload leads to ventricular dilatation, which increases wall tension and myocardial oxygen consumption.
- Repeat echo within hours of going on VA ECMO and at defined intervals to monitor successful ventricular decompression is essential.
- In case of dilated LV or LA the following treatment options are available:
  - The afterload should be decreased to aid in ventricular contraction, opening of the aortic valve and offloading the ventricle.
    - Keep in mind that patients on full VA ECMO flow tolerate lower mean arterial pressures compared to patients not supported by ECMO. In patients on full VA ECMO flows adequate oxygen delivery (as measured by indirect markers such as lactate and central venous saturations) is often maintained at blood pressures at the low normal range.
  - LA vent or drainage into circuit.
  - Balloon or blade septostomy in the cath lab.
  - While a ventricular cannula is theoretically possible we do not use this option currently at LCCH.

3.3 Systemic Arterial Hypertension

Systemic arterial hypertension during an ECMO run is not uncommon, and can be extremely detrimental in a patient with poor LV function, as it will lead to left atrial dilation and increased wall stress and myocardial oxygen consumption. In patients on “full” ECMO support systemic oxygen delivery is often adequate at lower mean arterial pressures than in a patient not supported by ECMO. Consider weaning inotrope(s) if appropriate.

If poor LV function and adequate DO2 (as measured by lactate and $ScvO_2$)

- Adequate DO2 (as measured by lactate and $ScvO_2$)
  - Lower systemic afterload aggressively and early
  - Accept low normal mean arterial blood pressure
  - Consider starting inotrope (if aortic valve not opening)

- Inadequate DO2 (as measured by lactate and $ScvO_2$)
  - Increase ECMO flows
  - Lower systemic afterload aggressively and early

If LV function normal

- Inadequate DO2 (as measured by lactate and $ScvO_2$)
  - Lower systemic afterload
  - Increase ECMO flow
- Adequate DO2 (as measured by lactate and $ScvO_2$)
  - consider weaning inotrope(s)

Drugs for afterload reduction include the following:

- Dexmedetomidine
- Milrinone
- Sodium Nitrupresside (aka SNP, nipride)
- Hydralazine
- Phentolomine
- Levosimendan: in some patient, particularly those that have decreased left ventricular function levosimendan may be the preferred drug of choice.

Consider decreasing patient flows if appropriate (must discuss with PICU ECLS Consultant).

3.4 Systemic Arterial Hypotension

As described above patients on full ECMO flow tolerate lower mean arterial pressures compared to patients not supported by ECMO. In patients on full ECMO flows adequate oxygen delivery (as measured by indirect markers such as lactate and central venous saturations) is often maintained at blood pressures in the low normal range. Treatment of hypotension should occur if the mean arterial pressure is unacceptably low (as defined by the goals set during ward round) or if there is evidence of poor DO2.

Causes:

- Not enough flow
- Hypovolemia
- Mechanical: poor drainage, poor ejection
- Over sedation and/or dilatation
- Sepsis
- Vasoplegia (from causes other than sepsis: adrenal insufficiency, peripheral shunt etc.)

Treatment depends on myocardial function. In the case of no myocardial dysfunction (vasoplegia) use

- Noradrenaline
- Vasopressin

With myocardial dysfunction: Always consider whether flows can be increased before instituting an inotrope (which may be deleterious to the patient). If increasing flows does not lead to a correction of the hypotension use

- Dobutamine
- Dopamine
- Adrenaline

4 Respiratory Care & Ventilation during ECLS

4.1 Modes of Ventilation on ECLS

Self-ventilating: rare in paediatric patients, more common in adult patient on VV ECMO or VAD.

Conventional Mechanical Ventilation is done with the following ventilators

- Evita XL (Draeger Medical AG, Luebeck, Germany)
- Servo I (Maquet Holding, Rastatt, Germany)
- Servo U (Maquet Holding, Rastatt, Germany)
- High Frequency Ventilation (SensorMedics, Cardinal Health Inc, Dublin, Ohio, USA)
  - 3100A model for patients < 20 kg
  - 3100B model for patients > 20 kg

4.2 Airway & Lung Care on ECLS

Airway

- Secured by cuffed ETT (Microcuff, Kimberly-Clark, Roswel, USA)
- Nasal ETT change with caution because of bleeding risk, especially in older age groups

Lung Care

- Frequency of endotracheal suctioning twice daily minimum, more often as clinically indicated
- Bronchoscopies with respiratory team involvement are frequently indicated in respiratory ECLS patients

Ventilation settings – principles:

1. Distinguish between patients with active lung disease, either due to collapse, infiltration or generalized inflammatory state. Depending on whether the lung is affected the following pulmonary considerations, guidelines and manoeuvres may be necessary
2. Ultra-lung protective: TV < 4ml/kg, PIP max 20 in newborns, max 25 in older patients.
3. No recruitment manoeuvres outside of the Pulmonary Function in ECLS study.
4. Keep lung open: PEEP 12 in newborns, 10 in older patients.
5. Continuous air leaks: consider CPAP or HFO.
6. Minimum FiO2 40%: in VA ECMO the coronary arteries are perfused by blood ejected from the left heart – ie blood that has bypassed the ECLS and passes through the sick lung. It is therefore imperative to continue to oxygenate the lung in all patients. In VV ECMO this is not as important a paradigm.
7. I-time and HFO: where lungs are collapsed an Airway Pressure Release ventilation strategy may be chosen, with an I-time of 4 sec (where the rate is 10 bpm, with a breath cycle time of 6 seconds and a resulting I/E ratio of 3 to 1). Alternatively HFOV with a mean airway pressure between 20 and 25 may be chosen.

4.3 Treatment Goal Parameters

Goal parameters *adjusted to individual patient needs/diagnosis*									
ECMO Mode		**Ventilator Mode**	**Vt** ml/kg	**PEEP** cmH2O	**PIP** cmH20	**FiO2** %	**RR** bpm	**Ti** sec	**PS** cmH2O
VA	**Full Support Healthy lung**	VC or PC	6 ml/kg	10	20	40	10 - 15	1 – 1.5	5
	Full support Diseased lung	VC or PC	≤ 4 ml/kg	10	20	40	10 - 15	1 to 4.5 sec	5
	Weaning Off	VC	≤ 6	5 – 10	PRN	Adapted to ABG	PRN	0.6 – 1.5	PRN
VV	**Full Support**	VC or PC	≤ 4	10 - 12	20-25	Adapted to ABG*	10 - 15	1 – 4.5**	5
	Weaning Off	VC or HFO	≤ 6	PRN	< 30	Adapted to ABG	PRN	0.6 – 1.5	PRN

Table 6: Treatment Goal Parameters on ECMO

VC = SIMV PCV+ / Pressure Regulated Volume Controlled ; PC = SIMV Pressure Control; PRN = as per need

* Depending on the adequacy of VV support higher FiO_2 requirements may be seen. If there is only "partial" VV support both ventilation and FiO_2 may need to be higher

** Significantly longer I-times may be chosen to keep the lungs at peak inspiratory pressure rather than at PEEP for longer ("Airway Pressure Release Ventilation" like setup: see above text.

Aims: Generally dependent on age, disease and ECLS mode.

In patients with severe lung disease a non-invasive mode is often selected. Tidal volumes in these patients are often low leading to ongoing alarms, which can be disabled by switching to a non-invasive mode. In addition for older children who would qualify for the adult mode the paediatric mode is more suited as tidal volume limits are lower.

Important

VA ECMO in infants with parallel circulation: clarify shunt situation; if shunts patent, blood flow may need to equal two cardiac outputs!

VV ECMO in infants with parallel circulation: extremely rare constellation

VA ECMO for respiratory support: goals may be adjusted as per VV ECMO

Femoro-femoral VA ECMO: watch out for differential oxygenation, and consider VAV or central VA for such situations.

4.4 Patient parameter goals

Goal parameters *adjusted to individual patient needs/diagnosis*				
ECMO Mode		**pCO2** mmHg	**SaO2** %; nc	**SaO2** %; pc
VA	**Full Support**	< 45	> 94	> 85
	Weaning Off	pH guided	> 94	75 - 85
VV	**Full Support**	PHC pH ≥ 7.25	> 85	> 85
	Weaning Off	PHC pH ≥ 7.25*	> 90	75 - 85

Table 7: Patient Goal Parameters on ECMO

Where:

nc = anatomically normal circulation
pc = parallel circulation
PHC = permissive hypercapnia

*pH is maintained >7.4 in patients with a high risk of pulmonary hypertension and a chronic (compensated) respiratory acidosis is aimed for to allow for less ventilation (ie/ congenital diaphragmatic hernia). In patients without risk of pulmonary hypertension permissive hypercapnia may be adequate.

Important - VA ECMO: the coronary arteries are perfused by the blood ejected from the heart, therefore it is imperative to continue to oxygenate with adequate PEEP and FiO2 in all patients with forward flow (aortic ejection)

4.5 Lung Recruitment

(Study only): ***Only in patients on respiratory ECMO***. Lung function test maneuvers (daily, sequence of 30 minutes) will be performed daily by using the Hamilton P/V-Tool (Hamilton Medical AG, Bonaduz, Switzerland). Pressure ramp will be set according to patient's age. Hysteresis, upper and lower inflection points, resistance and compliance values will be recorded.

Patient's age [years]	Maximal pressure ramp [mbar]
0-1	30
2-5	35
>5	45

Table 8: Lung Recruitment during ECMO

4.6 Procedures on ECLS

4.6.1 PICU procedures

IV access

Bronchoscopy

Linen changes

Bed changes

Trial off support

- VV:
- VA PCRTO:

4.6.2 Surgical procedures

Chest drain insertion

Chest re-open +/- wash-out

Lung biopsy

ECLS component/circuit change

Trial off “bridge” insertion

Decannulation

4.6.3 Intra-hospital transport

4.7 Additional Investigations

Chest X-ray: daily and PRN

Lung biopsy, bronchoscopy/BAL: part of standard diagnostic procedures before and/or during ECLS. More common in patients on respiratory ECMO support.

CT scan: as needed during ECLS for diagnostic and prognostic information.

5 Renal Replacement Therapy on ECLS

Both our ¼" and 3/8" ECMO circuits come standardly with an in-built haemofilter (Maquet BC20) that we can use to provide low level continuous renal replacement therapy (CRRT). The BC20 is located on the shunt line that comes off the arterial side of the oxygenator and returns to the venous limb before the pump head. Blood flow through the filter is created by the pressure gradient this setup provides (from an area of positive pressure to one of negative pressure).

The rate of blood flow through this shunt is controlled using a gate clamp on the shunt to restrict blood flow. The shunt line gate clamp position is repositioned one each shift, and should always be on the section of tubing between the haemofilter and the venous limb of the circuit – ensuring that the negative pressure from the venous limb does not reach the filter itself. The maximum blood flow rate through the shunt line is 200ml/min. The minimum shunt blood flow rate is to prevent clot formation in the shunt line and haemofilter;

- ¼" circuit = minimum 100 ml/min shunt blood flow
- 3/8" circuit = minimum 150 ml/min shunt blood flow

The shunt line and haemofilter are used to provide two of the three methods of renal support that we offer in ECLS; SCUFF and CAVHF.

5.1 Slow Continuous Ultra-Filtration (SCUF)

Most commonly we employ a free-flowing circuit using the ECLS pump to circulate the patient blood flow through the inbuilt haemofilter shunt. We are then able to use a large volume pump to remove fluid from the haemoconcentrator to achieve slow continuous ultrafiltration Effluent +/- dialysate is controlled via a BBraun large volume pump. Note; the set amount of effluent is often exceeded due to the highly positive pressure in the haemofilter.

5.1.1 Adverse Effects

Hypovolemia

SCUF especially in large volumes may remove significant amount of Heparin molecules from the circuit

- Apply gradual changes to SCUF rate, rather than quick removal of fluid e.g. aim for fluid removal over 12-24 rather than over 1-2 hours
- Expect higher doses of Heparin to achieve desired antiFXa level

5.2 Continuous Arterio-Venous Haemodialysis (CAVHD, aka "counter-current")

In continuous diffusive dialysis the dialysate is driven in a direction counter current to the blood. Solute clearance is achieved by diffusion of particles from the blood path into the dialysis solution. This provides reasonably effective solute clearance, although mostly small molecules are removed. The higher the dialysis solution flow rate through the outer chamber, the more effective the solute clearance. Fluid removal can still be achieved by setting the effluent pump rate higher than the dialysate pump rate.

5.2.1 Adverse Effects

Hypovolemia

SCUF with dialysis will remove a greater amount of Heparin molecules from the circuit

- Apply gradual changes to SCUF rate, rather than quick removal of fluid; aim for fluid removal over 12-24 rather than over 1-2 hours
- Strict indications for dialysis (?trial of diuretics first)
- Expect higher doses of Heparin to achieve desired antiFXa level

5.3 Filter Specification

BC20 is standard for all circuits. For 3/8 circuits a DHF02 filter is used occasionally if the BC20 is deemed not effective enough.

When required the counter current should be set to 20 ml/kg/hr

Choice of filters: There are two filters that can be used in our setup, namely the BC20 and the DHF02. Both are haemoconcentrators that are used in bypass machines, and are available as single items (as opposed to the filters used in the Prismaflex). Both filters have a sieving cut-off of around 65.000 Daltons, but they vary on how much ultrafiltrate they can generate (BC20 is limited around 45 ml/min, whereas DHF02 can generate an ultrafiltrate rate of close to 100 ml/min):

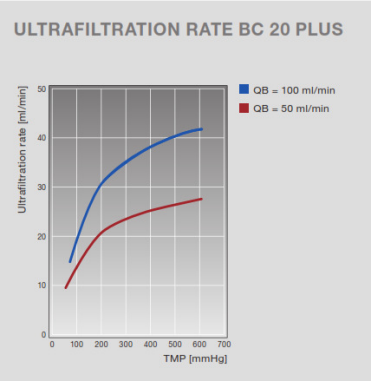


Figure 1: Ultrafiltrate properties BC20 Filter

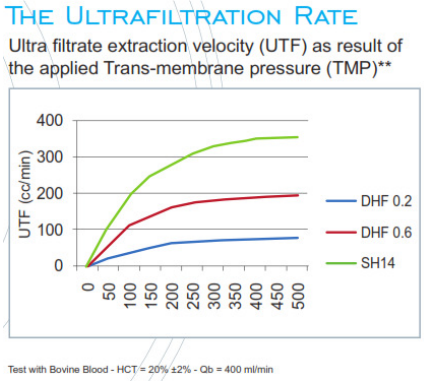


Figure 2: Ultrafiltrate properties DHF0.2

For our purposes where we never use these filters for haemofiltration, but for slow continuous ultrafiltration (SCUF). Given ultrafiltrate flow rates are low during SCUF the type of filter used is not highly important.

