CVICU

AUCKLAND
DISTRICT HEALTH BOARD
Te Toka Tumai

CVICU Adult ECMO Manual

February 2019

Welcome *Haere Mai* | **Respect** *Manaaki* | **Together** *Tūhono* | **Aim High** *Angamua*

Introduction

The Cardiothoracic and Vascular Intensive Care Unit (CVICU) and Starship Paediatric Intensive Care Unit (PICU) have provided Extracorporeal Membrane Oxygenation (ECMO) services to patients from around New Zealand for a number of years. The provision of an ECMO service is complex and multidisciplinary. Over time our systems have evolved and a large amount of institutional knowledge has been accumulated through the hard work, expertise and passion of a number of ADHB staff. The primary aim of this first edition of the Auckland City Hospital ECMO manual is to describe our current practice.

We hope that this manual will provide a reference describing how we provide ECMO support. It will also help the multidisciplinary ECMO team by providing checklists to guide routine management of our ECMO patients. In time we hope that it will become a benchmark for how we deliver ECMO. This manual is by no means a comprehensive account of ECMO management and we welcome any suggestions for further topics that can be added.

There will be ongoing modification to the material within this manual following printing of the hard copies. For the most up to date version, please refer to the CVICU internet site (www.cvicu.co.nz).

Bevan Vickery, January 2019.

ECMO governance

An ECMO governance group provides oversight to the ECMO service. Currently there are representatives from CVICU medical and nursing, PICU medical and nursing as well as perfusion. Ideally this allows a forum to improve standardisation and to clarify any issues across the service. Service development planning will hopefully be coordinated through this group. An annual review of ECMO is presented to the wider staff once a year and there are three monthly meetings to allow discussion on the cases and any morbidity and mortality.
An annual report on the service is generated.

ECMO Referral Process

The On Call CVICU Consultant is available to discuss patients that the referring Intensive Care Senior Medical Officer feels currently require ECMO. As well as this, the On Call CVICU Consultant is happy to discuss patients who the referring Intensive Care Senior Medical Officer feels are highly likely to require ECMO in the near future, as well as patients where it would be helpful to the referring centre to exclude ECMO as a treatment option.

The On Call CVICU consultant may be contacted directly on the following number: 0800 ADULT ECMO (0800 23858 3266). We ask that, to help make the discussion as useful as possible, the referral is made by an Intensive Care Senior Medical Officer. To facilitate the discussion, the ECMO referral form should be filled out and faxed to (09) 307 4906. Following acceptance of the referral, the referring hospital checklist will help prepare the patient for the ECMO retrieval. Both of these forms, and other referral information, can be found at https://www.cvicu.co.nz/ecmo/. Please note that faxing the form alone is not sufficient to make a referral, particularly out of hours, and the 0800 number should always be used.

Many ECMO referrals involve complex patients. Please allow time for discussion of these patients amongst our intensive care and other medical colleagues.

Once the decision is made to retrieve a patient on ECMO, CVICU will arrange a retrieval team. Please be aware that this may take time. The retrieval team is normally composed of CVICU SMOs and perfusionists, some of whom may not be on call. Availability of transport aircraft and weather conditions are also factors which need to be considered. We will make every effort to keep the referring hospital updated with the Expected Time of Arrival.

ECMO Indications and contraindications

VV ECMO

General indications

- Potentially reversible respiratory failure from any cause.
- Evidence of severe hypoxia, hypercarbia, or both.
  - *P_aO_2/F_IO_2 < 60-80 mmHg (< 8-11 kPa) despite maximum ventilatory support (PIP 30-35 cm H_2O, PEEP 10-20 cm H_2O) and non-ventilatory strategies (i.e., diuresis, prone ventilation, recruitment maneuvers, inhaled nitric oxide) to improve gas exchange.*
  - *P_aCO_2 > 80-100 mmHg (> 11-15 kPa) despite maximum ventilatory support (PIP ≥ 35 cm H_2O, $P_{plateau}$ ≥ 30 cm H_2O, RR > 20).*

- Factors to consider
  - *It may be appropriate to tolerate worse gas exchange if the patient has only been recently intubated and ventilated (e.g., < 12 hours).*
  - *It may be appropriate for patients with less severely impaired gas exchange to be considered for ECMO if they have been ventilated for a longer period (e.g., > 3 days) and have not responded.*
  - *Patients who are clearly deteriorating may be considered for ECMO despite less severely impaired gas exchange.*

Specific indications

For the following conditions, VV ECMO is associated with a good chance of bridging to recovery, and should therefore be considered:

- Pneumonia
- Pulmonary aspiration
- Drowning
- ARDs with a recognised precipitant (e.g. TRALI, pancreatitis)
- Following lung transplantation
- Severe pulmonary haemorrhage
- Life threatening asthma
- To facilitate airway surgery (e.g., tracheal stenosis)

Contraindications

There are no absolute contraindications to ECMO for respiratory failure except irreversible lung disease (bridging to lung transplantation is not provided as a treatment option in New Zealand), and each patient must be considered on a case by case basis. The following are **relative** contraindications:

- Prolonged mechanical ventilation (> 7 days) at high ventilatory pressures (PIP > 35 cm H_2O) and/or high F_IO_2 (> 0.8)
- Age > 65 years
- Weight > 125 kg
- Chronic organ dysfunction. Conditions to consider include: renal failure, neurological dysfunction, chronic pulmonary disease, chronic cardiac disease, malignancy, and cirrhosis
- Severe septic shock with evidence of severely impaired tissue perfusion (e.g., cold mottled limbs, severe metabolic acidosis)
- Progressive disease inflammatory or autoimmune conditions

VA ECMO

General indications

- Shock from a potentially reversible cause that is not responsive to maximal conventional treatment (mechanical ventilation, volume loading, inotropic support, ± IABP)
- Shock may be defined by two or more of the following: (1) MAP < 60 mmHg; (2) CI < 2.2 L/min/m^2 or S_VO_2 < 50%; (3) PAWP >20 mmHg or evidence of acute pulmonary oedema; (4) evidence of severe tissue hypoperfusion (e.g. impaired mentation, acute kidney injury, cold mottled limbs, impaired mentation)

Specific indications

For the following conditions, VA ECMO, as a bridge to recovery, has a high chance of success and should be provided if indicated by the presence of severe shock:

- Fulminant viral myocarditis
- Peripartum cardiomyopathy
- Drug overdose (note ECMO may be less beneficial for treating overdose of a vasodilator (e.g., amlodipine, felodipine) than from a drug causing myocardial depression (e.g., beta-blocker, diltiazem) or cardiac arrhythmia (e.g., antidepressant))
- Anaphylaxis
- Following heart or lung transplantation

Abrupt onset (over a few days) of severe viral myocarditis has a high chance of full recovery. Acute or sub-acute myocarditis, with an onset over many days or weeks, has a lower chance of recovery. Giant cell myocarditis typically does not recover.

For the following conditions, bridging to recovery with VA ECMO has an uncertain outcome, and should be considered on a case-by-case basis:

- Failure to wean from cardiopulmonary bypass
- Acute coronary syndromes
- Massive pulmonary embolus
- Septic shock with severe cardiorespiratory failure
- E-CPR for in-hospital cardiac arrest

Ideally, use of ECMO following cardiac surgery should be planned ahead of time. Septic shock may be considered for VA ECMO. However, 'cold shock' due to community acquired gram positive organisms (e.g., Staphylococcus aureus, Streptococcus pneumoniae, Neisseria meningitides) has a very poor outcome from VA ECMO, and should only be undertaken in exceptional circumstances. In the case of E-CPR, the following requirements should be met:

- Witnessed, in-hospital cardiac arrest.
- Less than 10-15 minutes of CPR prior to referral for ECMO or longer when only intermittent CPR required.
- High quality CPR throughout with maintenance of reasonable metabolic control (e.g., pH > 7.0).
- Event occurring in working hours (6 am-6 pm) or when a team can be rapidly assembled (i.e., intensivists and perfusionists are onsite).

Contraindications

- Absolute contraindications for VA ECMO are:
  - *Unrecoverable or end-stage cardiac failure in a patient who is not a candidate for heart transplantation*
  - *Prolonged CPR without good metabolic support.*

Relative contraindications are:

- Age > 65
- Weight > 125 kg
- Intracranial haemorrhage that is recent or expanding.
- Profound coagulopathy or uncontrollable surgical site bleeding.
- Chronic organ dysfunction. Conditions to consider include: renal failure, major neurological deficit, chronic pulmonary disease, underlying malignancy, cirrhosis.

Many patients being referred for ECMO are complex. Often the indications can be borderline and the contraindications are not absolute. The CVICU SMOs will consider all reasonable ECMO requests. Whenever practical, consensus is reached between two or more CVICU SMOs that ECMO support is appropriate. If uncertainty remains about the utility of ECMO in a given circumstance, consultation may be required with other medical specialties. The results of these discussions are then fed back to the referring centre and a treatment plan is made.

Oxygenator function

Gas exchange by the oxygenator is controlled by adjusting the flow and F_IO_2 of the sweep gas. The F_IO_2 determines the post-oxygenator oxygen tension, which equates to the oxygen tension in the return limb of the ECMO circuit. During VA ECMO F_IO_2 is titrated to the patient's arterial oxygen saturation whereas during VV ECMO it is usual to run an F_IO_2 of 1.0. In the discussion below, the term 'gas flow' refers to the sweep gas flow (i.e., through the gas phase of the oxygenator) and the term 'circuit flow' refers to the blood flow through the ECMO circuit (i.e., through the blood phase of the oxygenator)

Oxygen transfer

When an oxygenator is functioning normally, and working within its operating range of circuit flow (< 6-7 L/min), an F_IO_2 of 1.0 of the sweep gas typically results in a post-oxygenator PO_2 above 40 kPa. Despite such a high PO_2, the additional oxygen content of blood in the return cannula due to dissolved gas is negligible compared to oxygen bound to haemoglobin. At high circuit flows (> 6-7 L/min) or if the oxygenator is starting to deteriorate, the post-oxygenator PO_2 may fall to more physiologic levels (i.e., 12-15 kPa). In this circumstance, the oxygen saturation of blood in the return cannula is still at or near 100%, and therefore the oxygen content of blood in the return cannula is little changed. However, if the post-oxygenator PO_2 falls below 10-12 kPa, the oxygen saturation in the return cannula may fall below 100%, in which case oxygen delivery in the return cannula may be reduced. For this reason, it is usual to check a post-oxygenator PO_2 once every 24-hours (with the F_IO_2 set to 1.0) to assess oxygenator function. Additionally, if a patient becomes hypoxaemic, at post-oxygenator PO_2 should be checked to ensure oxygenator failure is not the cause.

If oxygenator failure is suspected, in the first instance the oxygenator should be 'coughed'. Coughing the oxygenator involves running very high gas flows (> 10 L/min) for approximately 60 seconds to remove any water vapour from the gas phase of the oxygenator. Following this manoeuvre, the post-oxygenator PO_2 should be rechecked. Then, if the post-oxygenator PO_2 remains low (< 12-15 kPa) the circuit should be replaced. If the problem is a failing oxygenator, a circuit with a single oxygenator may be used as the replacement. If the problem is the need to run very high circuit flows (> 6 L/min), exceeding the operating range of the oxygenator, a new circuit with two oxygenators positioned in parallel should be used as the replacement.

Carbon dioxide clearance

Sweep gas flow through the oxygenator determines the post-oxygenator carbon dioxide tension (PCO_2), which, in turn, controls the patient's P_aCO_2. Under most circumstances, a normal P_aCO_2 can be easily achieved with a sweep gas flow of between half and one times the ECMO circuit flow. Highly catabolic patients (i.e., high VCO_2) may require a sweep gas flow greater than ECMO circuit flow to achieve normocarbia. Also, if the oxygenator is failing, P_aCO_2 may rise despite a normal or high sweep gas flow. Checking the post-oxygenator PCO_2 in the ECMO circuit can help distinguish between a failing oxygenator (normal or high post-oxygenator PCO_2) and high patient VCO_2 (normal or low post-oxygenator PCO_2). As with a failing oxygenator function, inability to achieve normocarbia despite high sweep gas flow is an indication to change the circuit, with one or two oxygenators.

The need to change the circuit for failure of CO_2 clearance is much less common than failure to achieve an adequate post-oxygenator PO_2.

Veno-venous ECMO

VV ECMO provides support for gas exchange but does not directly support the cardiovascular system. However, not uncommonly, initiation of VV ECMO and institution of 'rest' ventilator settings leads to a significant reduction in vasopressor requirements due decreased intrathoracic pressure. Thus, VV ECMO has an indirect effect on the cardiovascular system.

While 'normal' oxygenation cannot be achieved with VV ECMO, an 'adequate' arterial oxygen saturation (S_aO_2) is usually possible, even in the absence of any native lung function. Normocarbia can usually easily be achieved. During VVECMO, circuit flow is primarily responsible for achieving adequate oxygenation whereas ECMO sweep gas flow is primarily responsible for achieving adequate carbon dioxide clearance.

Cannulae position

Both drainage and return cannulae are placed in systemic veins. With the configuration used in CVICU, a return cannulae, containing oxygenated blood, is placed in the right internal jugular vein and the tip advanced to junction of the superior vena cava (SVC) and right atrium (RA). The goal is for (virtually) all of the oxygenated blood from the return cannula to pass through the tricuspid valve and into the pulmonary circulation.

The drainage cannula, which drains the patient's systemic venous return, is placed in a femoral vein and advanced into the inferior vena cava (IVC) with the cannula tip at or around the level of the hepatic veins.

Blood flow and oxygen saturation in the pulmonary artery

As noted above, ideally, all of the oxygenated blood from the return cannula passes through the tricuspid valve and into the pulmonary circulation. Because flow in the drainage and return cannulae is exactly the same, and because both cannulae are in systemic veins, flow in the ECMO circuit has no direct effect on the patient's haemodynamics.

Oxygenated blood from the return cannula mixes with systemic venous blood in the right ventricle. Thus, the oxygen saturation of blood in the patient's pulmonary artery is determined by:

- **ECMO circuit flow.**
- **The oxygen saturation of blood in the ECMO return cannula.**
- **The systemic venous return that passes through the lungs.**
- **The oxygen saturation of the patient's systemic venous blood.**

ECMO circuit flow is normally 4-6 L/min, and the oxygen saturation of blood from the return cannula is normally 100%. The volume of systemic venous blood passing through the pulmonary circulation each minute depends on two factors: cardiac output and ECMO circuit flow. For instance, if cardiac output is 6 L/min and ECMO flow is 4 L/min, then theoretically, 4 L/min of systemic venous return passes to the ECMO drainage cannula and 2L/min will pass through the lungs. In the same scenario, and assuming all the return blood from the ECMO circuit passes through the tricuspid valve, blood flow through the pulmonary circulation will be 6 L/min in total, comprised of 4L/min of oxygenated blood from the ECMO return cannula and 2 L/min of deoxygenated blood from the patient's systemic venous return. Note that, irrespective of ECMO circuit flow, systemic venous return is the same as CO, and that flow in the pulmonary and systemic circulations is the identical.

Native pulmonary function

If the patient's lungs are entirely non-functional – which is not uncommon in the early part of an ECMO run – then the oxygen saturation of pulmonary arterial blood will be identical to the patient's S_aO_2. If the lungs have some functional capacity for gas exchange, then S_aO_2 will be higher than pulmonary arterial oxygen saturation.

Recirculation

Recirculation is the phenomenon whereby oxygenated blood from the return cannula passes directly to the drainage cannula rather than going through the pulmonary circulation. Recirculation has the effect of reducing 'effective ECMO circuit flow'. Some minor degree of recirculation always occurs. Clinically significant recirculation has the effect of depressing S_aO_2 despite seemingly adequate ECMO circuit flow. Also, because the degree of recirculation worsens at higher circuit flows, increasing circuit flow does not improve (and may worsen) S_aO_2.

There are two ways to diagnose clinically significant recirculation. First, echocardiography to identify streaming of blood from the ECMO return cannula, down the IVC towards the drainage cannula. Second, by measuring the pre-oxygenator oxygen saturation in the ECMO circuit. An abnormally *high* pre-oxygenator saturation (>70%) in the presence of low S_aO_2 (< 90%) suggests clinically significant recirculation exists. Treatment involves repositioning the ECMO cannulae; either manipulating the return cannulae to direct blood from through the tricuspid valve or withdrawing the drainage cannula further into the IVC.

Determinants of arterial oxygen saturation during VV ECMO

From the foregoing discussion, we can list the factors that determine the patient's S_aO_2:

- **Cardiac output**
- **Oxygen saturation of the patient's systemic venous return**
- **EMCO circuit flow.**
- **Oxygen saturation of blood in the ECMO return cannula (normally 100%).**
- **The degree of recirculation.**
- **Haemoglobin concentration.**
- **Native pulmonary function and ventilator settings.**
- **Oxygenator function.**

The main determinant of S_aO_2 is ECMO circuit flow relative to cardiac output. As a rule of thumb, if ECMO flow is at least 80% of cardiac output and recirculation is minimal, then a S_aO_2 of around 90% can be achieved even in the absence of any native pulmonary function. If S_aO_2 is lower than expected despite a seemingly adequate ECMO circuit flows the possible causes are:

- **High cardiac output/low systemic venous oxygen saturation**
- **A failing oxygenator**
- **Recirculation**
- **Anaemia**

Initial investigations include: (1) measuring the *post*-oxygenator PO_2 (to assess oxygenator function; described above); measuring the *pre*-oxygenator SO_2 (to assess for the presence of clinically significant recirculation); (3) echocardiography (to assess for recirculation).
If the oxygenator is functioning well and there is minimal recirculation, the most likely explanation for a low S_aO_2 is high cardiac output/low systemic venous oxygen saturation. The most common causes for high cardiac output are fever, systemic inflammation, and sepsis. Given it is difficult to achieve ECMO circuit flows of 80% of cardiac output in the presence of sepsis, arterial desaturation (< 85-90%) is inevitable. In this circumstance, the following manoeuvres can help return S_aO_2 to an acceptable level: (1) increasing haemoglobin concentration (which will increase the systemic venous oxygen saturation); (2) active cooling (which will increase the systemic venous oxygen saturation and reduce cardiac output); (3) increasing mechanical ventilation above rest settings (which only works if there is recruitable native lung function). In extreme situations, giving a beta-blocker to reduce cardiac output improves S_aO_2, but may have other adverse consequences.

Veno-arterial ECMO

With VA ECMO, blood is drained from the RA and IVC and is returned to a large systemic artery, either the aortic root or femoral artery. Thus, VA ECMO provides direct support for the circulation (left and right ventricles) and the lungs. Physiologically, VA EMCO is similar to cardiopulmonary bypass. Unlike VV ECMO, patients supported with VA EMCO frequently have normal S_aO_2.

Cannulae position

With VA ECMO, the drainage cannula is placed so that the tip is positioned in the RA. Most commonly, the drainage cannula is inserted into a femoral vein and advanced up the IVC. Rarely, the venous cannula used during cardiopulmonary bypass functions as the drainage cannula. The return cannula is placed in a systemic artery. There are two options for arterial cannulation: **central** and **peripheral**. With peripheral cannulation, the return cannula is placed in a femoral artery and advanced into an iliac artery. Peripheral cannulation may be performed percutaneously or surgically. With central cannulation, the return cannula is placed in the proximal ascending aorta. Central cannulation is always surgical. Central arterial cannulation is typically performed when VA EMCO support is used following cardiac surgery; peripheral cannulation is performed when VA ECMO support is used non-surgically (e.g., for fulminant myocarditis or drug overdose). Rarely, peripheral arterial cannulation is used for surgical patients; for instance, when VA EMCO is initiated postoperatively in CVICU.

Circulatory support

Systemic arterial blood flow during VA ECMO is the sum of the ECMO circuit flow and any ejection from the left ventricle (LV). Systemic blood pressure is determined by total blood flow (ECMO flow + native cardiac output) and arteriolar tone. If there is no LV ejection, the patient will have a non-pulsatile arterial waveform and blood pressure will be entirely dependent on ECMO flow and arteriolar tone. Conversely, if there is some LV ejection, the arterial waveform will be pulsatile. However, because some (or all) of the patient's systemic venous return is drained to the ECMO circuit (by an amount equal to the ECMO circuit flow), native LV ejection is never 'normal' even if ventricular function has fully recovered. The ECMO circuit flow can be thought of as reducing the cardiac preload. The adequacy of circulatory support during VA ECMO is guided by the oxygen saturation of the patient's systemic venous return and their blood pressure. Venous oxygen saturation can be measured by placing an oximeter in the drainage limb (i.e., pre-oxygenator) in the ECMO circuit.

Left ventricular distension

In some circumstances, ventricular ejection is minimal or absent (e.g., in the hyper-acute period of fulminant myocarditis). In this situation, systemic arterial blood flow is entirely dependent on ECMO circuit flow and pulmonary blood flow is absent or minimal. However, despite minimal or absent pulmonary blood flow, there is still some systemic venous return that passes to the LV via the bronchial and Thebesian circulations. If the aortic valve fails to open (due to a non-functioning LV), this ongoing left-heart return can cause severe LV distension. In turn, severe LV distension can cause myocardial damage, severe mitral regurgitation, LA hypertension, and fulminant pulmonary oedema. The problem is diagnosed by the presence of a

non-pulsatile arterial waveform, severe LV distension and a closed aortic valve on the echocardiogram, and the presence of frothy oedema fluid in the endotracheal tube. Treatment involves attempting to facilitate LV ejection with inotropic support and increasing ECMO circuit flow (to reduce any pulmonary blood flow that may be contributing to this problem). Ultimately, however, decompressing the LV with via an atrial septostomy or LV vent may be required.

Aortic regurgitation

Even minor degrees of aortic regurgitation can cause catastrophic LV distension in patients with minimal ventricular function supported with VA ECMO. Because of this, aortic regurgitation can be considered a contraindication to VA ECMO in the presence of severely depressed LV function.

Intra-cardiac thrombus

A further problem that can arise when ventricular function is minimal or absent is blood stasis in the heart, which can lead to intra-cardiac thrombus, an invariably fatal condition. Cardiac tamponade further reduces intra-cardiac blood flow, greatly increasing the likelihood of intra-cardiac thrombus formation. Thus, maintaining some degree of LV ejection – as evidenced by pulsatility on the arterial waveform – and rapid correction of cardiac tamponade are crucially important.

Gas exchange during VA EMCO

The patient's P_aO_2 and S_aO_2 during VA EMCO are determined by the relative amounts of oxygenated blood from the ECMO return cannula and that ejected from the LV. If there is no LV ejection, S_aO_2 is dependent on the oxygen saturation of blood in the ECMO return cannula, which is typically 100%. If LV ejection is occurring and the lungs are ventilated and working well, S_aO_2 will also be normal. For this reason, it is usual to ventilate the lungs with 'normal' ventilator settings during VA ECMO – in contrast to the 'rest' settings used during VV ECMO. Thus, in most circumstances it is possible to achieve normal gas exchange during VA ECMO support. One exception to this is when peripheral VA ECMO is used and myocardial function has recovered but pulmonary function is severely impaired. This situation can lead to differential oxygenation.

Differential oxygenation

With peripheral VA ECMO, oxygenated blood is returned to the patient via a femoral cannula. In the absence of significant LV ejection, systemic arterial blood passes in a in a retrograde direction through the aorta. However, if there is significant LV ejection and severely impaired pulmonary function, deoxygenated blood will be ejected from the LV and preferentially perfuse the upper body (heart and brain). The problem can be diagnosed by identifying a low S_aO_2 from in the right upper limb, despite a normal post-oxygenator PO_2 and/or a normal S_aO_2 in a lower limb. Treatment of differential oxygenation involves one or more of the following: (1) reducing LV ejection (stopping inotropes, increasing ECMO flow and thereby reducing cardiac preload), changing to VV ECMO, changing to veno-arterio-venous (VAV) ECMO.

With central VA ECMO the problem of differential oxygenation is largely avoided. As noted above, with both central and peripheral cannulation, S_aO_2 is dependent on the relative oxygen delivery from the ECMO return cannula and the left heart. However, unlike peripheral cannulation, with central cannulation immediate mixing of the two blood streams occurs in the aortic root. Thus, with central VA ECMO, while oxygen saturation in the aorta may be somewhat depressed by deoxygenated blood ejected from the lungs, it is not usually enough to cause significant arterial desaturation in the patient, and can usually be overcome by increasing the F_IO_2 on the sweep gas and increasing ECMO circuit flow.

As with VV ECMO, maintenance of normocarbia is usually easily achieved during VA ECMO support.

Veno-arterio-venous ECMO

VAV ECMO is used to treat differential hypoxaemia in patients supported with peripheral VA ECMO who develop severe hypoxaemia in their upper body. The technique involves involves draining deoxygenated blood from the IVC and returning oxygenated blood to both a (peripheral) systemic artery *and* the RA. Thus, oxygenated blood is returned to both the arterial and venous systems. The RA return cannula delivers oxygenated blood to the pulmonary circulation, helping to overcome the ejection of deoxygenated blood from the LV.

While appealing in theory, VAV ECMO has two problems. First, blood flow delivered is split between the two return limbs of the circuit. If, say, 4 L/min of arterial flow is required to support the circulation and 3/L min of venous flow is required to overcome differential hypoxaemia, total ECMO flow needs to be 7L/min, which is rarely possible. Second, it is difficult to control or adjust the relative blood flows in the two return limbs. Relatively too much blood flow to the RA return cannula may overcome the problem of hypoxia but result in insufficient circulatory support; too little blood flow in the RA cannula can lead to persisting hypoxaemia. In practice, VAV ECMO is used rarely and then only for a short duration (24-48 hours) until the patient can be safely converted to VV ECMO.

1. Contact Skyline 0800 111 400

- Confirm Transport Mode (Fixed, Rotary, Road)(see separate table)
- Confirm Max number of people allowable in Team (aircraft dependent)
- Flight Nurse (use for road as well)
- Patient Details (name, NHI, referring hospital)
- Earliest time Retrieval Team ready for pick-up (allow 60mins)

2. Organise Retrieval Team

- Perfusionist(s)
- 2 x CVICU Doctors (remember fellows if space permits)

3. Re-contact Skyline

- Confirm Patient details
- Retrieval Team Names
- Confirm departure time from Auckland Hospital for Retrieval Team
- Get ETA at destination to give referring Hospital

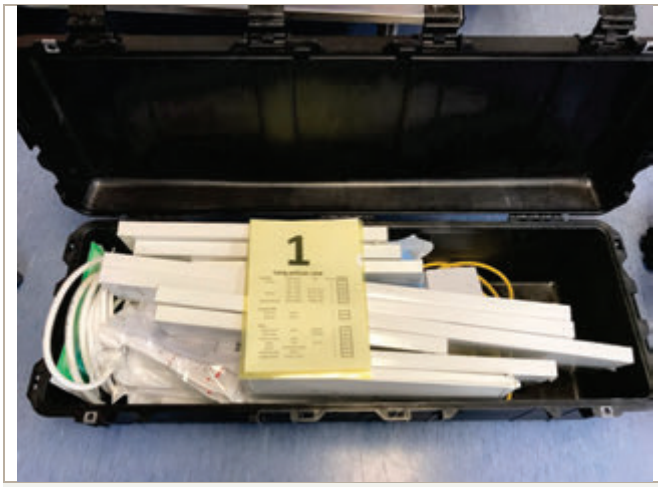
4. Contact Referring Hospital

- Give ETA
- Get any update in patient condition
- **Run through Checklist 2 with them**

5. Equipment Required That Is Not Already in Pelican Boxes:

- Obtain Blue/ Grey Sonosite and place in Pelican Box 3
- Obtain Sonosite Vascular Ultrasound Probe and place in Pelican Box 3
- Obtain Sonosite TOE Probe and Place in Pelican Box 1
- Black battery pack
- iStat
- If VA get perfusion to cut in SVO2 cell

1. Have 4 units of RBC cross matched and packed in chilly bag/bin to accompany patient to Auckland
2. Have platelets available if count < 100
3. Have FFP available if INR > 1.5
4. Free up Right Internal Jugular Vein but leave any cannula in situ. Let the CVICU retrieval team know if there have been any issues/difficulty with Right Internal Jugular Vein Cannulation
5. Establish large bore volume line if none
6. Get large set-up trolley from theatre
7. Organise for a Theatre scrub nurse to be available to assist if possible
8. Sedate and paralyze patient
9. De-prone Patient if applicable
10. Arrange transport for relatives to Auckland (not in air ambulance)
11. Photocopy all notes
12. Get PACS to send all radiology to ADHB PACS
13. Relative(s) available in unit for team for consent & discussion