BC20 (standard)

PRODUCT	BC 20
Membrane Surface	0.2 m2
Priming Volume	17ml
Max. transmembrane pressure	600 mmHg
Membrane material	Polyarylsulfone
Capillary wall thickness	50 µm
Interior Capillary Diameter	215 µm

DHF0.2 (used PRN)

PRODUCT	DHF0.2
Membrane Surface	0.25 m2
Priming Volume	30mls
Max. transmembrane pressure	495 mmHg
Membrane material	Polyarylsulfone
Capillary Wall thickness	30 µm
Interior Capillary Diameter	200 µm

Table 9: BC20 and DHF02 Properties

5.3.1 Clearance

Clearance depends on the size of solutes.

Clearance	Non clearance
Urea	Albumin
Creatinine	Haemoglobin
Sodium	Fibrinogen
Potassium	Bld components (Platelets,RBC,Leukocytes)
Chloride	
Glucose	

Table 10: Clearance Properties of solutes

5.4 Continuous Arterovenous Haemodiafiltration (CAVHDF)

CAVHDF is our standard renal replacement therapy for patients on ECMO. During CAVHDF

- Blood is circulated through a haemofilter.
- Dialysate is infused into the outer chamber of the filter.
- Effluent/ultra-filtrate is removed from the outer chamber of the filter.
- Replacement fluid is infused into the blood path before the filter.

The Prismaflex machine is placed within the ECLS circuit. To reduce risk of air entrainment the Prismaflex access line will be connected to a positive pressure area within the circuit and the return line to the negative, inlet line. However the Prismaflex machine has limitations related to pressure;

- Access pressure: maximum 350 mmHg – therefor perfusion should be contacted for troubleshooting and CRRT circuit placement options any time the access pressure is >300 mmHg.
- Return Pressure: must be a positive pressure – therefore a “gate clamp” must be placed on the return line to create positive pressure in the CVVH circuit.

5.4.1 Continuous Arterovenous Haemodiafiltration Prescription

The ECMO orders for renal replacement therapy on ECLS follows the guidelines of the renal replacement therapy on standard patients, with the exception of the renal replacement therapy blood flow rate, which in the case of ECLS patients should be set at 100 ml/min

- Anticoagulation Method: *Non-Citrate - ECLS*
- Prismaflex Mode: *CVVHDF* - for all patients
- Circuit type: *Heparin* - though no “extra” heparin given above the ECLS anticoagulation
- Filter/Circuit Type: *ST 100* - for all patients and circuit sizes
- Circuit Prime: *N/Saline 1L + 5,000u/s Heparin*
- Blood flow: *100 ml/min* – minimum rate, can be increased on patients with high ECLS pump flow
- Dialysate Rate (Countercurrent): *30 ml/kg/hr* with a maximum of 2500 ml/hr.
- PBP (or filtration rate): *30 ml/kg/hr* with a maximum of 2500 ml/hr
- The calculated effluent rate will therefore be 60 ml/kg/hr
- Replacement rate: 50ml/hr

See work Instruction section for:

1. Commencing shunt blood flow. See chapter 8.13.1
2. Repositioning gate clamp. See chapter 8.13.2
3. Commencing SCUF 8.14
4. Commencing CAVHD (aka Counter-current). See chapter 8.15
5. Prismaflex setup and operation. See chapter 8.16

6 Weaning off/Separating from ECMO

Weaning a patient from ECMO is the process of reducing the cardiorespiratory support (either VA or VV) provided by the ECMO blood flows, and ultimately results in decannulation (if weaning is successful). Weaning starts with an ECMO team decision to wean the ECMO blood flow, and usually this decision would occur in the cardiac/ECLS ward round. This decision is based on whether the initial process that lead to the requirement of ECMO has turned off/has significantly improved, and whether organ function, particularly cardiac and respiratory function, has improved to a point where mechanical support is not necessary anymore.
The weaning plan should be documented by the "First on" intensivist, or alternatively by the ECLS consultant.

6.1 Weaning & Trial Off in VA ECMO

Before weaning from VA ECMO is commenced the following steps should be instituted:

- Check recent ECHO and CXR is available, and pulmonary compliance is known/assessed
- Commence ventilation with appropriate settings – ie stop "rest" settings, and increase ventilation
- Ensure patient ETT is suctioned
- Commence appropriate inotrope
- Ensure patient volume status is adequate
- Ensure adequate patient Hb

Weaning phase:

- Reduce ECMO blood flow by 5-10 ml/min increments, usually no lower than 50-70 ml/kg/min
- Ensure that total oxygenator flow is at least 200 ml/min. If not enough blood flow through oxygenator remove gate clamp on AV shunt altogether, thus achieving higher oxygenator flows with same patient blood flow
- Perform ABG 15 min post each wean of ECLS flow
- Discuss plan for ECHO at lower flows
- Do NOT turn sweep gas off – all flow going through circuit bypasses lungs. Minimum sweep gas setting is 200 ml/min
- If the patient has been stable up to this point a "trial off period" can be achieved by PCRTO or "bridging" techniques

6.1.1 Pump Controlled Retrograde Flow Off (PCRTO)

Centrifugal ECMO pumps allow for blood flow to run either in a veno-arterial or an arterio-venous direction. When supporting a patient on VA ECMO the blood flow is always directed from the venous to the arterial side. The heart of the patient however ejects against the ECMO blood flow. When a patient recovers eventually the cardiac output may be sufficient to supply both the patient's circulation as well as drive the blood through the ECMO circuit in a retrograde fashion. This results in a reversal of the blood flow through the ECMO circuit. Haemodynamically it leads to a large left-to-right shunt, and volume loading of the heart. During retrograde flow there is systemic steal into the ECMO circuit, and some children actually increase their blood pressure on decannulation when retrograde flow is running during decannulation. The amount of flow through the shunt is controlled by the ECMO console: the revolutions in the pump prevent the retrograde flow to become too great. Depending on patient size retrograde flows can reach 250 ml/min, but minimum flows should be maintained at more than 80-100 ml/min. Failure to achieve sufficient retrograde flow can be related to the patient's size, or patient physiology. Patients with univentricular physiology may well fail as the single ventricle has to pump into two parallel circuits already, and the retrograde flow adds a third one.

6.1.2 VA trial off with AV shunt, aka "bridging"

This is achieved by placing an Arterial-Venous shunt into the circuit, near the inlet/outlet pressure line. This enables us to cease all blood flow provided by the ECMO system, while flushing the ECMO cannulas.

6.1.3 VA trial off with partial arterial line occlusion

As the centrifugal pump works on a constrained vortex which relies on resistant dependent flow, we are able to partially occlude the arterial (outlet) limb of the circuit with a clamp, which increases the pressure within the oxygenator – allowing for increased flow via the haemofilter shunt during a period of lower flow to the patient. This allows for longer periods of time at lower patient flow, while reducing the risk of clot within the oxygenator.

6.2 Weaning and Trial Off in VV ECMO

A decision about what type of ventilation each patient requires must be made prior to any weaning attempt (HFOV vs conventional ventilation, with or without iNO). Thereafter weaning from VV ECMO occurs by weaning the FiO2 on the sweep gas initially, and then weaning (and eventually turning off) the sweep gas altogether. The blood flow can be weaned if the inlet pressures are very negative, but generally the flows will be maintained around 70-90 ml/kg/min or 2.0 L/m^2 respectively.

Before commencing any weaning of blood flow the following steps should be checked:

- Check recent ECHO and CXR is available, and pulmonary compliance is known/assessed
- Commence ventilation with appropriate settings – ie stop "rest" settings, and increase ventilation
- Ensure patient ETT is suctioned
- Commence appropriate inotrope (where necessary)
- Ensure patient volume status is adequate
- Ensure adequate patient Hb
- NOTE: FiO_2 must be at 0.21 for at least 30 minutes prior to decreasing sweep gas rate (this is to flush all O_2 from oxygenator)
- Wean sweep gas down to zero
- Observe patient saturation
- ABG after 30 minutes
- Team to assess patient readiness for decannulation

6.3 Weaning centrifugal VAD

Weaning centrifugal VAD can be done either by the conventional way of turning flows down, possibly "bridging" and then decannulating the patient. However, pump controlled retrograde flow allows for a more elegant process of weaning the patient off centrifugal VAD. For a detailed description see 0.
The following steps should be employed when weaning a patient off centrifugal VAD:

- Individual patient weaning plan to be charted in MetaVision by Intensivist
- Check which inotropes are to be used and prepare syringe(s) if required
- Ensure adequate patient Hb
- Ensure patient volume status is adequate
- Perform ABG 15 min post each wean of flow
- ECHO at lower flows
- Team to assess patient readiness for decannulation
- Once patient has been decannulated, remember to cease the Heparin infusion.

7 Equipment & Maintenance

7.1 Spectrum M3/4

Spectrum Medical System M monitor offers real time monitoring for ECLS.

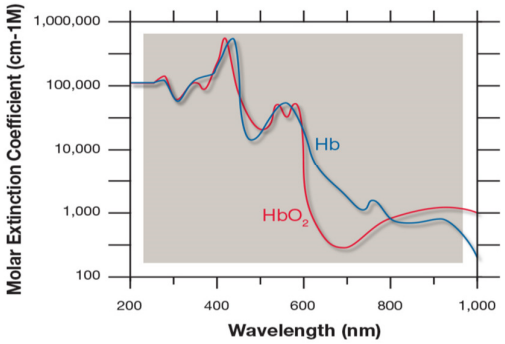
Non- Invasive: Maintains the integrity of the ECLS circuit, improved infection control with a reduction in the risk of blood clotting.

Real-Time: Second to second system updates using the latest technology.

Accuracy: Critical real time parameters, with accuracy maintained over range of short and long term cases, changes in temperature, haemodilution or blood flow.

Portable: Battery life up to 45minutes.

7.1.1 The Measurement of SaO_2 and SvO_2



The Measurement of O_2 saturation is achieved by analysing a specific region of the oxy-haemoglobin absorption curve. The use of this non-invasive optical shape recognition technology ensures the measurement of O_2 is highly accurate and extremely repeatable to its pre-shipped calibrations over the lifetime of the product.

The Measurement of Haematocrit and Haemoglobin

Spectrum Medical again uses non-invasive technology for the continuous reading of Haematocrit (15 to 50%) and Haemoglobin (5 to 17g/dl).

Infrared light from an LED is passed through a flowing tube of blood. A photodiode detects a receiving light level and converts the resultant light energy into a proportional electrical output.

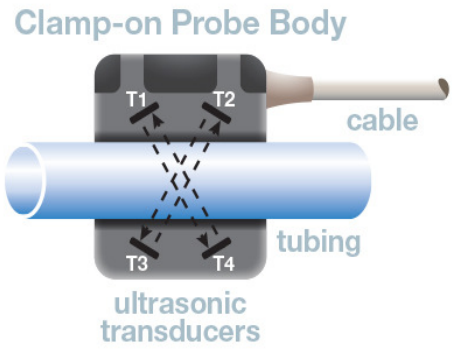
The sensors are delivered pre-calibrated with a high and low concentration value. Software algorithms linearize this relationship and convert the incoming signal to an actual value of Haematocrit or Haemoglobin.

Flow, Emboli & Bubble Detection (3 Channels)

The measurement of Blood Flow:

To provide the accurate measurement of blood flow Spectrum Medical uses the latest ultrasonic technologies and the proven concept of “transit time”.

Transit time is the name given to the “phase delay” between a pair of opposing Ultrasonic transmitters and receivers. Pair one will measure the upstream transit time and pair two will measure the downstream transit time.

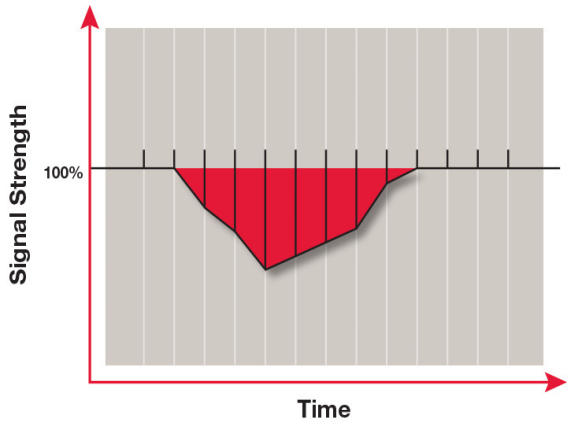


The transit time of the ultrasonic signal is decreased when travelling downstream with the blood flow and increased when travelling upstream against the blood flow. The phase delay between the integrated transit times is a measure of flowing blood.

If the transit times were equal in both the upstream and downstream sensing systems this would indicate that blood flow was static.

7.1.2 The Measurement of Emboli and Gross Emboli (bubbles)

Unlike blood flow, which is detected by changes in signal phase, emboli or gross Emboli (bubbles) is measured by detecting reductions in Ultrasonic signal strength. Gas as opposed to flowing blood is a poor conductor of ultrasonic energy and as emboli pass through the sensing elements the ultrasonic signal is reduced.



The level of emboli volume within the flowing blood will be dependent on the level of signal reduction multiplied by the number of signal reduction events.

Using ultra low-noise electronic technologies maximizes system sensitivity and speed of measurement. With channel specific samplings speeds now in excess of 2500 times per second Spectrum Medical has ensured system sensitivity to the presence of Emboli or Gross Emboli (bubbles).

7.1.3 Calculated Physiologic Indices:

Parameter	Units	Description
$ecDO_2$	ml/min	The total amount of oxygen delivered by the extracorporeal circuit to the body per minute
$ecVO_2$	ml/min	Oxygen consumption: systemic oxygen uptake
ecO_2ER	%	O_2 Extraction Ratio: the ratio of Oxygen consumption to Oxygen delivery
$ecDO_2i$	$ml/min/m^2$	DO_2 divided by the patient's BSA
$ecVO_2i$	$l/min/m^2$	The consumption of Oxygen divided by BSA
$ecVCO_2i$	$ml/min/m^2$	CO_2 production divided by BSA
$ecVCO_2$	ml/min	CO_2 production

Data used for the above calculations are provided from the extracorporeal circuit through input from Spectrum Medical sensors and use of clinically accepted formulas, and denoted by the use of "ec".

7.1.4 Ventilation Diagnostics (PaO_2/$PaCO_2$ etc.)

Spectrum Medical extends its diagnostic capabilities with patented technology that supports the non-invasive measurement of a wide range of parameters that enhance the overall-management of extracorporeal gas delivery and the optimization of Patient Ventilation.

By using real-time sensor inputs including inlet gas concentrations, gas flows and pressures to the inlet side of the oxygenator and oxygenator exit CO_2 values the proprietary algorithms will generate in real-time the non-invasive measurement of PaO_2 and $PaCO_2$.

Ventilation Parameters include:

Parameter	Units	Description
PaO_2	mmHg/kPa	The partial pressure of O_2 within the Arterial blood
$PaCO_2$	mmHg/kPa	The partial pressure of CO_2 within the Arterial blood
FiO_2	%	The fraction of inlet O_2 to the oxygenator
$FiCO_2$	%	The fraction of inlet CO_2 to the oxygenator
Sweep	l/min	Total gas flow to the oxygenator
$FeCO_2$	%	The fraction of exit CO_2 from the oxygenator
FeO_2	%	The fraction of exit O_2 from the oxygenator

7.2 HU 35

The HU 35 Heater works on the principle of heat dissipation to the blood stream through a thick membrane with the help of the oxygenator. It serves as a reliable and precise water supply unit for the oxygenator to maintain patient temperature from 33º to 39º C. The HU35 incorporates water and temperature alarms and an automatic function test to ensure operational reliability and safety. With a dimension of 200 x 330mm and a weight of nearly 9 kg, it is a robust yet portable device.

Figure 3: Maquet HU35 and details of water line connections for HU35

7.3 Rotaflow Console and Drive Unit

One drive cable – three functions: The unique set-up of the ROTAFLOW pump drive also includes flow sensing and bubble detection in one advanced unit. The blood flow is precisely measured in the pump outlet by ultrasonic transit time technology.

The ROTAFLOW Console operates independently as a stand-alone pump module with its own battery back-up and power supply. The swivel-joint bracket assures ideal positioning of the centrifugal pump with greater flexibility in handling, and allows shorter tubing lengths.

Maquet Rotaflow System Specifics	
RPM speed	0- 5000 RPM
Accuracy of flow display	0.1 LPM
Flow rates	0-9.9 LPM
Dimensions	180 x 380 x 240 mm
Weight (approx.)	15 Kg

Table 11: Maquet Rotaflow Specifics

Figure 4: Rotaflow console with drive unit; Drive unit with centrifugal pump and Rotaflow emergency drive

7.4 Sechrist Blender

The Sechrist air/oxygen mixer is a precision pressure regulation and proportioning device, which is designed to accurately mix medical grade air and Oxygen (a mixer is available so that Carbon Dioxide can be added to the ventilation if required).

The mixer can provide for FIO_2's of 21% > 100% for the delivery to a variety of respiratory devices.

The mixer receives air and Oxygen via Diameter index safety system (DISS), at a nominal pressure of 50psi. The unit will operate satisfactorily with inlet pressure of 30 – 70 psi, providing the pressures are within 20psi of each other.

Performance Verification: Prior to each clinical usage the user should perform an alarm test and analyse the full FIO_2 range, using an accurately calibrated Oxygen analyser. Additionally the user should briefly disconnect one supply gas to ensure the bypass/alarm system is functioning.

Theory of operation: The mixer is composed of 3 major components, the balancing module, the proportioning module, and the alarm/ bypass module.

Balancing Module: Inlet pressures are equalized, low pressure may result in incorrect function, excessive pressure may cause device damage or malfunction. Duckbill valves within prevent any reverse flow.

Proportioning Module: Gases are mixed to a defined concentration.

Alarm/Bypass Module: A continual flow of gas supports the alarm which provides an audible alarm in the event of supply pressure or loss of a single supply line.

Figure 5: Sechrist Model 3500 CP-G mixer and Sechrist Model 20090 – designed for ECMO applications

7.5 Medtronic DLP Pressure Display Box 66000

The pressure display box is designed to measure pressures during cardiac surgery/ECLS. It runs on 4 x AA batteries, which provides a 176 hour battery life.

DLP alarm range: -ve 100 → 500 mmHg

Zero offset range: 250 mmHg

Display modes:

- Instantaneous: measure 7 times per second
- Systolic: displays pressure waveform peaks
- Diastolic: displays waveform trough pressure
- Mean: displays calculation = [systolic+(2 x diastolic)] ÷ 3.

We use 'Mean' mode for all pressure monitoring on ECLS. The DLP box should be pole mounted at the same height as the site to be measured – Cannula height. The 3 knobs on the right hand side are used to turn monitoring on and off, zero pressure to atmosphere, set alarm limits and select display mode. The pressure pod is connected to the left-hand side of the box.

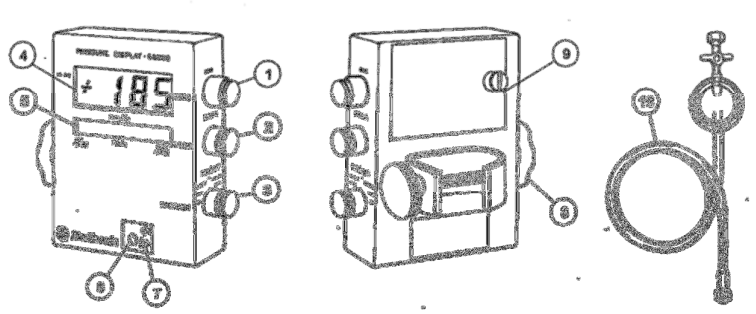


Figure 1. / Figure 1. / Abbildung 1. / Figure 1. / Afbeelding 1. / Figura 1. / Figur 1. / Figur 1.

1. Zero knob / Bouton de remise à zéro / Nullstellknopf / Mando Cero / Nulknop / Manopola di azzeramento (Zero) / Nollställningsratt / Knappen NOLLSTÄLL
2. Alarm knob / Bouton Alarme / Alarm-Drehregler / Mando Alarma / Alarmknop / Manopola Allarme / Larmratt / Knappen ALARM
3. Function knob / Bouton Fonction / Funktionswahlschalter / Mando Función / Functieknop / Manopola Funzione / Funktionsratt / Knappen FUNKTION
4. Pressure display / Écran de pression / Druckanzeige / Pantalla de presión / Drukweergave / Visualizzatore della pressione / Tryckdisplay / Trykdisplay
5. Status display / Écran d'état / Statusanzeige / Pantalla de estado / Statusweergave / Visualizzatore dello stato / Statusdisplay / Statusdisplay
6. Alarm light / Témoin d'alarme / Alarmleuchte / Luz de alarma / Alarmlampje / Spia dell'allarme / Larmlampa / Alarmlampe
7. Alarm mute switch / Interrupteur d'alarme sonore / Stummschalter / Interruptor para silenciar la alarma / Knop voor uitzetten alarmgeluidssignaal / Silenziatore dell'allarme / Larmavstängningsknapp / Knap til undertrykkelse af lydalarm
8. Pressure display set collar / Bague de réglage de l'affichage de pression / Drehknopf für Schlauchset mit integrierter Druckanzeige / Adaptador para el conjunto de monitorización de la presión / Aansluitring drukweergaveset / Collare del kit per la visualizzazione della pressione / Krage för tryckmätningssetet / Krave til trykmålesæt
9. Battery compartment / Compartiment des piles / Batteriefach / Compartimento de las pilas / Batterijvak / Vano della batteria / Batterifack / Batterirum
10. Pressure Display Set (not included) / Kit d'affichage de pression (non fourni) / Schlauchset mit integrierter Druckanzeige (nicht im Lieferumfang enthalten) / Conjunto de monitorización de la presión (no incluido) / Drukweergaveset (niet bijgeleverd) / Kit per la visualizzazione della pressione (non incluso) / Tryckmätningsset (följer inte med) / Trykmålesæt (medfølger ikke)

- See work instruction section for Zeroing and Flushing DLP

8 Work Instructions Menu

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8.2 Priming ¼" Rotaflow Circuit
8.3 Priming 3/8" Rotaflow Circuit
8.4 VAD Priming Equipment Requirements
8.5 1/4" VAD Circuit
8.6 3/8" VAD Circuit
8.7 Anticoagulation Management
Circuit Maintenance
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8.10 Rotaflow Flow Probe
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8.12 Medtronic DLP Box
Renal Replacement Therapy on ECLS
8.14 SCUF – Slow Continuous Ultra-Filtration
8.15 CAVHD - Continuous Arterio-Venous Haemodialysis (aka "counter-current")
8.16 Prismaflex
8.17 iNO into ECMO oxygenatorCircuit venous gas

8.1 ECMO Priming Equipment Requirements

Blood Products	Medications	Equipment
1 Unit PRBC	Unfractionated Heparin	Blood Filter
20% Albumin	$NaHCO_3$ 8.4%	Infusion Line
	Calcium Chloride	Vented Spike
		Syringes

Table 11: Priming Equipment Requirement

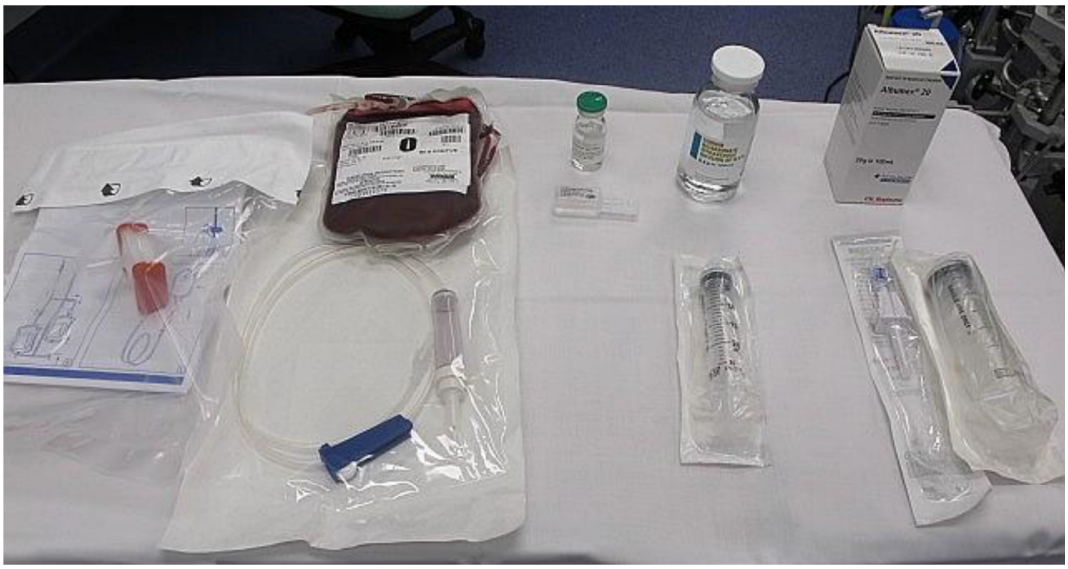


Figure 6: ECMO Priming Equipment Requirement

8.2 Priming ¼" Rotaflow Circuit

PRE-PRIMING CHECKLIST

Notify Blood Bank on Ext 3555 that pt is going on ECMO and request 1 Unit PRBC (request O-neg if no cross matched blood available). Collect the PRBC's from the Hillside PTS

Go to cardiac emergency equipment bay and remove sheet from emergency circuit

Ensure pump plugged into Mains Power and turn heater (HU35) and Spectrum on

Remove the vent cap from the Oxygenator

Ensure the haemofilter shunt is open

Apply ultrasonic grease to flow sensor if required

Turn on Rotaflow console (wait for 'VALVE?' message before acknowledging the 'no clamp system' by pressing the button with the picture of the clamps on it)

Turn the RPMs > 1000 then back down to zero (Wait for RPM display to read zero)

Silence the alarm and zero the pump, then start RPMs at ~ 2000 and watch for a de aired circuit

Use the Circuit Prime Sheet (on pump clipboard) to calculate desired pt flow

Prepare and check all priming drugs and blood products with a colleague

Once Spectrum M3 ready;

- press "details" and enter pt data (weight height/length)
- press "Record"

PRIMING THE ECMO CIRCUIT

BEFORE ADDING THE DRUGS TO CIRCUIT, DO A FINAL CHECK – "ARE WE GOING ON"??!

Clamp the circuit at the table loops below the 3 way tap to the recirculation bag

Drain excess Plasmalyte from the recirculation bag leaving ~ 100 mls in the bag (drop Plasmalyte bag below recirculation bag and opening clamp on that line)

Once this is complete, clamp the line to the Plasmalyte bag with a tubing clamp

Using the 3-way tap with the blue air filter add;

- 100 Units Heparin
- 20 mls Sodium Bicarbonate 8.4%
- Flush with 3 ml 0.9% NaCl (use PosiFlush)

Add 100 mls 20% Albumin using clave connector port on 3-way tap

Turn 3-way tap off to circuit

Remove tubing clamp from below the 3 way tap and circulate for 1 min to 'coat the circuit'

Unclamp the circuit at the table loops and circulate for 1 min to 'coat the circuit'.

Replace clamp below the 3 way tap (located on line to recirculation bag)

Add 1 Unit filtered PRBCs using provided blood filter and extension line (via clave on 3-way tap, and flush with 3 ml NaCl (PosiFlush)

Unclamp the circuit to circulate as before

Add 2 mls CaCl through the blue filter & flush through with 3 ml NaCl (PosiFlush)

Open effluent line to gravity drainage to begin concentrating the re circulation bag - Watch level closely

Clamp Effluent Line when recirculation bag is ~ 100mls (**watch closely!!**)

Take a circuit ABG from port located between pump and oxygenator; 2 mls waste - do not return. Use the 'Prime Circuit Sample' sticker for gas. ON THE GAS, look at

1. Ca++ Goal 0.5-1 mmol/L
2. K+ only accept <6 mmol/L)

Please keep the left over drugs from the prime at the bedside until Perfusion arrive.