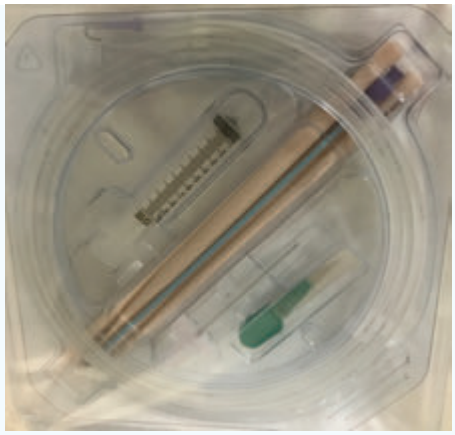
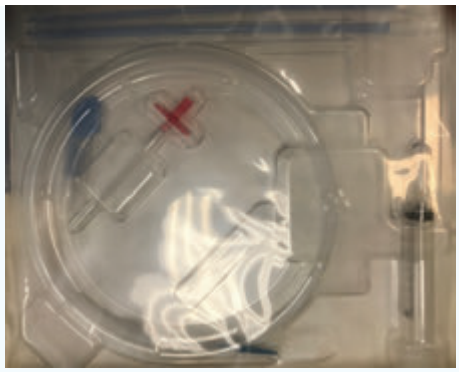


Pelican Box 1

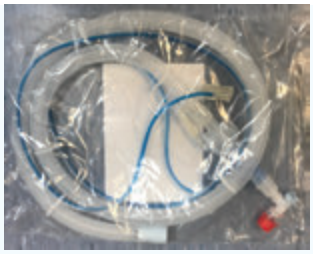
Things to put in box before departing:

- **Sonosite TOE Probe**

Contents		No	Photo if Applicable
Bag A – Main Insertion Kit			
Needles	18G 70mm	2	
	18g 15cm	1	
Wires	0.038 150cm **Merit Medical** InQwire	1	
	0.038 80cm **Intermed Medical**	1	
Dilators	10Fr 12Fr 14Fr 16Fr 18Fr 20Fr 22Fr 24Fr	1 of each	
Syringes	10ml - slip	2	

Contents		No	Photo if Applicable
Bag A1			
Maquet Avalon Vascular Insertion Set	18G Needle Wire – 0.038 210cm Dilators from 10Fr to 30Fr Scalpel #11 blade 10ml syringe		
Bag B – Distal Perfusion Cannula Insertion Kit			
Medtronic Paediatric Line Insertion Set kit	0.025 60cm J wire 18G needle 8Fr/10Fr dilator 12Fr/14Fr dilator #11 scalpel blade 10ml syringe	2	
Cannulae			
Return/ Arterial	17Fr short	1	
	19 Fr short	2	
	21Fr short	1	
Inflow/ Venous	25Fr multistage	1	
	29Fr multistage	1	
Distal Perfusion	Medtronic Biomedicus 8Fr (22.9cm long)	2	

ECMO Retrieval Equipment

Contents		No	Photo if Applicable
Other			
Oxylog Ventilator Circuit		2	
	Spare ECMO Circuit	1	
ECMO Circuit	Spare Rotaflow Pump	1	
	3/8 tubing		
	¼ tubing		
	Vygon 17 G x2		
	Pouch – multitool and gel		
	Yellow extension lead		
2 long Oxygen hoses	Female Star wheel to Male Star wheel	1	
	Female Star wheel to Female Schrader		
2 short oxygen hoses	Male Star wheel to Male Schrader adaptor		
	Male Star Wheel to Male Puritan Bennet adaptor		

Pelican Box 2

Contents		No	Photo if Applicable
Bag C	• Hats • Masks with visor • Masks no visor • 5% Chlorhexidene Scrub Brush		
Bag D	• Disposable Large Gowns x 3		
Bag E	• Gloves • Size 7, 7.5, 8, 8.5		
Bag F **Drapes**	• Universal Pack • Neonatal drape • ¾ Drape sheet • Blue Huck Towel		
Bag G	• Prep Tray • 2% Chorhexidine Alcohol 70%		
Bag H	• Chest Swab • Small Swab		

ECMO Retrieval Equipment

Contents	Photo if Applicable

Sterile Instruments

SET ECMO PERCUTANEOUS

Product Code:	A-CAR071-S
Wash:	ACH No Lube
Outer Packing:	RIGID CONTAINER GENESIS
Sterilization:	AUTOCLAVE

Item Code	Description	Qty	Critical
ACI0664	INSTRUMENT CLIP	1	1
FCP942	FORCEPS - MOSQUITO HALSTED - CVD - 12.7cm - 106-102 - JARIT / 15-080-12 - AS	2	2
NHO166	NEEDLE HOLDER - DEBAKEY - EXTRA LIGHT - 17.8cm - 121-185 - JARIT / 50-2500 - BOSS	1	1
NHO056	NEEDLE HOLDER - MAYO HEGAR - 20.3cm - 121-145 - JARIT	1	1
SCI086	SCISSORS - MAYO - STR - 17cm - 101-220 - JARIT / 50-1830 - BOSS / BC252R - AESCULAP	1	1
CLA056	CLAMP - TOWEL CLIP - LG - 14cm - BH085-01-X - DOWNS / MCK 5.5 MEDCHEM / BF464R - AESCULAP	5	5
CLA141	CLAMP - PRESBYTERIAN OCCLUDING - SML - 16.5cm - 110-150 - JARIT	2	2
FCP1115	FORCEPS - OCCLUDING TUBE JARIT - 20.3cm - 110-159 - JARIT	6	6
FCP256	FORCEPS - SPONGEHOLDER - FOERSTER - SERRATED JAWS - 24cm - 116-107 - JARIT / 15-736-25 - AS	1	1
SCI176	SCISSORS - TUBING - KS-104 - KEY SURGICAL	1	1
FCP1191	FORCEPS - DEBAKEY - STR - 19.7cm x 2mm TIP - 35-1602 - PILLING / 320-111 - JARIT / 13-208-20 - AS	2	2
RET1661	RETRACTOR - WEITLANER - BLUNT - 3 x 4 PRONGS - 20.3cm x 20mm DEEP - 205-161 - JARIT	1	1
	TOTAL INSTRUMENT COUNT:	24	24

Remarks:
- PLACE THE SUCTION TIP IN A STERIPOUCH AS SHOWN ON PHOTO

Red Tub

- Containing “Bags I, J, K and other”

Bag I

- 0 silk sutures
- Preloaded #11 Scalpel Blades

Bag J

- 50ml syringe, Slip Tip
- 20ml syringe, Slip Tip
- Normal Saline 10ml ampoules

Bag K

- Biopatches
- Tegaderm – plain
- Tegaderm – gel

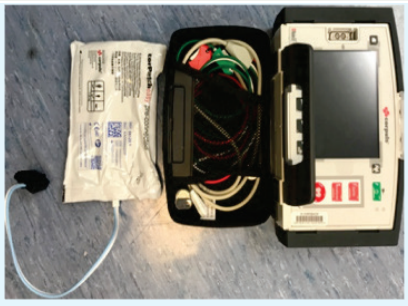
Other

- Site right cover
- Needle safe
- Floseal 5ml

Pelican Box 3

Things to put in box before departing:

- Sonosite (only old blue/silver console fits)
- Vascular U/S probe

Contents	Photo if Applicable
Corpuls defibrillator	
Drager BP cuff	
Pulse Oximeter • Ensure both finger probe and LNC cable present (as depicted in photo)	

ECMO Retrieval Equipment

Contents		Photo if Applicable
ECG	• 6 lead • + green extension	
Blue Draeger case	• containing ETCO2 (including plastic cuvette in its own bag)	
Blue power cable		
Sonosite Power cable		
Draeger Duel Hemo invasive pressure cable		

ECMO Retrieval Equipment

Backpack	Contents	Quantity
Front Compartment	Tubing clamps	4
	Jostra flowmeter cream	
	Snap ties and Tie Gun	Bag
	Allen key multi tool	1
	Hand crank	1
	0 silk sutures ref K834	2
Main Compartment	High flow 3-way taps	2
	3-way taps	2
	1-way taps	4
	Perfusion adapter	4
	Spiggo extentions	4
	Blunt needles	10
	Sharp needles	10
	Boes (sterile)	10
	50ml syringes	2
	30ml syringes	2
	10ml syringes	5
	3ml syringes	5
Main Compartment	Alcohol wipes + blades	5
	Sodium bicarbonate	1
	Heparin 5000iu/ml	1
	Calcium chloride	1
	sodium chloride	10
	Check / Datasheet / Clipboard	
	P148	2
	O2 0-10 Flowmeter with Schroeder + Fly wheel	2
	Green 1/4" Gas line and filter	1
	Blood Filters	2
Main Compartment	3/8 Y Connector	2
	Transfer Pack	2
	Codan Y Set	2
(EXTRAS)	1/4 Tubing Stub (50cm)	2

Other Equipment Required On Retrieval

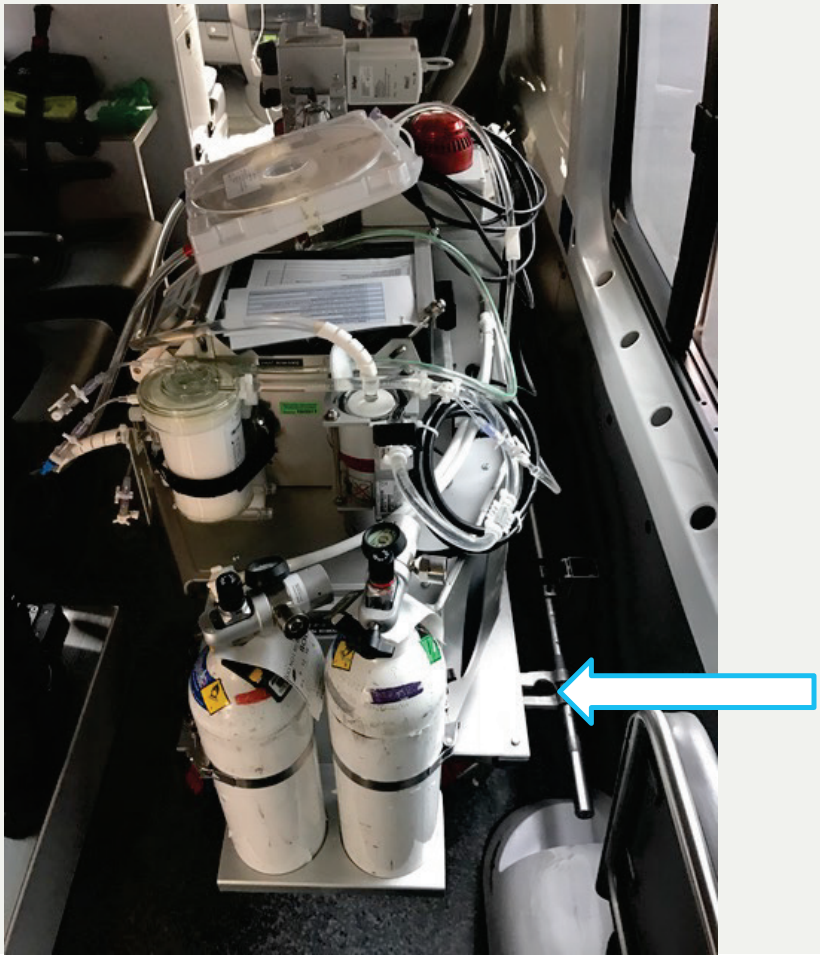
- **Battery Pack**

- **iStat**

Getting the ECMO Trolley Into the Ambulance at Auckland Hospital

This ramp is utilized for getting ECMO trolley into ambulance At ACH.

ECMO trolley is fixed in place with red clamps as shown. The driver will also secure the stretcher with an extra tie-down.

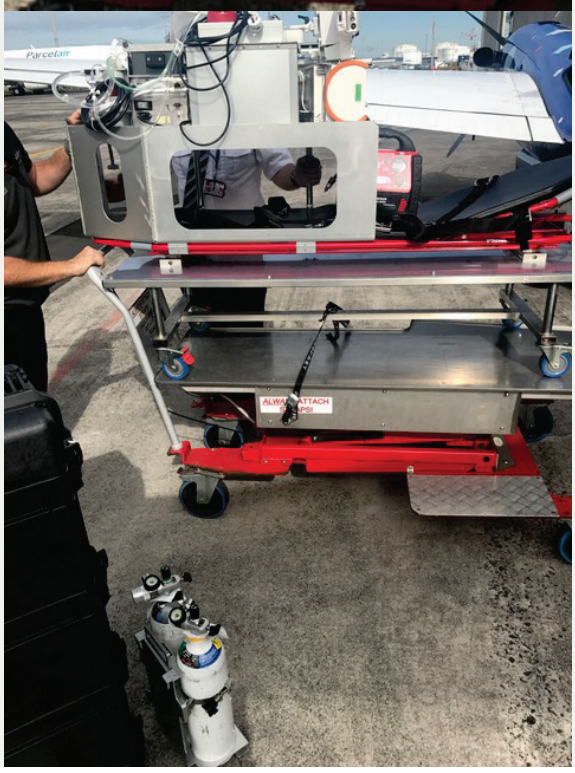


Getting the ECMO Stretcher From the Ambulance Into the Plane at Auckland Airport

ECMO stretcher and trolley exits ambulance onto the patient lifter which is in the hangar at the airport – the flight crew will do this.

ECMO trolley is strapped onto this patient lifter

Patient lifter is used to wheel ECMO trolley over to plane entry



This is the lifeport sliding platform that facilitates transfer of the ECMO stretcher into and out of the plane cabin.

ECMO trolley positioned so that it's leading edge is engaged with the lifeport sliding platform (see further picture below) that extends out of plane cabin entry. Transfer trolley is locked to ensure stability. ECMO stretcher now slides off ECMO trolley, along lifeport sliding platform, and into the plane cabin. At this point, the oxygen bottles need to be removed from the ECMO stretcher and stowed in the cabin separately.

This picture depicts the leading edge engaging with the slit on the lifeport sliding platform

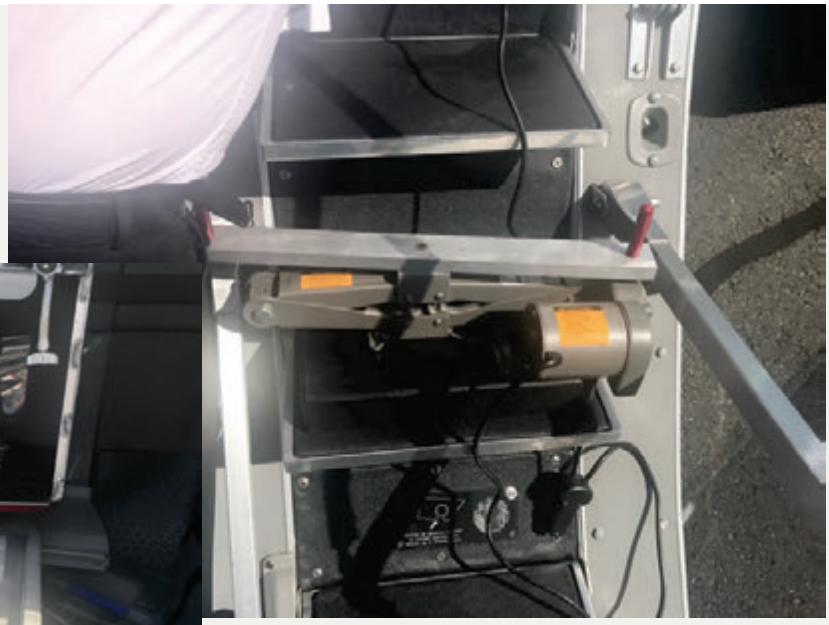
As the ECMO trolley slides into the cabin, it makes a 90 degree turn anticlockwise and is then advanced towards the front of the plane.

ECMO stretcher is advanced to its docking position to the front of the plane. There are two potential docking positions, either in the “for” or “aft” position.

Plane stretcher can be placed back in situ. This provides a base for the long Pelican Case to be stored securely

Getting from the Plane into the Ambulance at Airport Near Referring Hospital

This is the electric jack that allows adjustment of the height of the lifeport sliding platform for transfer of the ECMO stretcher onto the ambulance gurney base



This lifeport sliding platform has a further interface that is connected to it which can then attach to an ambulance gurney. It is fitted into the main lifeport sliding platform as shown

Most ambulances in NZ have Stryker self-loading stretchers which have two parts – the stretcher part (pictured) and the trolley base/ legs/wheels.
N.B. Some ambulances are changing to a different (electric) model.

The stretcher component is removed, leaving the trolley base. A Lifeport carbon fiber interface called a “clip deck” (that is carried in the aircraft) is designed to dock with the base.

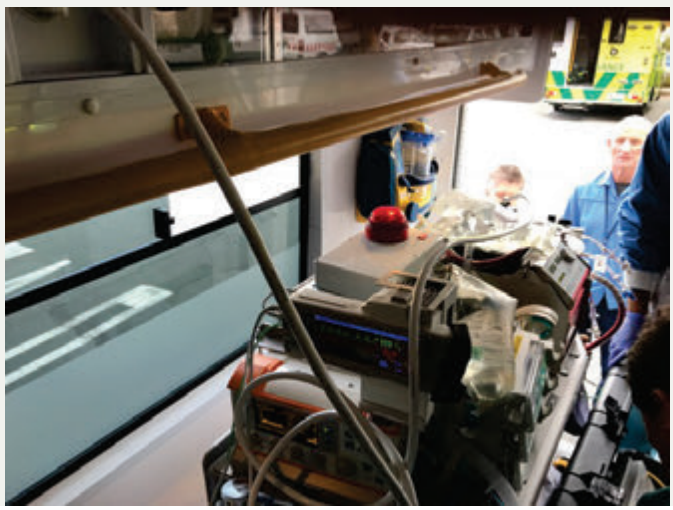
The sliding interlocking connecter slots into the clip deck on the ambulance trolley base to provide a secure connection (see picture alongside) . The ECMO stretcher can then be slid out of the plane cabin and onto the Lifeport clip deck. The ECMO stretcher/ clipdeck /trolley base is then moved into the ambulance for transfer to the referring hospital.

Sliding interlocking connector fastened to gurney base.
Once the ECMO stretcher is attached to the base it stays like that until it returns to the aircraft with the patient

Patient Transfer Onto ECMO Stretcher at Referring Hospital

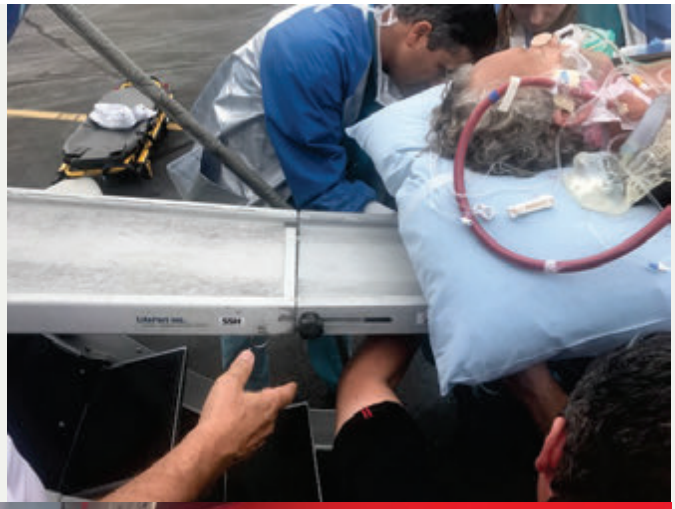
Patient transfer into the ECMO stretcher is facilitated by lowering the side bars (white arrow).
Use a patslide to transfer patient into ECMO stretcher.
Once the patient is on the ECMO trolley resecure the two support legs for the bridge with the pins.

ECMO stretcher remains on ambulance trolley base, and is wheeled to ambulance, and then into ambulance.



Transfer from Ambulance to Plane at Airport Near Referring Hospital

ECMO stretcher then requires transfer back into plane cabin. This is essentially the reverse of getting the ECMO stretcher out of the plane. The ambulance trolley base is fastened to the sliding platform with the interlocking connector.



The sliding platform is resting on the electric jack. The foot end of the ambulance stretcher is partly lowered so that it is aligned with the aircraft ramp

Once the ECMO stretcher is transferred onto the sliding platform, the jack is then used to raise the sliding platform so that it is level with the cabin stretcher platform. At this point the oxygen bottles require removal from the ECMO stretcher. Do this by passing the oxygen extension pipe into the aircraft and connecting it to the base supply and then turning off the cylinder and checking flow. Then disconnect the cylinder and remove them from the foot of the stretcher (these will be stowed in the cabin separately). Following this the ECMO stretcher is slid into the plane cabin. Although Oxygen is available in the aircraft at all times no power is available until the engines have started.

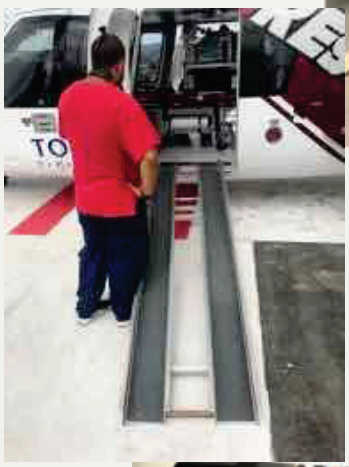
Transfer off plane Into Ambulance at Auckland Airport

Following arrival at Auckland airport, the ECMO stretcher and patient is transferred back onto the initial ECMO trolley, which itself is resting on the patient lifter.
The height is then lowered, and the patient/ ECMO stretcher and patient lifter is transferred to the ambulance.
From there on, the ECMO trolley is used to transfer the ECMO stretcher and patient into/ out of the ambulance and into CVICU

Helicopter Transfer

This is the base that the ECMO stretcher is placed on for helicopter transfers. It is lower, allowing it to fit in the helicopter. Once the ECMO stretcher is transferred onto this base, it remains there throughout the whole ECMO retrieval process.

The stretcher moves in and out of the helicopter on this ramp



The stretcher is secured in the helicopter as shown. The foot end of the stretcher is secured with a locking clip that is fixed to the floor of the helicopter. The head end is secured with a ratchet tie down strap on either side of the trolley.

The power and oxygen outlets are at the head end of the stretcher. Power will not be available until the helicopter engines have started up.

Points of Note about the Power Supply

The only way of powering the ECMO trolley is by the 240V power cable (figure 1). This runs into the box as illustrated and all electrical devices run from this cable (figure 2).
All the electronic devices on the ECMO trolley have their own battery. There is at least 2hrs of battery life within each device when fully charged.
If the ECMO trolley is connected to a 240V power supply, loss of power to the ECMO trolley will be indicated by each of the electrical devices alarming to say that they are now running on battery power.

All of the internal batteries on the ECMO trolley will be fully charged during the time spent cannulating a patient i.e. 2 hrs.
The battery pack/inverter (see figure 3A) takes approximately 3 hrs to charge. The battery pack should provide at least 1.5hrs of extra power to the ECMO trolley. At the time of writing this guideline, there is no cord to allow it to work as an inverter between 12V and 240V. See Figure 3B and 3C for information on charge status of the battery during use.

Power Supply during a Transfer

- **All aircraft have inverters for provision of a 240V supply. Connect main power cable to these during transfer**
  - *The FW aircraft have a single invertor in each stretcher base (so effectively there is a "spare" in the aircraft with 2 stretcher bases)*
  - *The S76 Helicopters have 2 invertors*
  - *On rare occasions the pilots may have to turn off the power to the stretcher bases – if this happens run off batteries as you will be landing soon.*
  - *For all aircraft power is only available once the engines are running.*
- **Most ambulances have inverters for provision of a 240V supply. Connect the main power cable to these during transfer. If 240V supply not available, then plug into the battery pack. See Figure 3D for instructions on how to do this.**
- **When transferring between transport modes, or between ambulance and hospital, it is safe to rely solely on internal batteries i.e. not to have trolley plugged in to battery pack.**
- **If the ECMO pump runs out of battery and there is no power supply available, there is a hand crank in the red back pack. This is fitted to the ECMO trolley as shown in Figure 4.**

Figure 1

Figure 2

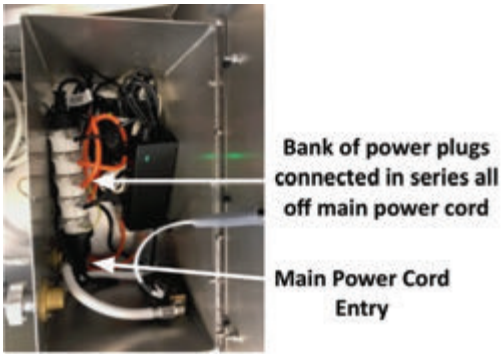


Figure 3A

Fig 3B

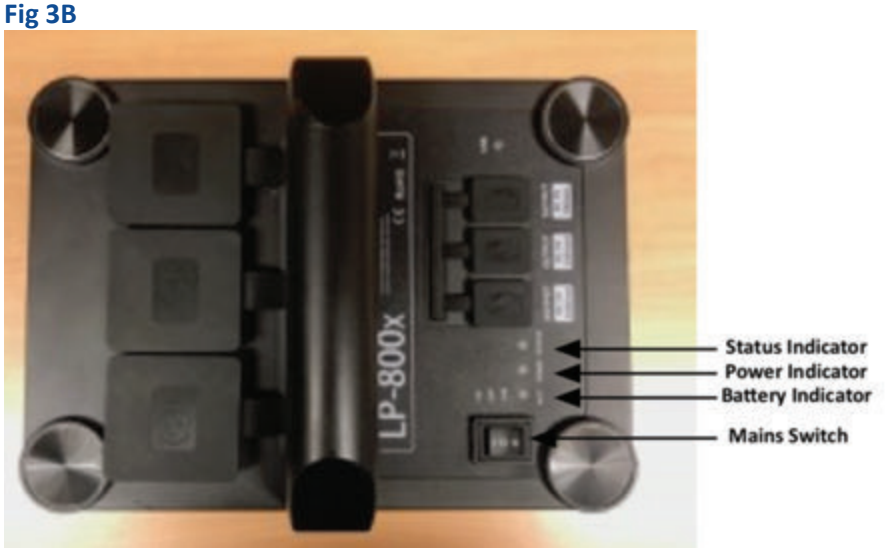


Figure 3 C

LED Indicators:

Battery Indicator
(indicating battery level)

Battery LED	Battery Voltage
Red, blinking	< 10.7 or > 15.4V
Red	10.7 – 11.2V
Orange	11.2 – 12.3V
Green	12.3 – 14.6V
Orange, blinking	14.6 – 15.4V

Power Indicator
(displaying power output level)

Power LED	Output Power
Off	0 – 35W
Green	35W – 230W
Orange	230W – 520W
Red	520W - 670W
Red, blinking	> 670W

Status Indicator

Status LED	Working Status
Red	No
Green	Yes

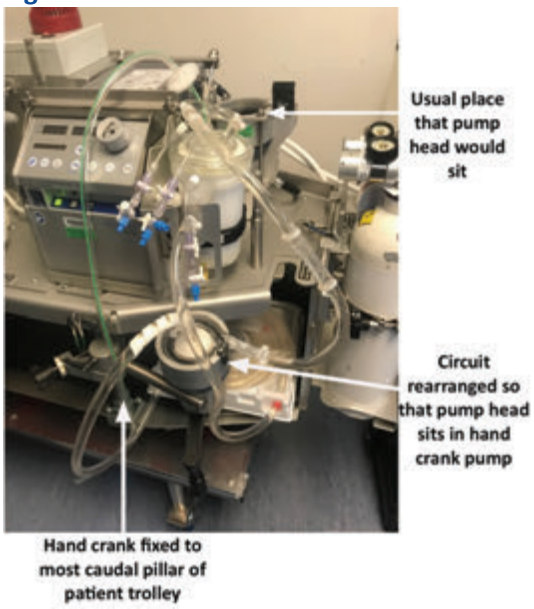
Figure 3D: Process for Connecting ECMO Trolley to Battery/ Invertor

Ensure the Main Switch is turned to OFF

Connect Trolley to AC Output

Turn Mains Switch to ON
Note green battery light indicating full charge

Figure 4



Points of Note about the Oxygen Supply:

There are 2 inputs (Figure 5) that allow switching between cylinder and wall supply without interrupting the oxygen supply.
There are non-return valves between the 2 oxygen hoses, which means that there won't be a leak if one isn't connected.
It is best practice that when connected to a cylinder that you aren't using, the cylinder should be turned off to prevent unintended use of the cylinder.