Place vent cap back on Oxygenator, turn heater off and clamp shunt before moving to pt bedside

SETTING UP CIRCUIT AT PATIENT BEDSIDE

Plug power, oxygen, and air into Wet Pendant and turn Heater on

PASSING UP THE STERILE LOOPS

Perfusion will clamp and pass up sterile table loop when possible: however if the instance of ECPR the ECMO Specialist is able to pass up the loops with Surgeon supervision

Ensure haemofilter shunt is clamped

Clamp Arterial then Venous lines close to you (pre-pump head and post oxygenator – you need to be able to reach clamps without contaminating sterile field)

It is helpful at this point to get a colleague to hold the recirculation and plasmalyte bags while you hand up the lines to the surgeon

Carefully holding underneath of the package, undo the sticky tape in preparation for opening the sterile plastic cover. Open the plastic packet containing the loops when the Surgeon indicates he's ready.

Once the surgeon has a firm grip on the loops let go of the tubing and ensure the ECMO cart is close to the bed

The lines attached to the recirculation bag will be handed back to your colleague – these can be discarded but you MUST KEEP THE CLAMPS on these lines are kept as they are NOT DISPOSABLE

Set Sweep 1:1 with desired blood flow and set FiO2 at 0.8

When surgeon says "ON ECMO" release venous clamp, then arterial clamp and increase RPM until desired flow is reached

Take ABG to adjust sweep gas rate and FiO2

Place pressure bag on Hep Saline bag, get pressure transducing line from scrub nurse and prime line into sterile field

Plug Rotaflow (purple) and Spectrum (green) cables into MetaVision Didgy Box.

8.3 Priming 3/8" Rotaflow Circuit

PRE PRIMING CHECKLIST

Notify Blood Bank on Ext 3555 that pt is going on ECMO and request 1 Unit PRBC (request O-neg if no cross matched blood available). Collect the PRBC's from the Hillside PTS

Go to cardiac emergency equipment bay:

- ensure pump plugged into Mains Power
- turn on heater (HU35)
- turn on Spectrum monitor
- Remove the vent cap from the Oxygenator
- Ensure the haemofilter shunt is open
- Apply ultrasonic grease to flow sensor if required
- Place clamp on circuit between 3-way taps where recirculation bag lines attach

Turn on Rotaflow console

- wait for 'VALVE?' message before acknowledging the 'no clamp system' by pressing the button with the picture of the clamps on it)
- Turn the RPMs > 1000 then back down to zero (Wait for RPM display to read zero)
- Silence the alarm and zero the pump, then start RPMs at ~ 2000 and watch for a de aired circuit

Use the Circuit Prime Sheet (on pump clipboard) to:

- calculate desired pt flow
- Prepare and check all priming drugs and blood products with a colleague

Once Spectrum M3 booted up;

- press "details" and enter pt data (weight height/length)
- press "Record"

PRIMING THE ECMO CIRCUIT

BEFORE ADDING THE DRUGS TO THE CIRCUIT, DO A FINAL CHECK: 'ARE WE GOING ON'?

Clamp both recirculation lines (lines connecting recirculation bag to circuit)

- Drain excess from recirculation bag to Plasmalyte bag, leaving ~100 mls in bag (drop Plasmalyte bag below the level of the recirculation bag and open clamp)

*NB – if the unit of PRBC you have is irradiated or > 5 days old, leave 400 mls in the bag

Using the blue air filter on 3-way tap add;

- 1000 Units of Heparin
- 30 mls of Sodium Bicarb 8.4%
- Flush with 3 ml 0.9% NaCl (use PosiFlush)

Using a clave connector port on 3-way tap add 200 mls of 20% Albumin

Unclamp the lines to the recirc bag and circulate for 1 min to 'coat the circuit'

Re-clamp both lines to the recirculation bag

If doing blood prime: add 1 Unit PRBC via clave on 3-way tap, and flush with 3 ml PosiFlush (use appropriate blood filter and extension line)

Add 3 mls CaCl through the blue filter & flush through with 3 ml NaCl (PosiFlush)

Unclamp both lines connecting the recirc bag to the ECLS circuit

Open Effluent line to gravity drainage and begin filtering fluid

Clamp Effluent line when recirculation bag at 50-100 ml – watch this closely!

Take a circuit ABG from port located between pump and oxygenator; 2 mls waste - do not return. Use the 'Prime Circuit Sample' sticker for gas. ON THE GAS, look at

1. Ca++ Goal 0.5-1 mmol/L
2. K+ only accept <6 mmol/L)

Place vent cap back on Oxygenator and clamp shunt before moving to pt bedside

Please keep the left over drugs from the prime at the bedside until Perfusion arrive.

SETTING UP THE CIRCUIT AT PATIENT BEDSIDE

Move circuit to pt bedside and plug power, oxygen, and air into Wet Pendant

Turn on heater and Spectrum M3 monitor

PASSING UP THE STERILE LOOPS

Perfusion will clamp and pass up sterile table loop when possible: however if the instance of ECPR the ECMO Specialist is able to pass up the loops with Surgeon supervision

Clamp haemofilter shunt and recirculation lines (2 lines from circuit to recirculation bag)

Remove clamp from ECLS circuit (between 3-way taps where recirculation bag lines attach)

Clamp Venous and Arterial lines close to you (pre-pump head and post oxygenator - you need to be able to reach clamps without contaminating sterile field)

Carefully holding underneath the package, peel back the clear plastic lid to allow the surgeon to remove the sterile loop (ensure Velcro loop does not fall into sterile field)

Once the surgeon has a firm grip on the tubing remove the loop container from the area and stand by pump

Zero flow probe

Set Sweep 1:1 with desired blood flow and set FiO2 at 0.8

When surgeon says "ON ECMO" release venous clamp, then arterial clamp and increase RPM until desired flow is reached

Check SVO2 and Arterial trace. The patient may need a fluid bolus to achieve desired flows.

Take ABG to adjust sweep gas rate and FiO2

Place pressure bag on Hep Saline bag, get pressure transducing line from scrub nurse and prime line into sterile field

8.4 VAD Priming Equipment Requirements

Equipment	Blood Products
Blood Filter	1 Unit PRBC
Infusion Line	20% Albumin
Vented Spike	
Syringes	**Medications**
Sterile scissors or blade	Unfractionated Heparin
2x straight 1/4”-3/8” connectors	$NaHCO_3$ 8.4%
Sterile blood transfer bag	Calcium Chloride

Table 12: VAD Priming Equipment Requirement

Figure 7: VAD Priming Equipment Requirement

8.5 1/4" VAD Circuit

CIRCUIT SETTING UP

Collect required equipment and 1/4" Maquet ECLS pack and modify as per following work instructions:

Using aseptic technique while the circuit is sterile and dry in the box take a sterile blade or sterile scissors and remove the portions of tubing pre and post pump head (where luer lock connectors/3 way taps normally go on a standard ECLS Circuit). This results in shortening the tubing length pre and post pump head, and not in the sterile loop portion.

Replace each section with a 3/8" x 1/4" straight non luer lock connector and cable tie.

Also add a 1/4" x 1/4" straight LL connector on the arterial limb pre prime bag and place a 3 way tap on it to assist with the priming process and also as a place to take a prime sample that has not been exposed to bicarb and calcium.

Use the VAD checklist to record pack lot number and relevant setup details. The usual clamps, torch, ultrasonic grease and red folder with VAD checklist are required to be with the setup.

PRIMING THE 1/4" VAD CIRCUIT

Ensure that the VAD circuit is situated on a Rotaflow pump and clear prime using Plasmalyte. Turn on pump, ensuring adequate ultrasonic grease is applied prior to zeroing flow probe. Circulate to ensure de-aired circuit and prepare priming drugs, albumin and RBC where required (double-check medications and blood with ECLS nurse or other appropriate staff).

Place clamp on circuit below Y connector on venous limb and drain excess crystalloid from the recirculation bag into the Plasmalyte bag. Clamp line to Plasmalyte bag and venous limb below 3-way tap.

Using 3-way tap, add:

- 100 Units Heparin
- 20 mls Sodium Bicarbonate 8.4%, and flush with 3 ml Posiflush
- Add 100 mls 20% Albumin

Remove tubing clamp on circuit below 3-way tap and circulate for 1 minute, then reclamp.

Using 3-way tap on venous line add 1 unit PRBC and 1.5 ml calcium chloride to the recirculation bag, flush with 3ml 0.9% NaCl (Posiflush) and gently agitate the recirculation bag.

Attach the blood transfer bag to the 3-way tap on the arterial limb below recirculation bag and place clamp between 3-way tap and recirculation bag.

Reduce RPM to 500 and remove clamp from venous line and use the pump to blood prime the circuit – while chasing the clear prime into the blood transfer bag. When clear prime chased through to the "blood bag", turn 3-way tap off to "blood bag" and remove clamp from arterial outlet. Allow to recirculate, ensuring again that circuit is free of air.

Where possible take a prime sample gas (from 3-way tap on arterial limb).

As fluid warms up in ambient room temperature, micro bubbles can appear – thoroughly tap tubing as it circulates and surgeon to tap/check loop prior to clamping.

Ideally no luer lock connectors or taps should exist in the VAD circuit

8.6 3/8" VAD Circuit

CIRCUIT SETTING UP

Collect required equipment and 3/8" Maquet ECLS pack and modify as per following work instructions:

Using aseptic technique while the circuit is sterile and dry in the box take a sterile blade/scissors and remove the portions of tubing pre and post pump head (where luer lock connectors/3 way taps normally go on a standard ECLS Circuit).

Replace each section with a 3/8" x 3/8" straight non luer lock connector, cable tie only the connector on the outlet at this time.

Also add a 1/4" x 1/4" straight LL connector on the arterial limb pre prime bag and place a 3 way tap on it to assist with the priming process and also as a place to take a prime sample that has not been exposed to bicarb and calcium.

Use the VAD checklist to record pack lot number and relevant setup details. The usual clamps, torch and red folder with VAD checklist are required to be with the setup.

PRIMING THE 3/8" VAD CIRCUIT

Ensure that the VAD circuit is situated on a Rotaflow pump and clear prime using Plasmalyte. Apply tubing clamp on venous line between recirculation lines and turn on pump, ensuring adequate ultrasonic grease is applied prior to zeroing flow probe. Circulate to ensure de-aired circuit and prepare priming drugs, albumin and RBC where required (double-check medications and blood with ECLS nurse or other appropriate staff).

Clamp recirculation lines and drain excess crystalloid from the recirculation bag into the Plasmalyte bag. Clamp line to Plasmalyte bag and venous limb below 3-way tap.

Using 3-way tap, add:

- 1000 Units Heparin
- 30 mls Sodium Bicarbonate 8.4%, and flush with 3 ml Posiflush
- Add 200 mls 20% Albumin

Unclamp recirculation lines and circulate for 1 minute, then reclamp recirculation lines.

Using 3-way tap on venous line add 1 unit PRBC and 2 ml calcium chloride to the recirculation bag, flush with 3ml 0.9% NaCl (Posiflush) and gently agitate the recirculation bag.

Attach the blood transfer bag to the 3-way tap on the "outlet" recirculation line (the 3-way tap distal to the pump head), turning the tap so that the circuit is closed to the recirculation bag and open to the blood transfer bag.

Reduce RPM to 500 and remove clamp from venous line and use the pump to blood prime the circuit – while chasing the clear prime into the blood transfer bag. When clear prime chased through to the "blood bag" turn 3-way taps to recirculation lines off to circuit and remove clamp from between 3-way taps. Allow to recirculate, ensuring again that circuit is free of air.

Where possible take a prime sample gas (from either 3-way tap).

Using aseptic technique and a sterile blade/scissors remove the section of tubing where the 2 recirculation lines attach, connecting the 3/8" tubing onto the straight connector where a cable tie was not placed during circuit setup. Place and secure a cable tie on this pre-pump connection.

Ideally no luer lock connectors or taps should exist in the VAD circuit.

8.7 Anticoagulation Management

LCCH ECLS Anticoagulation and Blood Product Administration Standard

Anticoagulation Management

Cannulation

Unfractionated heparin into circuit prime: 100 units for ¼", 1000 units for 3/8" circuit (see priming section)
50 units/kg bolus of heparin to patient at time of cannulation

Post cannulation

Measure ACT q 30 min until heparin infusion commenced
Give 5 ml/kg of cryoprecipitate after cannulation for children <10 kg
Commence heparin infusion at 28 units for neonates, and 20 for non-neonates once ACT <300 sec, and switch to Anti Xa monitoring
Send coag Test Panel 4 hours post starting heparin infusion, and adjust therapy as per target range chart

Ongoing management:

Heparin infusion at 10-50 units/kg/hr, titrate to achieve target parameters

Target parameters for the <u>non-bleeding</u> patient

Anti-Factor Xa 0.4-0.6 (may be lowered in bleeding patient)
Fibrinogen >1.0
Antithrombin >0.4 (>0.8 if heparin infusion rate >35 units/kg/hr)
PLTs > 80.000
Hb > 80 – 100 g/L (non-neonate) or 100 – 120 g/L (neonate)
TEG: additional information without targeting strict numbers. Keep CFF MA >15 mm

AT management

Antithrombin deficiency is treated based on the the AT level and heparin dose required to maintain the anti-Factor Xa within goal range.

Heparin dose < 35 U/kg/hr: maintain AT level >0.4
Heparin dose > 35 U/kg/hr: maintain AT levels >0.8

Target level of 100 when calculating replacement dose.
Decrease heparin infusion by 30% prior to administration

Fibrinogen management

Administer routine 5 ml/kg dose of cryoprecipitate after initiation of ECMO for children <10 kg, for all others target measured levels.