The oxygen supplies:

- **The ECMO sweep gas**
- **The Minute Ventilation (of oxygen) being given to the patient**
- **The Ventilator driving gas**
- **There is 450L of oxygen in each of the two cylinders on the ECMO trolley when they are full.**
- **Overall Oxygen Consumption of ECMO Trolley will be:**
  - *ECMO sweep gas (L/min)*
  - *Minute Ventilation (L/min) X FiO2 (this actually overcalls the oxygen used as it doesn't account for the oxygen in the air)*
  - *Driving Gas (average 0.5 L/min)*

Oxygen Connection Fittings:

- **The ECMO trolley has starwheel adaptors (Figure 5).**
- **Many regulators on oxygen cylinders in the country use the same star wheel adaptor and the two regulators on the cylinders on the ECMO trolley have these. This means that you can always run off an oxygen cylinder in a hospital, using one of our regulators if required, even if you can't find the wall adaptor for that particular hospital.**
- **Connection to oxygen supply within ambulance, plane and helicopter is via starwheel fittings sometimes with bayonet fitting adaptors (which are carried by perfusion and a set live on each of the FW aircraft), and we use the long Female Star wheel to Male Star wheel adaptor for this (see figure 6A)**
- **The wall supply for different hospitals around the country use different connectors. Within the**
- **transport equipment are different adaptor hoses for this (Figures 6C and 6D).**

Figure 5

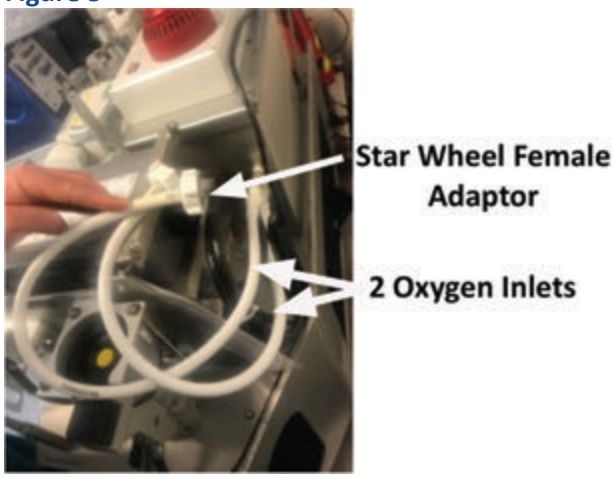


Figure 6A
Female Star wheel to Male Star wheel

Figure 6B
Female Star wheel to Female Schrader

Figure 6C
Male Star wheel to Male Schrader adaptor

Figure 6D
Male Star Wheel to Male Puritan Bennet adaptor

Points to note about the Oxygen Supply Failure Alarm (Fig 7):

- **This is a pressure switch at the manifold where the two oxygen pipes join into one (Figure 8). If the O2 supply pressure at this point drops, the Oxygen Supply Failure Alarm will sound.**
- **The switch to turn this on is on the front panel, as indicated by the red arrow in Figure 7**
- **It has a siren component as well as a red flashing light for when ambient noise levels are high.**

If you have evidence of no oxygen delivery to the ECMO oxygenator (e.g. dark blood in the return cannula) but the oxygen failure alarm is not sounding then:

- **Check the oxygen flow meter (Figure 8B). It is possible that the tubing from this to the oxygenator is either kinked/obstructed (O2 flowmeter will indicate no/low flow) or disconnected.**
- **Check the oxygen failure alarm is turned on**

Figure 7

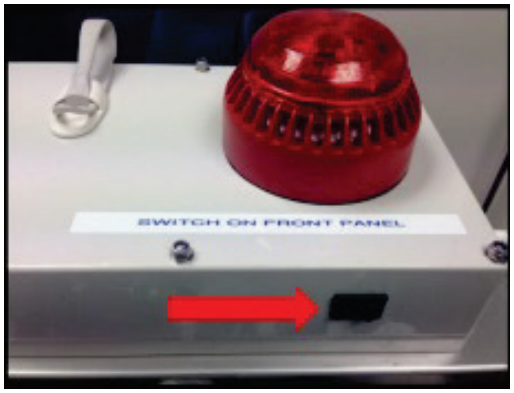


Figure 8A

Figure 8B

Step By Step Guide To Managing Oxygen and Power During an ECMO Transfer

On outward bound trip

1. Ensure battery/invertor pack is charged. Turn on - I down (not II) (Red arrow Figure 9). Green light should come on. If not green (orange or red) will need to be plugged in on arrival at patient's bed space (figure 10 – shows battery pack charging – white arrow). We do not routinely take the power charger with us on retrievals.
2. Ensure all devices (Pump unit, infusion pumps and ventilator) are also fully charged. Pump unit will indicate battery at 25.8 or more (Figure 11)
3. Ensure two full O_2 bottles on stretcher
4. Ensure two full D O_2 bottles in the vehicle
5. Ensure hand crank is operational

Arrival at bed space

1. Plug in stretcher to 240V supply (using plug at back of pump – Fig 12)
2. Ensure ECMO pump unit using wall electricity (white arrow – Fig 13)
3. Plug in to wall oxygen, with one oxygen pipe, using perfusion's adaptors/extensions (red arrow – Fig 14, see also Figs 6A to 6D). Ensure other pipe attached to O_2 bottle and that this bottle is turned off
4. Open oxygen rotameter and ensure have O_2 flow (figure 8B)
5. Turn on O_2 failure alarm (red arrow figure 7)
6. Check function of O_2 failure alarm by unplugging wall O_2 now (with oxygen flowing through rotameter) – ear plugs!
7. Set up ECMO circuit and get patient on

Figure 9

Figure 10

Figure 11

Figure 12

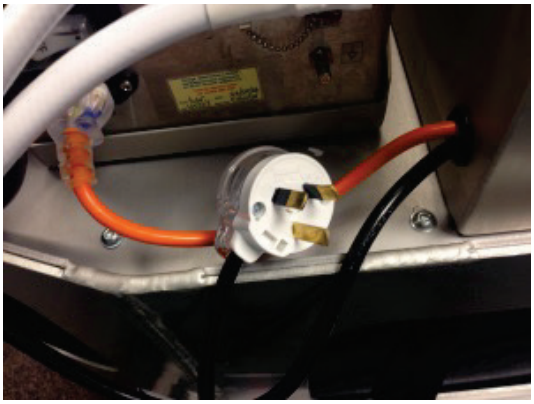


Figure 13

Figure 14

Ready to Transport

1. Place patient on transport ventilator on 'rest settings' (it will likely alarm low tidal volumes constantly)
2. Check function of O_2 failure alarm by unplugging wall O_2 and then turning on bottle O2 valve as soon as alarm sounds
3. After disconnecting wall O_2 hose it is easiest to leave this unconnected with the extension left on. It is then easily available to connect up to the oxygen supply when getting in to the next vehicle.
4. Disconnect 240 V power cable and ensure all machines are working on own batteries
5. MOVE TO AND BOARD VEHICLE
6. Plug in trolley to vehicle's 240 V source if available
7. If 240V source not available, use invertor/battery pack. This should last 1 hour 30 minutes (ensure hand crank is immediately available if on battery pack). See figure 3D for instructions on how to do this. Use of the invertor/ battery pack is not required when transitioning between vehicles or between hospital and vehicle. At the time of writing this guideline, there is no cord to facilitate inverting a 12V supply to 240V using the invertor/battery pack.
8. Ensure ECMO pump indicates it is using external power source (white arrow Figure 13).
9. Connect to Vehicle O2 supply using oxygen extension hose (starwheel to starwheel).
10. Now ensure O_2 bottles are both off
11. Check O_2 failure alarm is on (red arrow figure 7)

VV ECMO Cannulation Checklist

Preparation for Cannulation:

- **Orientation to the ICU**
  - Introductions to ICU staff
  - Explanation of the procedure to ICU staff
  - Role allocation (see below)
  - Explanation to scrub nurse

- **Patient assessment:**
  - Height and weight consistent with capabilities of ECMO trolley (if ECMO transport planned).
  - Decide cannulae size
  - History consistent with potentially reversible condition
  - Review of medical therapies including:
    - *Ventilation parameters and blood gases*
    - *Circulatory support*
    - *Microbiology and antimicrobial therapy*
    - *Metabolic state and degree of acidosis*
    - *Coagulation and platelets*
    - *Previous TTE or TOE studies*
  - Fill out ECLS Registry Form
  - Blood cross matched and 2 units available for transfer back to CVICU

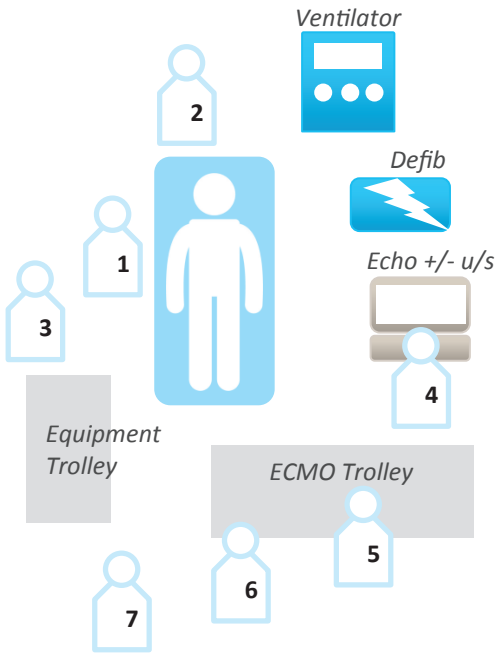
- **Family**
  - Authority to treat form to be completed
  - Explanation provided to include:
    - *ECMO as a supportive therapy*
    - *Potential time frame of support*
    - *Outcomes including failure for lung function to improve and discontinuation of ECMO for futility*
    - *Potential complications, including circuit complications, risk of transport, bleeding complications (including potential for cerebral haemorrhage)*
  - Explanation that alternative therapies (e.g., vitamin C) will not be offered

Preparation of Bed Space

- **Set up portable TOE +/- Separate ultrasound machine for vascular access**
- **Set up sterile trolleys (see below)**
- **Remove unnecessary clutter from bed space**

Allocate Roles:

- **Usually 2 proceduralists**
- **Usually 1 scrub nurse**
- **1-2 Nurses in a running/ support role (e.g. transport nurse and one nurse from home unit).**
- **A hands-off resuscitation doctor from referring unit is ideal to monitor patient status during cannulation**
- **Perfusionist**



1. *Femoral drainage cannula proceduralist*
2. *RIJ return cannula proceduralist*
3. *Scrub nurse*
4. *Runner*
5. *Perfusionist*
6. *Hands-off resuscitation doctor*
7. *Runner*

Prepare Patient

- Ensure appropriate monitoring (including capnography)
- Large bore IV access
- Ensure patient adequately anaesthetized and paralysed
- Insert TOE probe
- Apply defibrillation pads
- Cannulation sites exposed – shave sites if required. Consider confirming adequacy of target vessels
- Ensure RIJ vein is free or the CVL in the RIJ is free
- If cannulation is occurring in CVICU, ensure patient is on appropriate mattress
- Perform pre-cannulation TOE examination, including identifying the IVC

Prepare Equipment

- Open onto Equipment Trolley,

Initially:

- Bag F with drapes, and additional fenestrated (neonatal) drape for RIJ cannulation
- Bag G for prepping the patient
  - *Prep Tray*
  - *2% chlorhexidine in alcohol 70%*
- Sterile instrument set
- Bag A contents
  - *Cannulation needle/ 0.038 wires (150cm and 80cm)/ dilators*
- Ultrasound probe cover

Subsequently, during the procedure further equipment will be opened:

- Cannulae
- Equipment for connecting cannulae to ECMO circuit
  - *Shears (in with instruments)*
  - *50ml syringe, Slip Tip*
  - *20ml syringe, Slip Tip*
  - *Normal Saline 10ml ampoules*
- Contents of red tub will be required for cannula fixation and dressing

Prepare Medication/ Fluids/ Blood Products

- Anaesthesia, analgesia and neuromuscular blockade
- Identify a convenient site to administer medications
- Discuss plan for administration of:
- Heparin: 1000units administered (if not contraindicated) prior to insertion of cannulae (typically once venous wires are in situ)
- Calcium chloride
- Dilute adrenaline available to bolus if necessary
- IV fluid attached and ready to infuse
- Blood available
- FFP (INR>1.5), Plts (<100)

Procedure:

- Asepsis:
  - Glove gown mask
  - Chlorhexidine wash to cannulation sites
- Drapes

  Femoral cannulation site:
  - Blue Huck Towel covering groin
  - Side drape closest to proceduralist
  - Other side drape contralateral to proceduralist
  - Bottom drape and top drape to complete sterile field

  Internal Jugular cannulation site:
  - Use fenestrated (neonatal) drape (drape with central aperture)

Cannula Insertion

Right Internal Jugular Return Cannula Insertion:

- If rewiring an existing line, clean thoroughly with chlorhexidine wash.
- Insert 80cm 0.038wire into right internal jugular via percutaneous puncture or existing line
- Visualise correct wire placement with ultrasound
- Sequentially dilate over wire

- Advance cannula with introducer into the RIJ to the ridge (on cannula)
- Remove wire and occlude introducer hole with finger
- Remove introducer whilst assistant clamps the line as it is removed
- Ensure an occlusive bung is screwed firmly onto access port of return cannula
- Connect to circuit and flush cannula from pump

Femoral Vein Drainage Cannula Insertion

- Insert 0.038 150cm wire into common femoral vein via percutaneous puncture or existing line
- Confirm placement of the wire within the IVC with TOE
- Sequentially dilate over wire
- Insert multistage 55cm drainage cannula loaded with introducer into common femoral vein
- Withdraw introducer by 5cm once cannula has been inserted 10cm after last drainage hole
- Use TOE to site the tip of the cannula in the intrahepatic IVC, at the level of the hepatic veins
- Remove wire and occlude hole in introducer with finger
- Remove introducer whilst assistant clamps the line as it is removed

Connection of Cannulae to Circuit

- Cut ECMO circuit
  - Take sterile primed ECMO circuit from packaging and place in sterile field
  - Clamp and cut ECMO circuit after consideration of length of tubing required
  - Remove curl from lines
  - Align “blue” line with drainage cannula; align red tubing with return cannula
- Connect Primed ECMO Circuit to Cannulae
  - Expel air as circuit is attached to cannula by syringing in crystalloid during connection
  - Blue sticker tubing attached to drainage cannula
  - Red sticker tubing attached to return cannula

Pre Initiation of ECMO Checklist

- Gas connected and Rotameter set to 6L/min
- FiO2 set to 1
- RPMs at 800/min or more
- Perfusion flush bag clamped
- Emergency drugs available and port available to inject these through
- Calcium
- Adrenaline

Initiation of ECMO:

- Remove drainage and return line clamps
- Commence ECMO flows at 1L/min and slowly increase RPMs to full flow (4-5L/min) as haemodynamic state allows.
- Confirm adequate oxygenation (return line bright red)
- Confirm lack of recirculation (SpO2 > 85% when on full flows, drainage cannula dark red)