In stable run keep fibrinogen > 1.0 g/L, and TEG 6s CFF MA > 15 mm

Administer cryoprecipitate 5-10 ml/kg to achieve targets

INR management

For INR > 1.8 start vitamin K 0.3 mg/kg for 3 days
Treat with cryoprecipitate 5-10 ml/kg. Depending on response of INR to cryo administration repeat cryo. Only after cryo administration may FFP be needed (few cases only)

Hb management For neonates keep Hb 100-120 g/L For non-neonates keep Hb 100 g/L Give 15 ml/kg of PRBC over 3 hours, with additional 5 ml/kg if target levels not reached	**PLT management** Generally keep PLTs > 80,000. For non-bleeding, clean patients accept PLTs > 70,000 Give 10-20 mls depending on PLT level

Table 13: Anticoagulation management for ECLS patients at LCCH

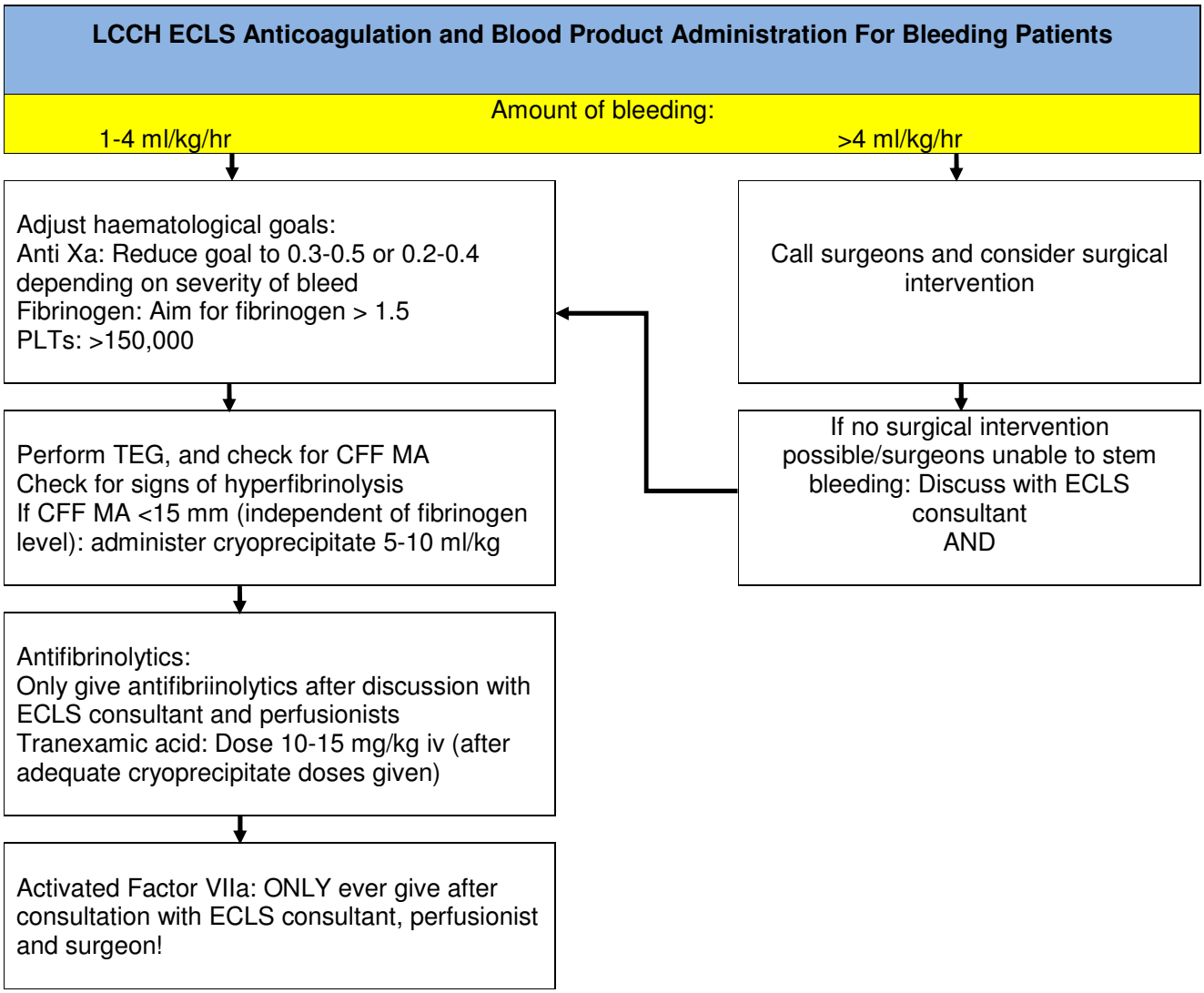


Table 14: Blood product management in bleeding patients on ECLS at LCCH

8.8 Circuit Maintenance

8.8.1 Circuit venous gas

ECLS Specialists will only access the circuit for routine venous blood gases at the 3 way tap located post pump head and pre-oxy. This area of the circuit is under positive pressure so ensures no air can be entrained into the circuit. Post pump head and pre oxygenator also increases safety by maintaining a "filter" between the access site and the patient. There are clave connectors on all ports, thus maintaining the closed system.

Equipment required

- 1 x tubing clamp (not when Prismaflex in circuit)
- 1 x 1 ml syringe
- 1 x 3 ml syringe
- 1 x alcohol wipe

Procedure

1. Swab clave connector on 3-way tap located between pump head and oxygenator.
2. Don PPE
3. Pause shunt flow
    a. BC20: Place SCUF / CAVHDF large volume infusion pumps on hold and place tubing clamp on shunt line proximal to inlet line. This stops shunt flow - ensuring no arterial blood mixes into the venous line pre pump head.
    b. Prismaflex: Select "Stop" from Prismaflex screen
4. Using the 3 ml syringe take a 1mls waste
5. Using the 1 ml syringe take 0.5 ml for the blood gas
6. Restart filter blood flow:
    a. BC 20: Remove the tubing clamp from the shunt line and restart infusion pumps
    b. Prismaflex: select "Resume" from Prismaflex screen
7. Press capture on the Spectrum monitor
8. Run as a circuit gas (URN 1012275), ensuring you enter it as Venous and Pre-Oxy
9. Calibrate the Spectrum monitor (see Spectrum protocol for steps)

8.9 Spectrum M3

8.9.1 Start Up

- Press power button to turn on – the screen will remain blank for a few minutes while the system boots up.
- Enter Patient Data by pressing the “details” button on the touch-screen.
  - Patient name
  - Weight
  - BSA
- Press “record” to start measuring. The monitor will calculate the patients cardiac index in both ml/kg/min and L/m_2/min.

8.9.2 Calibrating Saturations and Hb

- Take a **circuit** VBG (see checklist Appendix 3)
- Press “setup” to enter monitor menu
- Press “capture” on the bottom menu
- Enter results from VBG into individual parameters
- Press “SvO_2” box
- Press “Sync to”
- Enter value from VBG
  - Set alarm limits
  - Repeat steps for Hb
  - Press “ok” when both parameters entered.

8.9.3 Zeroing flow probes

- Remove flow probes from the circuit and place on the zeroing fluid loop (found on ECLS cart).
- Press “setup” to enter monitor menu
- Press “Patient Flow”
- Press “Set Zero”
- Press “Pump Flow”
- Press “Set zero”
- Replace flow probes on the circuit ensuring that
  - the flow direction is correct (look at the arrow on the probe) and
  - they are not placed over writing on the circuit.

8.9.4 Zeroing the Emboli counter

- To be done every time a flow probe is removed from circuit (zeroing, repositioning, etc)

- From main screen press “Setup” then select “Emboli Count” parameter
- Press “Set Zero” then “Ok”.

8.10 Rotaflow Flow Probe

Applying Ultrasonic Grease

- To be done when circuit is primed or when “sig” alarm goes off
- Clamp shunt
- Clamp arterial line first, then venous line
- Turn RPM off
- Remove pump head from drive unit
- Apply ultrasonic grease to flow probe
- Replace pump head in drive unit
- While lines are still clamped, zero flow probe
- Turn RPM back to previous settings
- Release clamps: venous line, arterial line, open shunt
- Document in MetaVision

  NB Re-greasing after ‘sig’ alarm with caution in unstable patients, can wait as flows available from Spectrum M3

8.11 HU 35

The HU 35 Heater Unit works on the principle of heat dissipation via a thick membrane to the blood stream with an oxygenator (Maquet, 2008 p9.).

Initial setup

- Ensure the lines are securely connected to oxygenator
- Ensure the water level is adequate - top up via port at top of unit
- Turn machine on
- Set water temperature using the up and down arrows (can be set between 33^{o} & 39^{o}C)

Daily management

- Monitor water level
- Monitor temperature
- Perform a function test each shift by pressing the performance test key

8.12 Medtronic DLP Box

8.12.1 Zeroing DLP

- Isolate patient from DLP circuit:
  - Turn off Inlet pressure line 3-way tap at the circuit
  - Place a tubing clamp on pressure line under housing of DLP set
- Removed cap from DLP set
- Open 2-way valve on DLP set: opening line to atmosphere
- Set function knob to ‘Instantaneous’
- If required, adjust ‘zero’ knob to achieve 0 mmHg on display
- Close 2-way valve
- Replace cap onto DLP set
- Set function mode to ‘mean’
- Remove clamp from DLP line
- Open Inlet pressure line 3-way tap to the circuit, ensure all connection are tight

8.12.2 Flushing DLP

- Isolate patient from DLP circuit by turning off Inlet pressure line 3-way tap at the circuit
- Turn 3-way tap where DLP line connects to inlet transducing line off to the circuit
- Remove cap from DLP set and attach 20 ml syringe
- Open 2-way valva on DLP set
- Use inlet pressure transducer to flush heparinzed saline from transducing bag up DLP line into the syringe until line is free of air/blood.
- Place a tubing clamp on pressure line under housing of DLP set
- Remove syringe from DLP set and zero DLP as required (refer to ‘Zeroing DLP’ work instructions above)

8.13 Renal Replacement Therapy on ECLS

8.13.1 Commencing Shunt Blood Flow

To be done once the patient is stable on full ECMO flows

Fully close gate clamp on shunt distal to the haemofilter

Open 3-way taps at both ends of the shunt

Slowly open gate clamp while watching total pump flow aiming for shunt flow of:

- 1/4” circuit => minimum 100 ml/min blood flow
- 3/8” circuit => minimum 150 ml/min blood flow

The shunt clamp can be removed entirely for patients where the total ECMO blood flow is low but oxygenator flows should be kept high. Opening the shunt will achieve higher oxygenator blood flows while keeping patient blood flow low.

8.13.2 Repositioning gate clamp (once per shift)

Clamp shunt with one tubing clamp

Remove gate clamp

Fully close gate clamp on a new section of shunt tubing

Slowly open gate clamp while watching total pump flow and aim for minimum shunt flow of:

- 1/4” circuit => 100ml/min
- 3/8” circuit => 150ml/min

8.14 SCUF – Slow Continuous Ultra-Filtration

Perfusion will commence blood flow through the filter once the patient is stable on support. To commence SCUF via the inbuilt shunt line;

1. Ensure blood flow through the filter is adequate
2. Turn on Braun pump
    a. ensure the effluent line is correctly loaded in pump
    b. Ensure the roller clamp on the effluent line is open (located between the filter and the Braun pump)
    c. Empty urometer into fluid bag
3. Set the desired hourly rate of fluid removal on the Braun pump (remember that the high transmembrane pressure often results in higher volumes removed than set on pump)
4. MetaVision documentation – hourly on “ECLS Fluids” tab;
    a. Enter SCUF Pump Rate
    b. “Volume Out” = actual amount of effluent removed

8.15 CAVHD - Continuous Arterio-Venous Haemodialysis (aka “counter-current”)

1. Prime IV giving line with dialysate solution
2. Pause Braun pump on SCUF effluent line
3. Clamp shunt on either side of haemofilter (use 2 x tubing clamps)
4. Connect dialysate line to the distal port on haemofilter (the empty port – closest to venous line on circuit)
5. Set Braun pump on dialysate line to desired rate
6. Set Braun pump on effluent line to dialysate rate (dialysate rate plus desired fluid removal amount)
7. MetaVision documentation - hourly on “ECLS Fluids” tab;
    a. Ensure dialysate ordered and rate correct in top section (infusion list)
    b. Enter SCUF Pump Rate
    c. “Volume Out” = actual amount of volume removed

8.16 Prismaflex

8.16.1 Setup and operation

The Prismaflex is setup following the standard Prismaflex heparin CVVHDF setup guide, with the ST100 filter regardless of patient size/weight. The Prismaflex circuit will be attached to the ECMO circuit in the setup used for the haemofilter shunt. Connecting the Prismaflex to the ECMO circuit is the role of the ECLS Specialist so long as clave connectors are present on the 3-way taps. If there are no claves present at the BC20 connection site, please liaise with the on-call Perfusionist to plan for this procedure within normal working hours. If after hours discuss with Intensivist whether there is a need to call in a Perfusionist from home or wait until the morning.

Prismaflex Set Up

- The setup for the Prismaflex follows the RRT guidelines described here (Heparin CVVHDF)
- **Anticoagulation will always be with heparin, as the patient is already heparinised for the ECLS circuit**.
- Dialysate and replacement fluid will be with Hemosol B0
- Hemosol B0 does not contain potassium – please note patient potassium, if normal or low clarify with Intensivist if this will be managed by adding K to the Hemosol or commencing a potassium infusion.

Connection Prismaflex to ECMO circuit

- Prismaflex circuit to be connected at same 3-way taps used for the haemofilter shunt line.
- Prismaflex access line will be connected to 3-way tap at top of arterial side of oxygenator (red to red)
- Prismaflex return line is to be connected to 3-way tap pre-pump head on ECLS circuit Inlet line.
- Apply gate clamp to Prismaflex return line (as this is a negative pressure are in the ECLS circuit we need the gate clamp to generate a positive pressure in return line.
- Prismaflex Blood flow rates will be ordered between 100 to 300 ml/min (NOT per kg)

8.16.2 Prismaflex orders

The ECMO orders for renal replacement therapy on ECLS follows the guidelines of the renal replacement therapy on standard patients, with the exception of the renal replacement therapy blood flow rate, which in the case of ECLS patients should be set at 100 ml/min

- Anticoagulation Method: *Non-Citrate - ECLS*
- Prismaflex Mode: *CVVHDF* - for all patients
- Circuit type: *Heparin* - though no “extra” heparin given above the ECLS anticoagulation
- Filter/Circuit Type: *ST 100* - for all patients and circuit sizes
- Circuit Prime: *N/Saline 1L + 5,000u/s Heparin*
- Blood flow: *100 ml/min* – minimum rate, can be increased on patients with high ECLS pump flow
- Dialysate Rate (Countercurrent): *30 ml/kg/hr* with a maximum of 2500 ml/hr.
- PBP (or filtration rate): *30 ml/kg/hr* with a maximum of 2500 ml/hr

- The calculated effluent rate will therefore be 60 ml/kg/hr
- Replacement rate: 50ml/hr

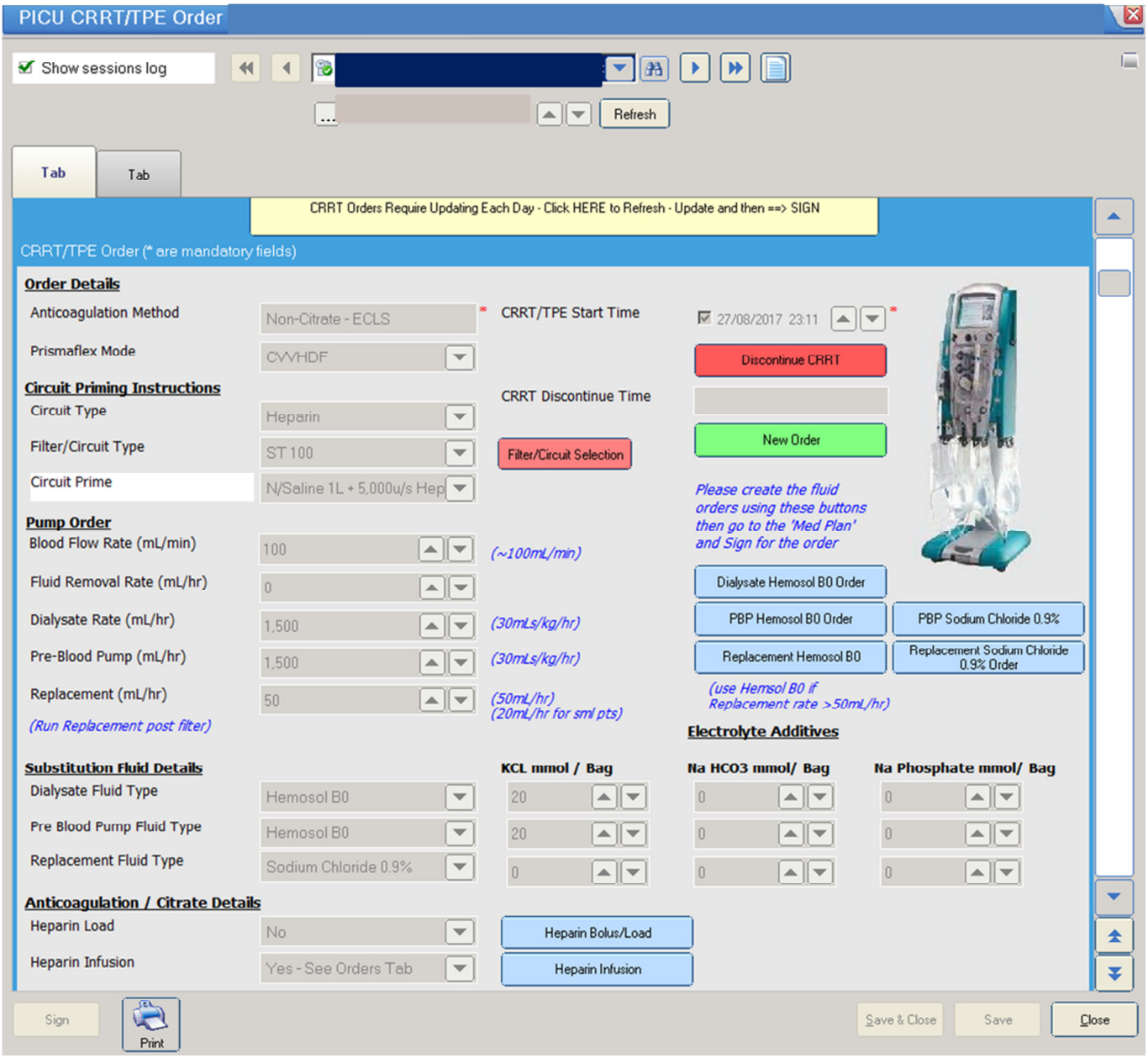


Figure 8: Prismaflex orderset for ECLS patients

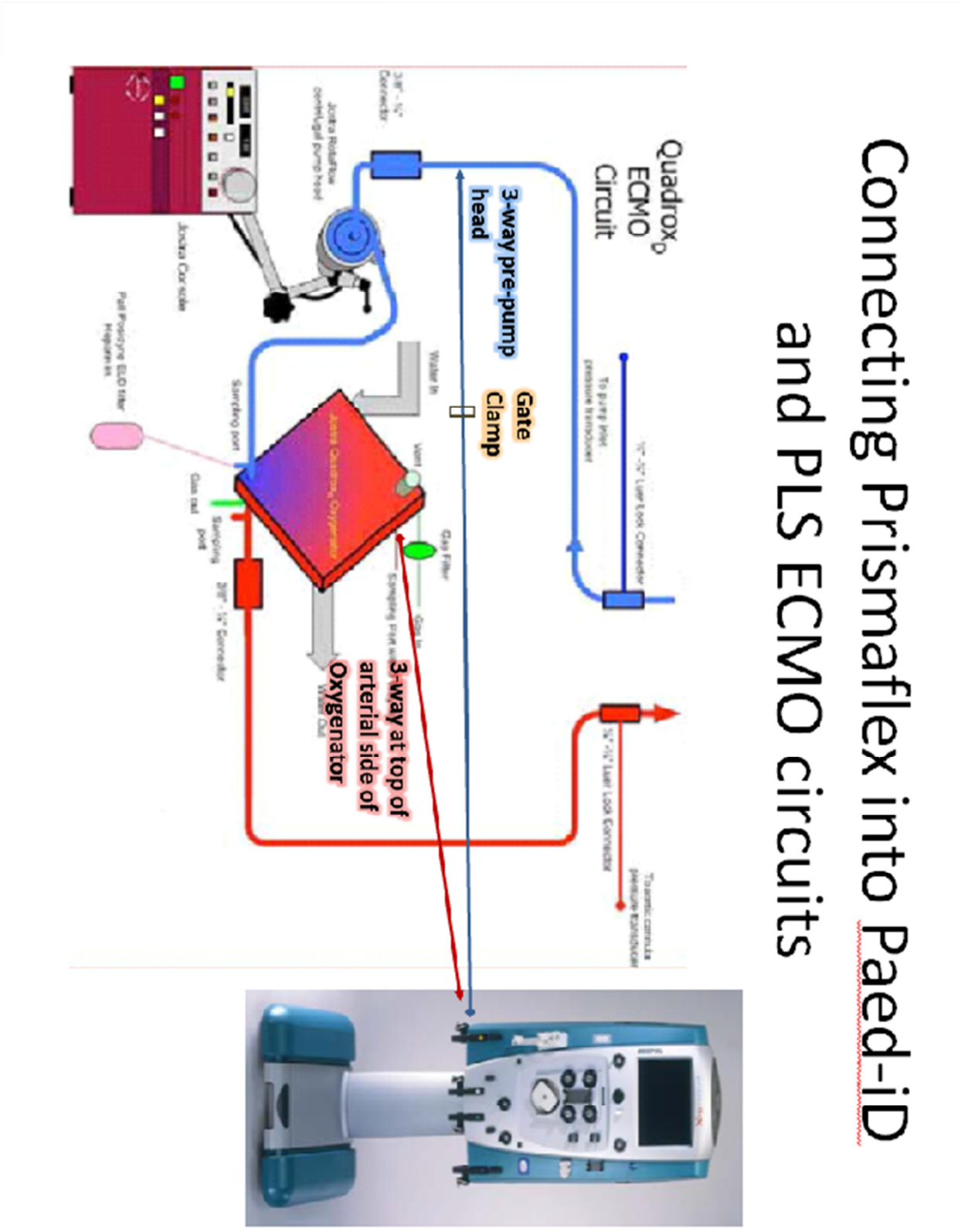


Figure 9: Setup of Prismaflex on ECLS circuit

8.17 iNO into ECMO oxygenator

iNO may be ordered with delivery into the ECMO oxygenator for the purpose of;

a. Pulmonary vasodilation in a pt without adequate Vt on the ventilator, or
b. Prevention of platelet aggregation

Perfusion must be present for setup of iNO into the ECMO oxygenator

The inovent requires a minimum of 2 L/min gas flow, therefore all patients with a sweep gas <2.5 L/min will require a different blender and sweep gas setup to enable appropriate patient PaCO2 management.

To enable the sweep to run at 2 L/min without clearing all the CO2 from the sweep gas flow, CO2 is delivered directly into the sweep gas. This is done with a blender that has a CO2 flow meter;

1. There is an additional flow meter on the left of the blender setup which is connected to a CO2 gas bottle – please monitor the level of the bottle!

Figure 10: Secrist Blender with CO2 setup

2. The CO2 canister is sourced from perfusion, and it is connected to the blender using the grey gas tubing
3. The standard green oxygen tubing comes off the back of the blender – and the iNO cell is connected into it prior to the green filter.

Figure 11: iNO Setup 1

The blue vent tubing is then connected to the sweep gas line prior to the usual green filter;

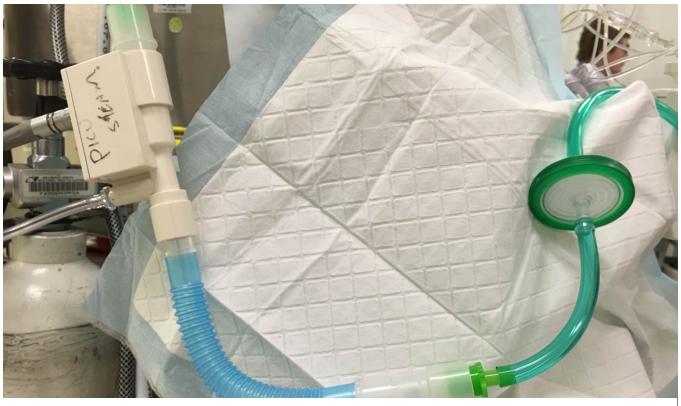
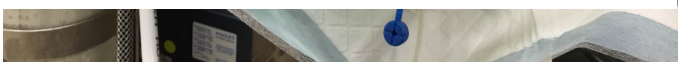


Figure 12: iNO Setup 2



4. The green sweep gas tubing then connects in the usual fashion to the oxygenator;

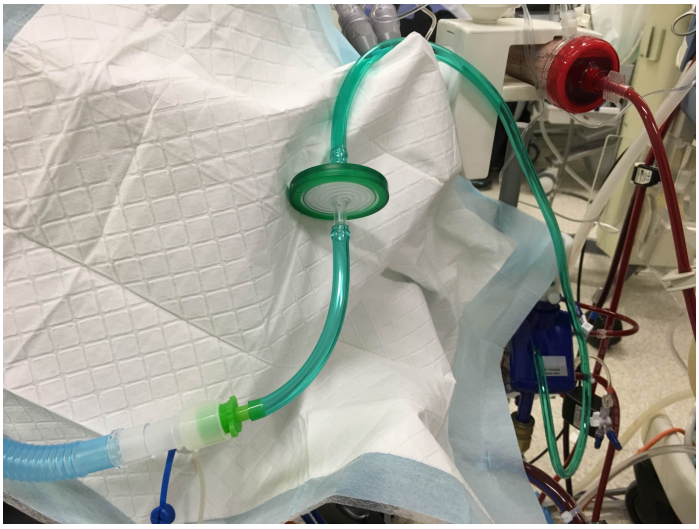


Figure 13: iNO Setup 3

ADJUSTING sweep gas flow to patient gases

- the **absolute minimum sweep gas flow is 2 L/min**
- the **absolute minimum CO2 flow rate is 75 ml/min**
- A black arrow will be drawn on the flow meters at these 2 points.

If the sweep gas flow rate is at 2L/min and the pts PaCO2 is low the CO2 gas flow rate will need to be increased;

- Increase CO2 gas flow rate on the CO2 flow meter by 25 ml/min
- Check a patient ABG in 10-15 min
- Adjust sweep gas flow according to PaCO2

8.18 Pump Controlled Retrograde Trial Off (PCRTO)

Before a period of PCRTO is considered the following items should run through:

- Have the processes that lead to the need to support the child been reversed?
- Has pulmonary function been assessed? (Pulmonary compliance known?)
- Echo done within the last 24 hours?
- Renal function assessed and need for ongoing renal replacement therapy clarified?

Preparation

- CXR checked
- Ventilation increased to appropriate levels?
- Inotropes running/increased to appropriate levels?
- Emergency drugs available?
- Fluid bolus available?
- ABG and VBG obtained
- First on and ECLS consultant aware of procedure?
- Perfusion aware of procedure?
- Are then any additional cannula that will need clamping w/ hep-saline flush (ie/ limb perfusion cannula)
- Rotaflow and Spectrum downloading automatically into MetaVision?
- Full circuit check performed and documented prior to trial off

Documentation:

- HR, BP, lactate and spectrum monitor values in MV before trial off starts
- Initial HR, BP once PCRTO established (after initial minute of establishing PCRTO). Spectrum values should be entered into MV at this stage as well
- Spectrum values q 5-10 min
- ABG after 5-10 min of PCRTO
- Reasons for failure documented in patient notes at end of trial (Intensivist to document)
- Clot status of circuit before and after trial, and 6 hours post trial should be documented in MV

Initiating PCRTO

- Intensivist and ECMO specialist at bedside, ideally with Perfusionist present
- Clamp RRT shunt
- Reduce revs until patient blood flow becomes zero, then decrease until patient blood flow becomes minus 100 to minus 250 ml/min.
- If patient cannot generate flows of ≥ 70 ml the trial should be abandoned
- If the patient can generate 250 ml/min (this will only be able in bigger children) this should be aimed for. The limitation will be the patient's cardiac output, and how the patient can compensate the large L-R shunt that the retrograde flow induces.
- As soon as retrograde flow is achieved the sweep flow should be turned off

Stopping PCRTO

- PCRTO does not need to be stopped in case the decision for decannulation is made
- PCRTO should continue until decannulation where possible
- Where PCRTO leads to a decision to continue the ECMO run, the patient blood flow and the sweep gas flow should be increased back to the levels pre PCRTO
- Restart the renal replacement shunt (discuss w/ perfusion if clamp can be removed OR if the shunt needs to be replaced)
- Depending on the amount of blood flow aimed for ventilation should be decreased back to "rest settings" or be kept at a higher ventilation setting (ECLS team decision based)

9 Trouble Shooting

9.1 Oxygenator Failure

Increasing pCO_2, decreasing pO_2 and decreasing oxygen saturations +/- Blood/plasma leak from the oxygenator gas exhaust port	
Possible Causes	**Management**
• Oxygenator Rupture (air at the top of oxygenator)	• **Call 555 – Code ECMO** • **Isolate patient - clamp arterial and venous lines** • Maintain CO and ventilation • Turn RPM to off • Prime new circuit
• Clots in Oxygenator • Inadequate anticoagulation • Blood flow too low • Increased transmembrane pressure (TMP)	• Call Perfusionist • Increase heparin infusion • Increase RPM to maintain patient blood flow • Increase sweep and FiO_2 as per ABG • Increase pt ventilation
• Ruptured Membrane (sudden gush of blood from gas exhaust port)	• **Call 555 – Code ECMO** • **Isolate patient - clamp arterial and venous lines** • Maintain CO and ventilation • Turn RPM to off • Prime new circuit

9.2 Air in Circuit

9.2.1 Small Amount on Venous Side

Small marching air bubbles seen on venous side in cannula, pre or post pump head, or small air bubbles found in elevated section of venous side

- Management

Remove vent cap from oxygenator
Walk air through pump head to oxygenator
Ascertain air entry point (circuit connections, inlet pressure line, patient CVL)
If it returns or becomes continuous contact Perfusionist – and discuss tie banding cannula connection if this is the perceived source.