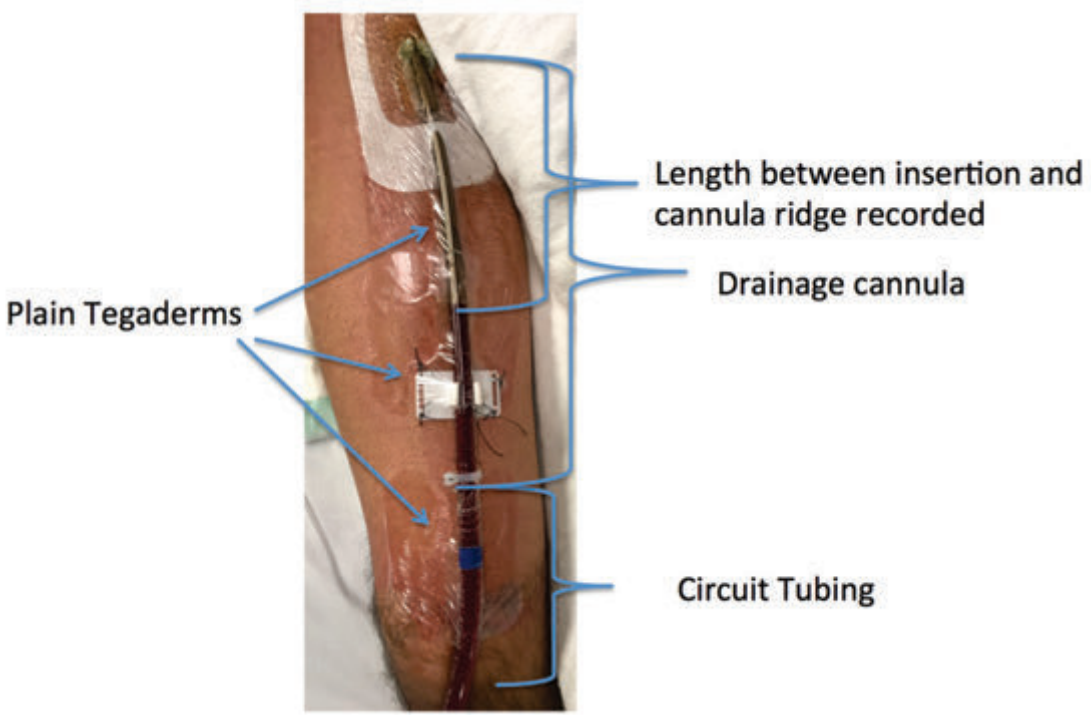
ECMO Checks and Settings Following Initiation of ECMO

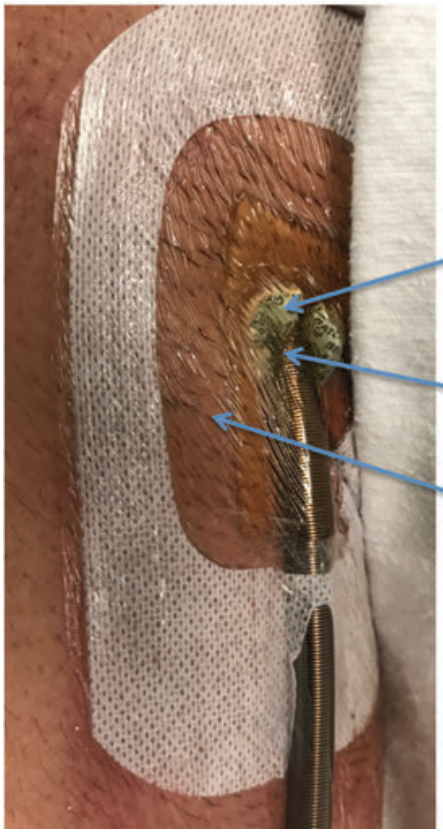
- Ensure Flow Calibrated
- Ensure water lines are connected to water bath
- Set high/low flow alarms
- Check stopcocks on all ports
- Ensure spare non-toothed clamps available

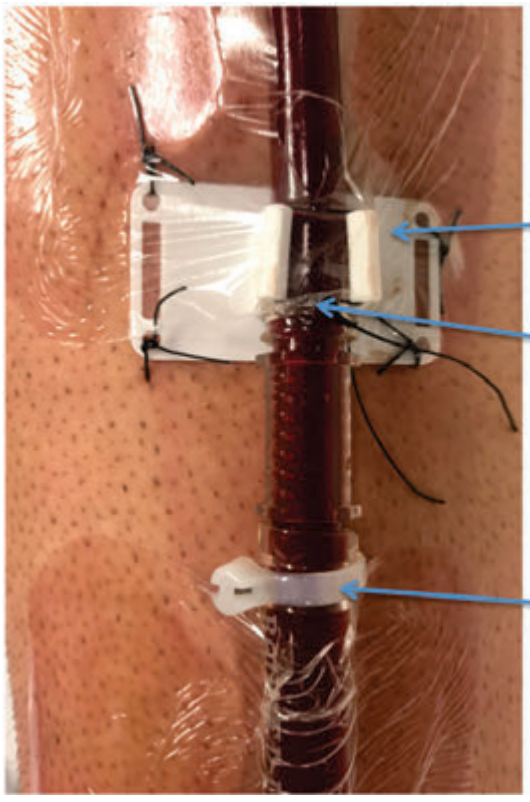
Following Establishment of ECMO

Cannula fixation

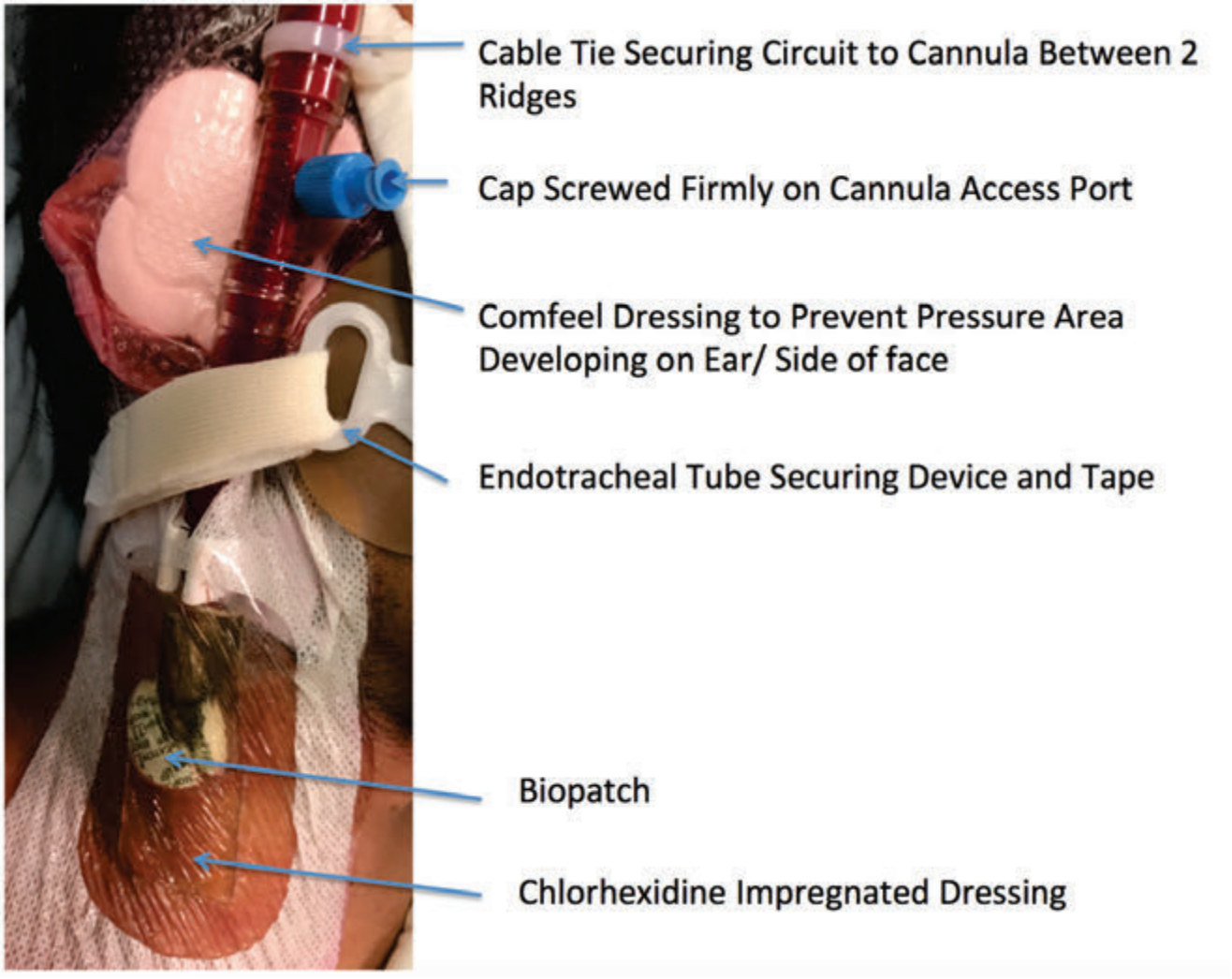
- **Femoral cannula**
  - Biopatch around cannula (orientated so that blue surface with writing is facing out)
  - Holding suture approximately 1cm from puncture site
  - Use suture to provide 4 Point fixation of white plastic skin anchor
  - Secure cannula within skin anchor with suture
  - If cannula is not fully inserted note length of cannula between skin and cannula ridge
  - Apply cable tie to secure circuit tubing to cannula
  - Apply Chlorhexidine Impregnated Dressing
  - Apply 3 tegaderms to length of cannula in contact with thigh




Biopatch
Anchoring suture
Chlorhexidine Impregnated Dressing


Plastic Skin Anchor with 4 point fixation into skin
Suture to secure cannula in Plastic Skin Anchor
Cable Tie securing Circuit Tubing to Cannula between 1st and 2nd ridge on Cannula

- **Return IJ cannula**
  - Biopatch around cannula (orientated so that blue surface with writing is facing out)
  - Holding suture at cannula ridge or 1cm from puncture site
  - Suture in white plastic skin anchor if this can be applied easily and away from the ear. Secure cannula within skin anchor with suture
  - Apply cable ties to circuit join.
  - **During cannula fixation, ensure that the cannula access port and cable tie join is orientated away from the patient to avoid pressure areas**
  - Apply chlorhexidine impregnated dressing
  - Apply square tegaderm fixing return cannula to shoulder



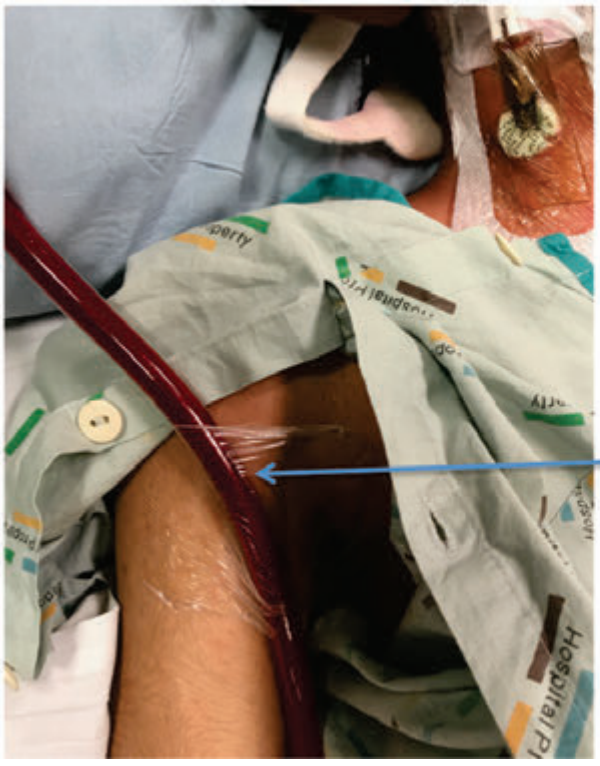
Suture to secure cannula in Plastic Skin Anchor

Plastic Skin Anchor, variably positioned depending on relative position of Cannula and Ear of patient

Holding Suture near entry site

Cannula usually inserted to ridge

Biopatch



Tegaderm providing point of fixation of return limb of circuit to patient's right shoulder

Transfer patient to Trolley

- **Patient transfer into the ECMO stretcher is facilitated by lowering the side bars of the ECMO trolley**
- **Allocate tasks**
  - One person to airway
  - One person to RIJ cannula
  - One person to Femoral cannula
- **Perfusionist to monitor slack on the lines**
- **Use a patslide to transfer the patient into the ECMO stretcher.**

Predeparture Checklist

- **Ambulance staff present and ready to transfer to airport/ helipad**
- **Pilots notified that we are now en route to airport**
- **Airway secure**
- **Rest ventilator settings**
  - PCV, PIP 10cmH2O, PEEP 10cmH2O, FiO2 0.4, RR 10
- **All monitoring connected**
  - Pulse oximeter, preferably on right arm for accessibility during transfer
  - ECG
  - Arterial line zeroed and transducer securely fixed to shoulder
  - Capnography
- **ABG performed post going on ECMO**
- **Infusions running and clamps/3 way taps open**
  - Propofol
  - Vasoactives if needed
  - Spare lumens for further medication administration
- **1000ml of crystalloid attached via giving set to a volume line**
- **Patient recently paralysed**
- **Spare medications**
  - Neuromuscular blocker
  - Adrenaline 1:10000
  - Flushes
  - Propofol syringe
  - Spare vasoactive
- **Blood for transfer**
- **Patient notes**
- **ECLS form filled out**

Following Transfer to CVICU

- **Transfer patient to CVICU bed with air mattress**
- **Transfer ECMO circuit to Bedside ECMO stand**
  - 3 people to facilitate this
    - *one person to hold oxygenator (there isn't enough length on circuit to put this in the oxygenator holder)*
    - *one person to transfer pump*
    - *one person to man the controls*
  - The person in charge of the pump clamps the drainage and return limbs of the circuit, transfers the pump to the pump mount on the bedside circuit, then releases the clamps, and ECMO flows increased.
  - Then place oxygenator in its holder
- **Ensure Cannulae are secured to bed**
- **CXR once stable**

CVICU VA ECMO Cannulation Checklist

Key differences with VA compared to VV cannulation:

- **Preparation:**
  - Rule out significant Aortic Regurgitation on TOE.
  - Arterial line in right arm is preferable
  - RIJ CVL can continue to be used
  - SVO2 cell cut in to ECMO circuit
  - 5000 units of heparin, as opposed to 1000units
- **Procedure**
  - Distal perfusion cannula needed
  - High flow 3 way tap to be applied to arterial return cannula following insertion and flushed
  - Tip of venous drainage cannula should sit at SVC/ RA junction
- **Post Institution of ECMO**
  - Maintain adequate lung ventilation
  - Monitor for differential hypoxaemia

Preparation for cannulation:

- **Orientation to the ICU**
  - Introductions to ICU staff
  - Explanation of the procedure to ICU staff
  - Role allocation (see below)
  - Explanation of procedure to scrub nurse
- **Patient assessment:**
  - Height and weight consistent with capabilities of ECMO trolley if ECMO transport planned
  - Decide cannulae size (See ECMO Cannulae and Circuit Document):
    - *Arterial cannula: Generally 19 or 21 Fr*
    - *Venous cannula: Generally 25 or 29 Fr multi-hole*
- **History consistent with potentially reversible condition (See ECMO Indications and Contraindications Document)**
- **Review of medical therapies including:**
  - Ventilation parameters and blood gases
  - Circulatory support
  - Microbiology and antimicrobial therapy
  - Metabolic state and degree of acidosis
  - Haemoglobin, coagulation tests and platelet count
  - Previous TTE or TOE studies
- **Fill out ECLS Registry Form**
- **Blood cross matched and 2 units available for transfer back to CVICU**
- **Family**
  - Authority to treat form to be completed
  - Explanation provided to include:
    - *ECMO as a supportive therapy*
    - *Potential time frame of support*
    - *Outcomes including failure for heart function to improve and discontinuation of ECMO for futility*
    - *Potential complications, including circuit complications, risk of transport, bleeding complications (including potential for cerebral haemorrhage*
    - *Explanation that alternative therapies (e.g., high dose vitamin C) will not be offered*