9.2.2 Small Amount on Arterial Side

Small air bubbles found in elevated section of arterial side

- Management

Patient Nurse:
- Maintains pt ventilation, oxygenation and cardiac output

CSN:
- Notify Intensivist and Perfusionist

ECLS Specialist:
- Isolate the patient from the circuit by clamping arterial and venous lines between the patient and the pressure lines
- Reduce RPM to 1000
- Attach syringe to outlet pressure monitoring 3-way tap
- Flush Inlet pressure transducer and simultaneously withdraw into syringe on the outlet pressure tap
- When air is no longer present
- Unclamp arterial and venous lines
- Increase RPM to previous setting

9.2.3 Massive Air Entrainment

Management:

Patient Nurse:

- Maintains pt ventilation, oxygenation and cardiac output
- Reposition patient head down

CSN :

- Notify Intensivist and Perfusionist

ECLS Specialist:

- Isolate the patient from the circuit by clamping the lines at the arterial and venous cannula
- Turn RPM OFF
- Remove the yellow cap from the oxygenator
- Turn the shunt off (turn 3 –way tap off to the oxygenator)
- Remove the pump head from the drive unit and drop it down to allow gravity to move the air up towards the venous side of the oxygenator
- Prime the de-airing bag and lines with approximately 2 X 50ml syringes (~ 100ml) of Plasmalyte
- Connect the de-airing bag to the inlet and outlet 3-way taps at the available clave connectors
- Ensure no air left in pump head and place it back in drive unit
- Turn inlet/outlet 3-way taps to off to the pressure monitoring lines, and open to the de-airing bag for ***Recirculation***
- Increase RPM to 1500
- Recirculate until entire circuit is air free (the de-airing bag traps the air in the bag)
- Once adequate de-airing is achieved, clamp the de-airing bag and unclamp to the patient

9.3 Pump Head Failure

9.3.1 Decreasing Blood Flow Rate

Pt Nurse: Maintains pt ventilation, oxygenation and cardiac output **CSN:** Notify Intensivist and Perfusionist	
Possible Causes	**Management**
• Blood leaking from pump • Crack in pump head	• **Isolate the patient -clamp arterial and venous lines** • Turn RPM off • Obtain new ECLS circuit from pump room
• Decoupling of pump head (dropping flows and whirring noise)	• **Isolate the patient - clamp arterial and venous lines** • Close Haemofilter shunt • Turn RPM off • Remove pump head from drive unit • Replace pump head in correct position • Increase RPM to previous setting • Unclamp arterial and venous lines • Open shunt
• Noisy pump head	• Call Perfusionist to asses pump head

9.4 Power Failure

9.4.1 Absolute power failure

No RPM **Pt Nurse:** Maintains pt ventilation, oxygenation and cardiac output **CSN:** Notify Intensivist and Perfusionist	
Possible Causes	**Management Steps**
• Circuit breakers triggered • Internal battery failure • UPS failure	**Isolate patient - clamp arterial and venous lines** • Clamp Haemofilter shunt • Turn RPM off • Remove pump head from drive unit and insert into hand crank • Crank until equivalent RPM reached • Remove clamps from circuit • Monitor patient BP for adequate C.O. • Check equipment is plugged in and turned on • Check if circuit breakers have been triggered • Obtain new ECLS console from pump room

9.4.2 Console power failure

Console switches to battery power	
Possible Causes	**Management**
• Wall power supply interrupted • Power lead disconnected	• Check power cord is properly connected at Rotaflow console, ECLS Cart power bar, and wall outlet (if red outlet has no power switch to blue UPS outlet)
• Circuit breaker triggered	• Reset circuit breaker
• Power cord damaged	• Replace power cord
	➢ If it is hospital power supply issue: • ensure hand crank is available • collect backup ECLS cart from pump room

9.5 Accidental Decannulation

9.5.1 Partial Cannula Displacement

Bleeding from wound/insertion site but cannula still in place	
Possible Causes	**Management**
• Patient Movement • Cannula movement during procedures / cares • Breakdown of skin / sutures • Inadequate securing of cannula / circuit tubing	• Apply pressure to insertion site • Notify Cardiac Surgeon • Give volume replacement as needed • Check FBC and Coags

Table 15: Causes and Management of partial cannula displacement

9.5.2 Accidental Arterial Decannulation

Massive blood loss from cannula site, hypotension and high blood flow alarm, dropping outlet pressure **Pt Nurse:** Maintains pt ventilation, oxygenation and cardiac output **CSN: Call 555 – Code ECMO**	
Possible Causes	**Management**
• Patient Movement • Cannula movement during procedures / cares • Breakdown of skin / sutures • Inadequate securing of cannula / circuit tubing	• **Call 555 – Code ECMO** • **Isolate patient - clamp arterial and venous lines** • Turn RPM to 1000 and remove shunt gate clamp – allow to recirculate • Apply pressure to cannula site • Give volume replacement • Administer inotropes • Commence CPR if necessary

9.6 Blood Flow Management

9.6.1 Increasing Inlet Pressure (more positive)

Possible Causes	Management
Fluid overload	Increase fluid removal via haemofilter
RA distension	ECHO to check RV function • If caused by ↑ PVR – commence NO • If caused by inadequate cardiac function – increase patient blood flow
Weaning patient blood flow	• Inlet pressure may rise to match CVP as blood flow is reduced – this is expected as we allow the heart to fill • If signs of fluid overload increase fluid removal and/or commence diuretics
Zero Drift	• Re-level and recalibrate transducer

9.6.2 Decreasing Inlet Pressure (more negative)

Possible Causes	Management
Intravascularly dry	If blood flow rate stable; • Reduce fluid removal rate via haemofilter If blood flow rate decreasing; • Give a fluid bolus, commencing with 5ml/kg
Cannula position up against vessel wall	Sudden decreasing inlet pressure with decreasing blood flow and decreasing outlet pressure can indicate inlet cannula up against vessel wall; • Reduce RPM until inlet pressure decreases • Slowly increase RPM to previous settings It may be necessary to give volume into the RA at the time of reducing RPM
Zero Drift	Re-level and recalibrate transducer

9.6.3 Increasing Blood Flow

Possible Causes	Management
Decreased PVR	Adjust RPM to achieve level of support the patient requires; Assess patient SvO2, perfusion, oxygen saturations

9.6.4 Decreasing Blood Flow

Possible Causes	Management
Cannula kinked	• Manipulate cannula position
Cannula up against vessel wall	• Reduce RPM until inlet pressure decreases • Slowly increase RPM to previous settings
Hypovolemia	• Check BP / CVP, if low give intravascular volume

9.6.5 Inadequate urine output

Possible Causes	Management
Inadequate cardiac output	VA: Increase blood flow rate VV: assess fluid status and heart function, consider inotropes
Hypovolemia	Give intravascular fluid
Renal failure secondary to pre-ECLS ischemia	• Monitor renal function • Commence haemofiltration / peritoneal dialysis

9.6.6 Increased urine output

Possible Causes	Management
Diuresis of “accumulated” fluid	Monitor
Polyuric renal failure	Monitor, possibly replace fluid if high losses
Salt wasting	Replace water and sodium

9.7 Patient Bleeding

9.7.1 Visible Bleeding

Increased losses from chest drains, line sites, etc. Decide if "surgical" bleed or "medical" bleed. For surgical bleed, call surgeons.	
Possible Causes	**Management**
Anti Xa too high	• Reduce Heparin infusion as per Heparin Protocol to achieve desired Anti Xa range
Altered coagulation profile	• Check Coags, FBC, and TEG • Administer appropriate blood product(s)
Infection / sepsis	• Culture patient and commence appropriate antibiotic therapy
Pre-ECLS surgical procedure	• Optimize coagulation profile • Replace loses with PRBC / volume as needed • Notify cardiac surgeon

9.7.2 Internal Bleeding

Decreasing Hb with no visible bleeding	
Possible Causes	**Management**
Pre-ECLS surgical procedure	• Assess wound site for bleeding, swelling • Check coags, FBC and TEG • Correct coagulopathy • Increase platelet count • Decrease heparin and goal ACT range
NEC	• ECHO, X-ray, U/S, CT scan as indicated • Check coags, FBC and TEG • Correct coagulopathy • Increase platelet count • Decrease heparin and goal anti Xa range • Surgical consult • NBM • Antibiotics
Trauma	• ECHO, X-ray, U/S, CT scan as indicated • Check coags, FBC and TEG • Correct coagulopathy • Increase platelet count • Decrease heparin and goal anti Xa range • Surgical consult
Intracranial hemorrhage	• ECHO, X-ray, U/S, CT scan as indicated • Check coags, FBC and TEG • Correct coagulopathy • Increase platelet count • Decrease heparin and goal anti Xa range

9.8 Haemolysis

9.8.1 Plasma Hb > 30

Possible Causes	Management
Hyperthermia	• Check patient temperature • Administer antipyretics • Check set temperature of heat exchanger and reduce if necessary
Coagulopathy	• Check anti Xa, coags, FBC and TEG • Correct coagulopathy
Clots	• Check circuit for visible clots • Check anti Xa, coags, FBC and TEG • Inform Perfusionist • Repeat plasma Hb in 4 hours
Excessively low inlet pressures	• Reduce ECLS flow if possible • Give volume

9.9 PaO2 Management

9.9.1 Decreased PaO_2 in VA ECMO

Cyanosis, acidosis, poor perfusion, worsening ABG	
Possible Causes	**Management**
Inadequate ECLS flow	• Increase blood flow rate • Treat changes to preload and afterload
Pneumothorax / Tamponade / Haemothorax / Pericardiac Effusion	• Evacuate pneumothorax / haemothorax / effusion / Tamponade. • Check chest x-ray / ECHO / chest drain insertion
Oxygenator failure	• Check trans membrane pressure / check circuit SvO_2 vs SaO_2 on Spectrum • Check ratio of sweep gas rate to blood flow rate – ensure not exceeding 3:1 • Call Perfusionist
• Pulmonary venous desaturation (VQ mismatch, intrapulmonary shunting, hypoventilation or diffusion block with respective differential diagnoses • Right -> left shunt • Increased cardiac output where gas exchange in lungs impaired	• Increase patient blood flow • Cardiac ECHO • Start pulmonary vasodilators (iNO)
Sweep gas delivery failure	• Gas line disconnected ➢ Reconnect • Gas line ruptured ➢ Replace O_2 tubing ➢ Gas line obstructed or kinked
Sepsis	• Treat sepsis
Ventilator malfunction	• Check ventilator and vent circuit • Increase ECLS support as required

9.9.2 Decreased PaO_2 in VV ECMO

Cyanosis, acidosis, poor perfusion, worsening ABG	
Possible Causes	**Management**
Decreased cardiac function	• Consider vasopressors • Consider conversion to VA
Increased cardiac function	• When the cardiac output goes up but the VV ECMO flow is unchanged relatively less cardiac output is captured by the VV ECMO flow, and hence the patient PaO_2 will decrease. • Increase VV ECMO blood flow to adjust for increased cardiac output
Worsening lung function	• Increase ECMO blood flow
Increased Recirculation	• Minimize recirculation • Check cannula position • Reposition patient

9.9.3 Increased PaO_2 in VA

Cyanosis, acidosis, poor perfusion, worsening ABG	
Possible Causes	**Management**
Inadequate cardiac output	• Increase ECMO blood flow
Pneumo/haemothorax/ effusion	• Evacuate pneumo / haemo / effusion • Chest x-ray
Tamponade	• Strip mediastinal drain if present • Drain pericardium
Sepsis with peripheral shunting	• Treat sepsis
Tissue death with decreased O2 consumption	

9.9.4 Increased PaO_2 in VV

Patient looks well	
Possible Causes	**Management**
Improving respiratory function	• Consider weaning support
	•

9.10 PaCO2 Management

9.10.1 Decreased $PaCO_2$

Possible Causes	Management
Patient over ventilated	• Check ventilator settings and reduce if possible
Sweep gas flow too high	• Reduce sweep flow rate • Call Perfusion to add CO_2 to circuit (If sweep already at minimal setting, 200 ml/min)
Improved respiratory function	• Consider weaning support

9.10.2 Increased $PaCO_2$

Possible Causes	Management
Oxygenator failure	• Check trans membrane pressure / check circuit SvO_2 vs SaO_2 on Spectrum • Check ratio of sweep gas rate to blood flow rate –> ensure not exceeding 3:1 • Call Perfusionist
Sweep gas flow too low	• Increase sweep flow rate
Under-ventilation	• Adjust ventilator support / ETT
Patient agitated	• Optimize sedation
Pneumo / hemothorax / effusion	• Evacuate pneumo / hemothorax effusion

9.11 SvO2 Management

Increased SvO_2 in VA ECMO with well looking patient

Possible Causes	Management
Blood flow rate too high	• Reduce patient blood flow to ordered rate
Shunt • Intra-atrial communication	• Cardiac ECHO to check for shunts
LA vent	• No change required

Increased SvO_2 in VA ECMO with unwell looking patient

Possible Causes	Management
Inadequate cardiac output – pt not extracting/shunt in periphery	• Consider vasodilation and/or increased blood flow rate
Temperature	• Check patient temperature – warm if hypothermic • Hyperthermia increases metabolic rate; increase blood flow rate and aim for normothermia
Sepsis	• May need up to 300 ml/kg/min blood flow to meet metabolic demands
Cyanide toxicity	• Check lactate, stop SNP

Decreased SvO_2 in VA ECMO

Possible Causes	Management
Inadequate cardiac output	• Increase patient blood flow rate
Neurological disease/seizures	• Neurological assessment • Cranial ultrasound
Increased extraction	• Sepsis • Hyperthermia

Increased SvO_2 in VV ECMO (measured from the patient, NOT the ECMO cannula)

Possible Causes	Management
Sepsis with peripheral shunting	• Treat sepsis
Tissue death with decreased O2 consumption	

Decreased SvO_2 in VV ECMO

Causes for decreased SvO_2 in VV ECMO are the same as for VA ECMO. See table above.