Preparation of Bed Space

- **Set up portable TOE +/- Separate ultrasound machine for vascular access if possible**
- **Set up sterile trolleys (see below)**
- **Remove unnecessary clutter from bed space**

Allocate Roles:

- **Two proceduralists**
- **One scrub nurse**
- **One to two nurses in a running/ support role (e.g. transport nurse and one nurse from home unit). Transport nurse can also use cannulation period to make up infusions**
- **A hands-off resuscitation doctor from referring unit is ideal to monitor patient status during cannulation and administer resuscitation drugs as needed**
- **+/- Person to perform TOE to guide cannulation (may need to be part of the role of the hands-off resuscitation doctor)**
- **Perfusionist**

Prepare Patient

- **Ensure appropriate monitoring (including capnography)**
- **Arterial line in right arm is preferable**
- **Large bore IV access**
- **Ensure patient adequately anaesthetized and paralysed**
- **Insert TOE probe and perform an echocardiogram. Confirm absence of significant aortic regurgitation**
- **Apply defibrillation pads**
- **Cannulation sites exposed**
- **Preferably venous and arterial cannulation sites in contralateral femoral vessels**
- **Shave sites if required**
- **Consider confirming adequacy of target vessels with ultrasound prior to prepping and draping**
- **If cannulation is occurring in CVICU, ensure patient is on appropriate mattress**

Prepare Equipment

- **ECMO Circuit**
  - Ensure SVO2 cell cut into circuit
- **Open onto Equipment Trolley**

Initially:

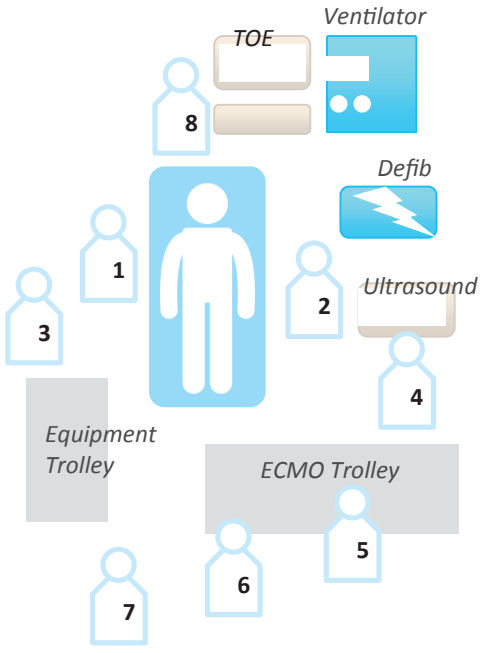
- Bag F with Drapes.
- Bag G for prepping the patient
  - *Prep Tray*
  - *2% chlorhexidine in alcohol 70%*
- Sterile instrument set
- Bag A contents
  - *Cannulation needle/ 0*.038 wires (150cm and 80cm)/ dilators
- Bag B – Distal Perfusion Cannula Insertion Kit
  - *Medtronic Paediatric Line Insertion Set*
  - *J – wire 0.025 mm*
  - *Echogenic Needles if needed*
- Ultrasound probe cover

Subsequently, during the procedure further equipment will be required:

- **Cannulae**
  - Equipment for connecting cannulae to ECMO circuit
    - *Shears x 4 (plus one for Perfusionist)*
    - *50ml syringe (leur slip)*
    - *20ml syringe, (leur slip)*
    - *Normal Saline 10ml ampoules x 5.*
  - Contents of red tub will be required for cannula fixation and dressing

Prepare Medication/ Fluids/ Blood Products

- **Anaesthesia, analgesia and neuromuscular blockade**
- **Identify a convenient site to administer medications**
- **Discuss plan for administration of:**
  - Heparin: 5000units administered (if not contraindicated) prior to insertion of cannulae (typically once wires are in situ)
  - Calcium chloride
  - Adrenaline (10 mls of 10 mcg/mL + 9 mls 100 mcg/mL)
- **IV fluid attached and ready to infuse**
- **Blood available**
- **FFP (if INR>1.5), Platelets (if platelet count <100) (Note: in an emergency there is no requirement to wait for these results)**



1. *Femoral return cannula and distal perfusion cannula proceduralist*
2. *Femoral drainage cannula proceduralist*
3. *Scrub nurse*
4. *Runner*
5. *Perfusionist*
6. *Hands off resuscitation doctor*
7. *Runner*
8. *TOE proceduralist*

Procedure:

- **Asepsis:**
  - Glove, gown, mask
  - Chlorhexidine wash to cannulation sites
- **Drapes for Femoral cannulation sites:**
  - Blue Huck Towel covering groin
  - Side drape closest to proceduralist
  - Other side drape contralateral to proceduralist
  - Bottom drape and top drape to complete sterile field

Cannula Insertion

Points of Note

- **Configuration of cannulae**
  - Ideally the drainage and return cannulas are placed in contralateral groins.
  - Ideally, right femoral vein used for venous drainage cannula
  - Ipsilateral placement is fine if needed however.
- **Distal Perfusion CannulaTiming of Insertion**
  - Ideally, the wire for this is inserted **prior** to siting the femoral artery return cannula, unless emergent cannulation required
  - If ECMO cannulation is being performed emergently, or if placement of the distal perfusion cannula is difficult, it can be inserted by a vascular surgeon via formal cutdown once back in CVICU. If this is the case, consider using a smaller return cannula (eg 17 French).

Distal Perfusion Cannula Insertion

- **Use ultrasound to identify the superficial femoral artery (SFA) at the level of the upper or mid thigh**
- **Place wire in SFA (direction of insertion is caudal) and visualize wire within SFA for distal perfusion cannula**
- **Place wire in common femoral artery for return cannula (direction of insertion is cranial)**
- **Insert SFA cannula/introducer. A skin incision is strongly recommended prior to this to facilitate dilation over the small caliber wire and prevention of the wire kinking.**
- **Note: both femoral arterial wires should be placed and confirmed before any cannulation**
- **Once inserted, flush with saline.**
- **To connect the distal perfusion cannula to the ECMO circuit:**
  - Screw perfusion adaptor onto 3-way tap
  - ¼ tubing is then used to run from the perfusion adaptor onto the distal perfusion cannula

Arterial Return Cannula Insertion

- **Insert 80cm 0.038 wire into common femoral artery via percutaneous puncture**
  - Visualise wire in descending aorta with TOE
- **Place cannula using seldinger technique and serial dilatation.**
- **Remove introducer whilst assistant clamps the cannula as it is removed**
- **Place a high flow 3 way tap on the arterial cannula for reperfusion cannula and flush.**
  - If SFA cannula not inserted prior to femoral artery cannula, it is still best to place this three way tap on the return cannula at this point.

Venous Drainage Cannula Insertion

- **Insert 150cm 0.038 wire into common femoral vein and try to get wire into SVC under TOE guidance**
- **Place cannla using seldinger technique and serial dilatation.**
- **Insert multistage drainage cannula loaded with introducer into common femoral vein**
  - Withdraw introducer by 5cm once cannula has been inserted 10cm after last drainage hole to avoid atrial perforation
- **Use TOE to site the tip of the cannula in the SVC, just proximal to the SVC/RA junction**
- **Withdraw wire and put back on wire holder, and occlude hole in introducer**
- **Get clamp ready**
- **Withdraw introducer and clamp cannula**

Connection of Cannulae to Circuit

- **Cut primed ECMO circuit**
  - Take sterile primed ECMO circuit from packaging and place in sterile field
  - Clamp and cut ECMO circuit after consideration of length of tubing required
  - Align blue end with venous cannula and red end with arterial cannula
  - Stretch tubing to remove 'memory' and reduce coiling
- **Connect Primed ECMO Circuit to Cannulas**
  - Expel air as circuit is attached to cannula by syringing in crystalloid during connection
- **Blue sticker tubing attached to drainage cannula**
- **Red sticker tubing attached to return cannula**

Pre-initiation of ECMO Checklist

- **Gas connected and Rotameter set to 6L/min**
- **FiO2 set to 1**
- **RPMs at 800/min or more**
- **Perfusion flush bag clamped**
- **Emergency drugs available and port available to inject these through**
  - **Calcium**
  - **Adrenaline**

Initiation of ECMO:

- **Remove drainage and return line clamps**
- **Commence ECMO flows at 1L/min and slowly increase RPMs to full flow (4-5L/min) as haemodynamic state allows.**
- **Confirm adequate oxygenation with colour differential between drainage and return lines**

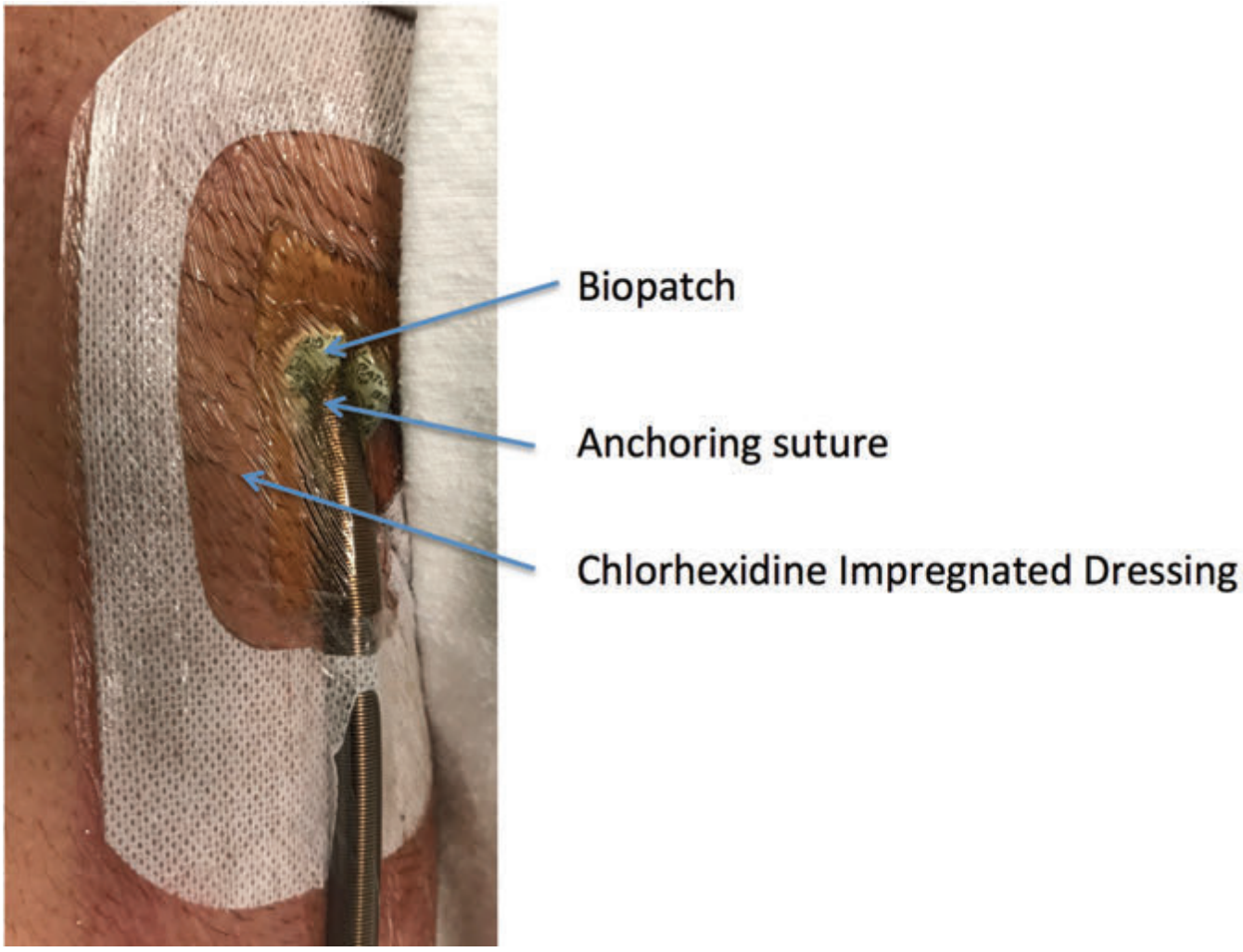
ECMO Settings Following Initiation of ECMO

- **Ensure Flow Calibrated**
- **Ensure water lines are connected to water bath**
- **Set high/low flow alarms**
- **Check stopcocks on all ports**
- **Ensure spare non-toothed clamps available**

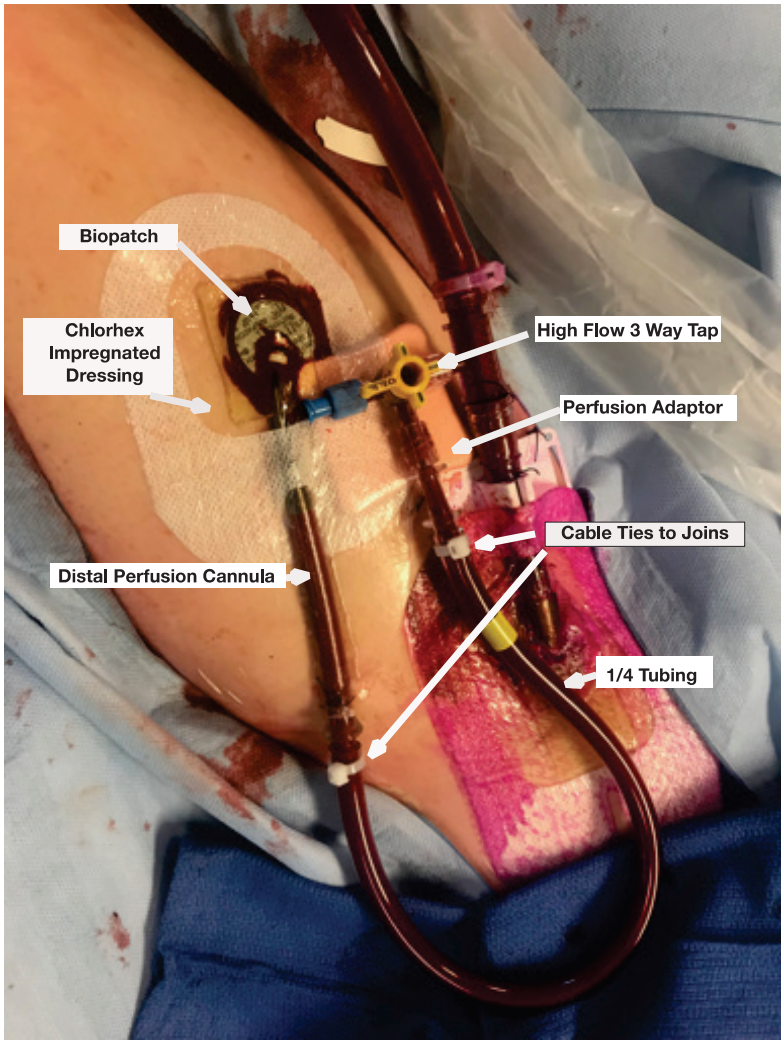
Following Establishment of ECMO

Cannula fixation

- **Femoral drainage and return cannulae**
  - Biopatch around cannula (orientated so that blue surface with writing is facing out)
  - Holding suture approximately 1cm from puncture site
  - Ensure arterial cannula is inserted up to ridge
  - Suture in white plastic skin anchor, and suture this closed
  - Apply cable tie to secure circuit to cannula
  - Apply dressings
  - Apply 3 tegaderms to length of cannula in contact with thigh