10 Appendices

10.1 Daily Care Plan

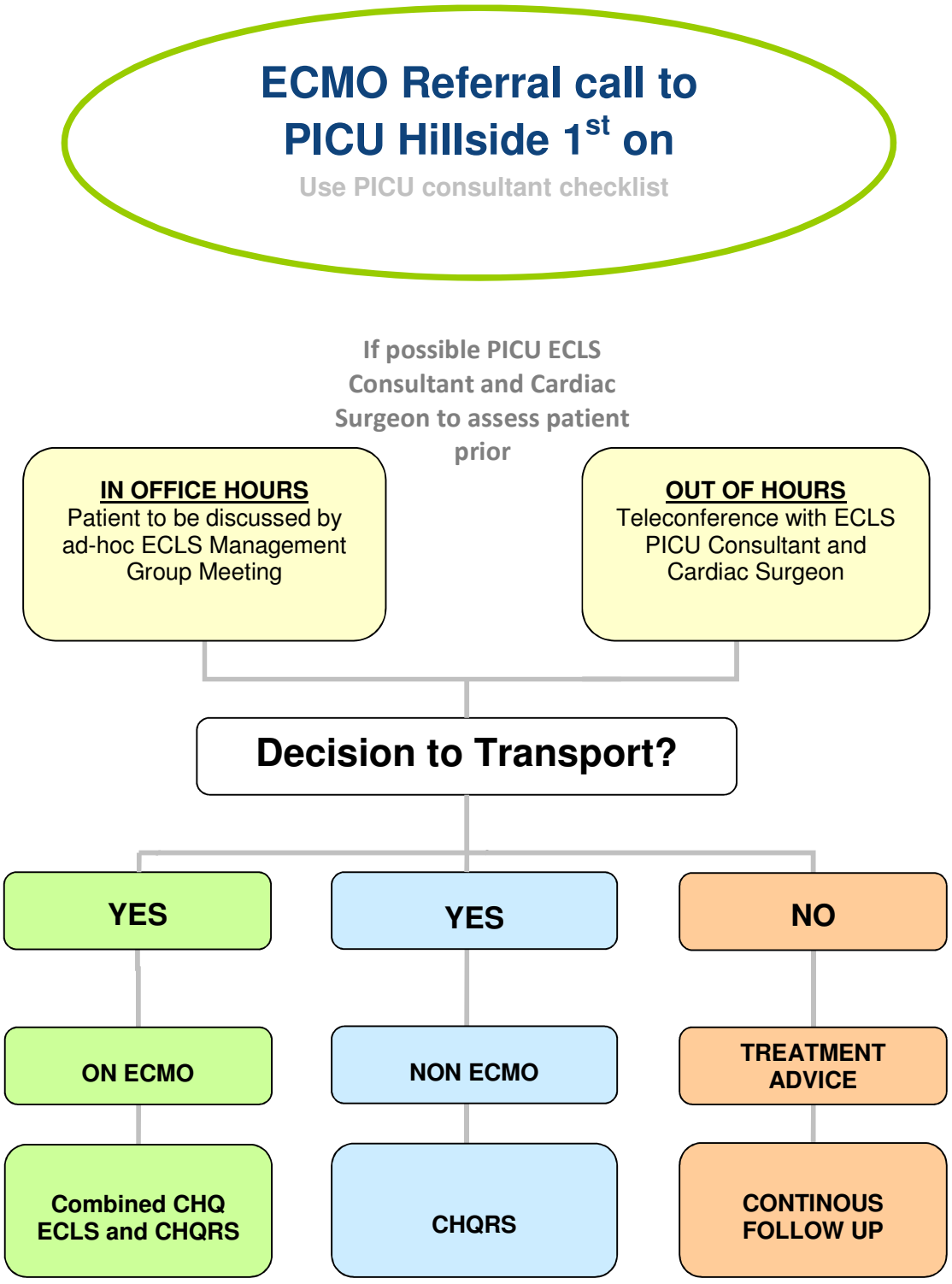
Daily Care Plan	ECMO DAY ___	
	01:00	
	02:00	
	03:00	
	04:00	Pre & Post Oxygenator pressures
	05:00	Chem20, CRP, PCT, blood culture Triglyceride level (if on lipids or propofol) Do they need T3, TnI, BNP? Every **Monday an ETT aspirate** must be taken
	06:00	**Turn lipid infusion off** for plasma Hb testing at 0800
	07:00	Chest X-Ray
	08:00	Paired ABG and VBG (pt SvO_2), Plasma HB Reposition haemofilter gate clamp Pre & Post Oxygenator pressures
	09:00	Zero Spectrum flow probe Calibrate Spectrum SvO2 and Hb (Circuit VBG)
	10:00	
	11:00	
	12:00	Pre & Post Oxygenator pressures
	13:00	
	14:00	
	15:00	
	16:00	Pre & Post Oxygenator pressures
	17:00	
	18:00	
	19:00	
	20:00	Paired ABG and VBG Reposition haemofilter gate clamp Pre & Post Oxygenator pressures
	21:00	
	22:00	
	23:00	
	24:00	Pre & Post Oxygenator pressures

10.2 ECLS Emergency Management Plan

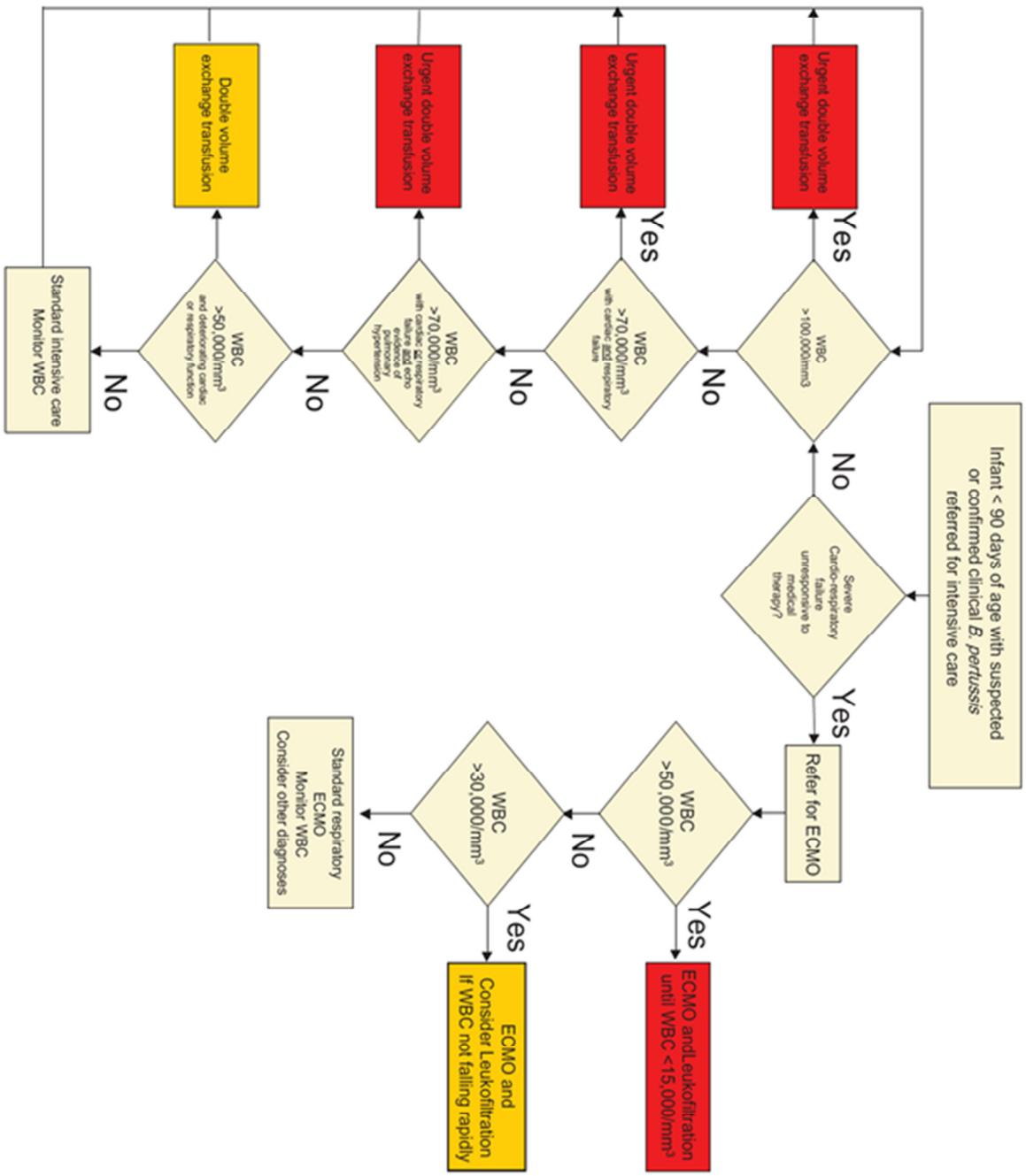
Name: **Date:** **Time:**

Ventilation	
SaO_2: _____ % $PaCO_2$: _____-_____mmHg pH: _____ BP (MAP): _____ (SYST):_____ (DIAS): _____	
☐ **iNO:_____ppm**	
☐ **Conventional**	☐ **HFOV**
MODE: SIMV / PRVC / _____ PIP:_____cmH2O or Vt: _____ml/kg RATE: _____ PEEP: _____cmH2O FiO2: _____% iTime: _____	PAW: _____cmH2O Delta P: _____ Hz: _____ FiO2: _____%
Cardiovascular	
Inotropes & Starting Dose	**Pacing**
☐ Adrenaline: _____mcg/kg/min ☐ Noradrenaline: _____ mcg/kg/min ☐ Dobutamine: _____ mcg/kg/min ☐ Dopamine: _____ mcg/kg/min ☐ Vasopressin: _____units/kg/hr (<20kg) ☐ Vasopressin: _____ units/hr (>20 kg) ☐ Other _____	☐ Mode: DDD / AAI / _____ ☐ Rate: 120 / _____bpm ☐ A Output: _____mA ☐ V Output: _____mA
Fluid Resuscitation	
☐ 0.9% NaCl: _____ml/kg ☐ 4% Albumin: _____ml/kg	☐ PRBC: _____ml/kg ☐ Other: _____ml/kg
On-CALL TEAM	
ECLS Consultant: _____ Perfusionist: _____	Cardiac Surgeon:_____ Cardiac Fellow:_____

10.3 ECLS Referral Process



10.4 Pertussis Management Flow Chart



10.5 ECLS Service Governance

10.5.1 The ECLS Board

Function & Purpose

- Ensures good clinical ECLS service practice
- Conduit between ECLS Management Group & Divisional Directorate
- ECLS Service issue resolution

Specific Tasks

- Sign off strategic matters
- Provide advice to Divisional Directorate
- Supervise financial & budgetary affairs
- Members report to their pertinent Department Directors

Members

- CNC ECLS: Emma Haisz
- Intensive Care: Adrian Mattke (Medical Director & Chair)
- Cardio-Thoracic Surgery: Prem Venungopal
- Perfusion: Carla Zazulak
- Cardiology: Ben Anderson

Meetings: monthly

10.5.2 ECLS CNC Coordinator & ECLS Medical Director

Role assignment

- CNC ECLS: interview process
- ECLS Medical Director: agreed on by PICU ECLS SMOs, cardiology and cardiac surgery SMOs, confirmed by ECLS Board

Tasks

- Coordination of ECLS Management Group activities
- Service administration
  - ECLS Nurse Specialist & ECLS SMO roster
  - Finances & budget: ELSO membership, equipment purchase etc
- Quality & Safety assurance
  - Update ECLS Clinical Guidelines
  - Deal with incident reports concerning ECLS patients & service
  - Contribution to QPCS M&M
  - QPCS data reporting

  - ELSO data reporting
- Coordination of Teaching & Education (see ECLS Management Group)
  - Buddying of new ECSL Course graduates
  - Monthly ECLS Study Days
  - ECLS Courses
- Coordination of research involving ELCS service & patients
- ECLS Nurse Specialist & ECLS SMO rosters

Reporting

- Professionally: pertinent professional/administrative line managers
- Strategically: ECLS Board
- Clinically: ECLS Management Group

10.5.3 The ECLS Management Group

Purpose

- Patient management
- Service operations

Tasks

- Provide advice to Hillside PICU Clinical Leadership Team (Hillside SMO, TL, AH) & clinicians (ECLS Nurse Specialist, Registrars) on patient management
- Management of difficult & complex ECLS patient or with unusual course & complications
- Teaching & Education as directed by ECLS Nurse Coordinator & ECLS Medical Director: ECLS study days, ECLS courses
- Research, Development & Innovation

Members

- Chairs: ECLS CNC or ECLS Medical Director or rostered ECLS SMO
- Hillside PICU SMO
- Cardiothoracic surgeons & fellows
- Cardiologists
- Perfusionists
- ECLS Nurse Specialist
- Invited medical specialists as required (Respiratory SMO, Oncology SMO, General Surgeon, etc)
- Emergency Quorum: Hillside SMO, ECLS SMO, Cardiothoracic Surgeon, Cardiologist, Perfusionist, ECLS Nurse Specialist, and Primary/Speciality Team if applicable

Meetings

- Default monthly as part of QPCS Quality Assurance Meeting
- Daily as part of cardiac PICU round for management of difficult ECLS patient
- Ad hoc physically or via phone conference

11 Abbreviations

12 Glossary

13 References