- **Distal Perfusion cannula**
  - Biopatch around cannula
  - Holding suture at cannula ridge or 1cm from puncture site
  - Suture in to prevent cannula working its way out
  - Apply dressings



Post Procedure Echocardiogram

- **Check that the left ventricle is adequately decompressed, and that there is not significant aortic or mitral regurgitation**
- **Ideally there will be some LV ejection, with the aortic valve opening at least every 2-3 cardiac cycles**
- **If no ejection consider increasing inotropy**

Transfer patient to the ECMO Trolley

- **Patient transfer into the ECMO stretcher is facilitated by lowering the side bars of the ECMO trolley**
- **Allocate tasks**
  - One person to airway
  - One person to the cannulae

- Perfusionist to monitor slack on the lines

- **Use a patslide to transfer the patient into the ECMO stretcher**

Pre-Departure Checklist

- **Ambulance staff present and ready to transfer to airport/helipad**
- **Notify pilots that we are about to leave for airport/helipad.**
- **Airway secure**
- **Ensure ventilator settings remain appropriate**
  - Typically: PEEP 10cmH2O, tidal volume 5-6 ml/kg, FiO2 sufficient to achieve SpO2 in right hand >96%
- **All monitoring connected**
  - Pulse oximeter right hand for to detect differential hypoxaemia
  - ECG
  - Arterial line zeroed and transducer securely fixed to shoulder
  - Capnography
- **ABG performed post going on ECMO**
- **Infusions running and clamps/3 way taps open**
  - Propofol
  - Vasoactives if needed
  - Spare lumens for further medication administration
- **1000ml of crystalloid attached via giving set to a volume line**
- **Patient recently paralysed**
- **Spare medications/infusions**
  - Neuromuscular blocker
  - Adrenaline 1:10000
  - Calcium chloride
  - Flushes
  - Propofol syringe
  - Spare vasoactive
- **Blood for transfer**
- **Patient notes**
- **ECLS form filled out**

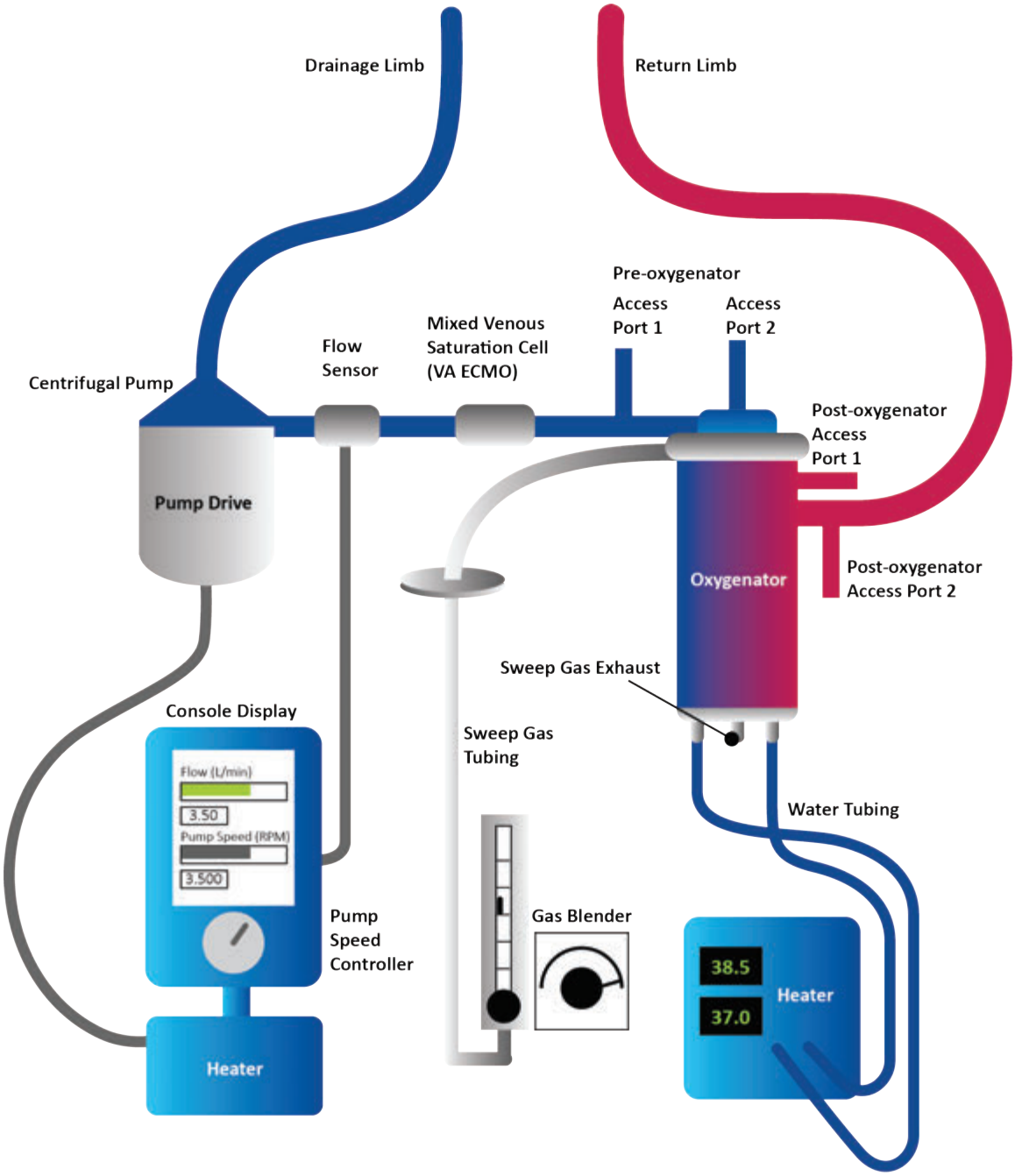
Following Transfer to CVICU

- **Transfer patient to CVICU bed with air mattress**
- **Transfer ECMO circuit to Bedside ECMO stand**
  - 3 people to facilitate this
    - *one person to hold oxygenator (there isn't enough length on circuit to put this in the oxygenator holder)*
    - *one person to transfer pump*
    - *one person to man the controls*
  - The person in charge of the pump clamps the drainage and return limbs of the circuit, transfers the pump to the pump mount on the bedside circuit, then releases the clamps, and ECMO flows increased.
  - Then place oxygenator in its holder
- **Ensure Cannulae are secured to bed**
- **CXR once stable**

Adult Circuit Weight Cutoff

A patient weighing more than 30kg should be placed on ECMO with an adult circuit.

Standard Circuit Configuration



Veno-Venous ECMO

Preferred Cannulae Configuration

Femoral venous drainage and Right Internal Jugular Return Cannulae (see fig A below)

Drainage Cannula:

Femoral vein access using Maquet Multistage Venous Cannula

Cannula Size:	patient **> 60kg**	29Fr or 25Fr
	Patient **< 60kg**	23Fr or 21Fr
Position:	Tip sitting in IVC at level of hepatic veins	

Return Cannula:

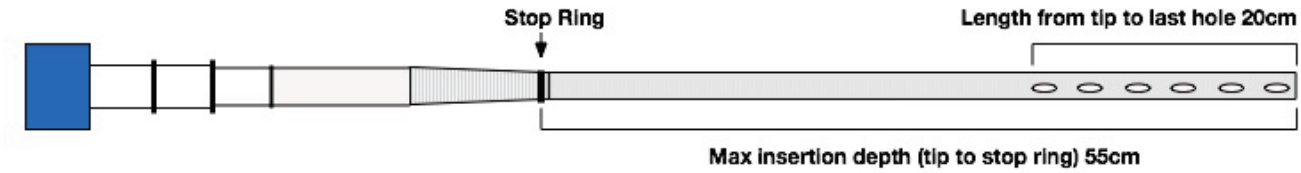
Right Internal Jugular vein access using Maquet HLS Arterial Cannula for 'Return'

Cannula Size:	patient **> 60kg**	21Fr or 19Fr short 15cm cannula
	Patient **< 60kg**	19Fr or 17Fr short 15cm cannula
Position:	Tip sitting at RA/SVC junction. Typically cannula is inserted to the taper	

Femoral Venous Drainage Cannula Dimensions:

When manipulating the venous drainage cannula position, it is useful to know the distance from the tip of the cannula to the last drainage hole. For a standard long drainage cannula, this distance is 20cm (see diagram below). It is important therefore that at least 30cm of cannula is inserted, to minimise the chance of cannula migration outside the patient with consequent catastrophic air embolus to the pump.

Important Measurements on a Long (55cm) 21G to 27G Maquet Multistage Drainage Cannula



NB: 1. 21G to 25G Multistage Venous Cannulae are also available in a 38cm length with different dimensions
2. Stylised Diagram... not strictly to scale

Alternative Cannulae Configuration if RIJ not available:

Femoral venous drainage and Femoral venous return (see fig B below).

Drainage Cannula:

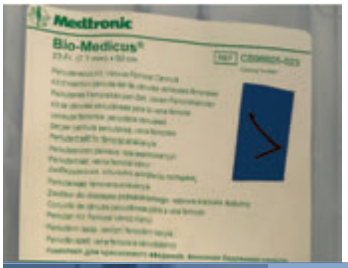
Femoral vein access using Maquet Multistage Venous Cannula

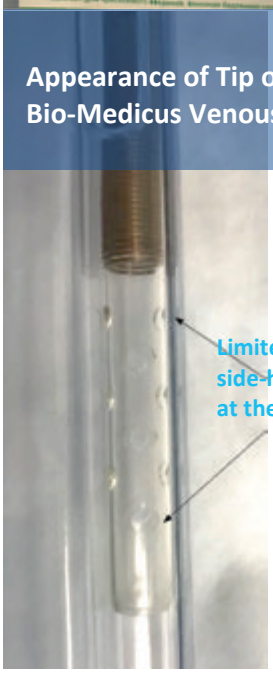
Cannula Size:	patient **> 60kg**	29Fr or 25Fr
	Patient **< 60kg**	23Fr or 21Fr
Position:	Tip sitting in IVC at level of hepatic veins	

Return Cannula:

Femoral vein access using Medtronic Bio-Medicus Venous Cannula. This has a limited number of sideholes located at the distal tip, allowing return of blood near the tip of the cannula and minimizing the chance of recirculation (See pictures of the 23 Fr cannula below).

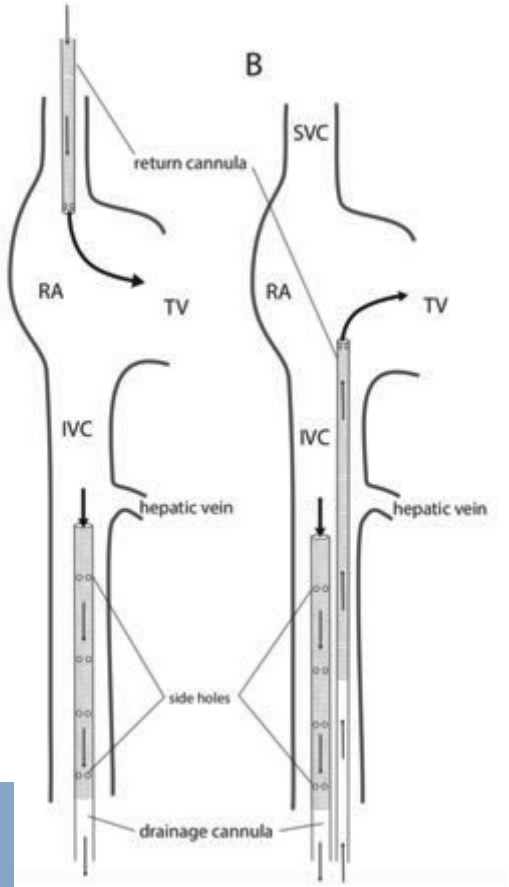
Cannula Size:	19 Fr or 23 Fr 50cm cannula (ADHB does not currently stock the 21 Fr cannula).
Position:	Tip sitting at junction of IVC and Right atrium, as depicted in diagram below.





Appearance of Tip of Medtronic Bio-Medicus Venous Cannula

Medtronic Bio-Medicus Femoral Cannula Kit



Veno-Arterial ECMO

Peripheral Veno-Arterial ECMO

Preferred cannulation sites are femoral for both arterial and venous cannulae. A distal femoral arterial cannula is required in all circumstances.

Drainage Cannula

Femoral vein access using Maquet Multistage Venous Cannula for drainage

Cannula Size:	patient **> 60kg**	29Fr or 25Fr
	Patient **< 60kg**	23Fr or 21Fr
Position:	Cannula traversing right atrium with tip sitting at RA/SVC junction or in distal SVC.	

Return Cannula

Femoral artery using Maquet HLS Arterial Cannula

Cannula Size:	patient **> 60kg**	21Fr or 19Fr	15cm cannula
	Patient **< 60kg**	19Fr or 17Fr	15cm cannula
Position:	Cannula is inserted to the Taper (tip typically in the iliac artery)		

Distal Leg Perfusion Cannula

Medtronic Bio-Medicus 8Fr 22.9cm paediatric arterial cannula

Alternative Strategies:

If femoral vein is deemed too small for the above sized drainage cannulae, then a second drainage cannula could be considered in the right internal jugular.

Central VA ECMO

We prefer central arterial return but peripheral venous drainage

Drainage Cannula:

Femoral vein using Maquet Multiport Venous Cannula for drainage

Cannula Size:	patient **> 60kg**	29Fr or 25Fr
	Patient **< 60kg**	23Fr or 21Fr
Position:	Cannula traversing right atrium with tip sitting at RA/SVC junction or in distal SVC	

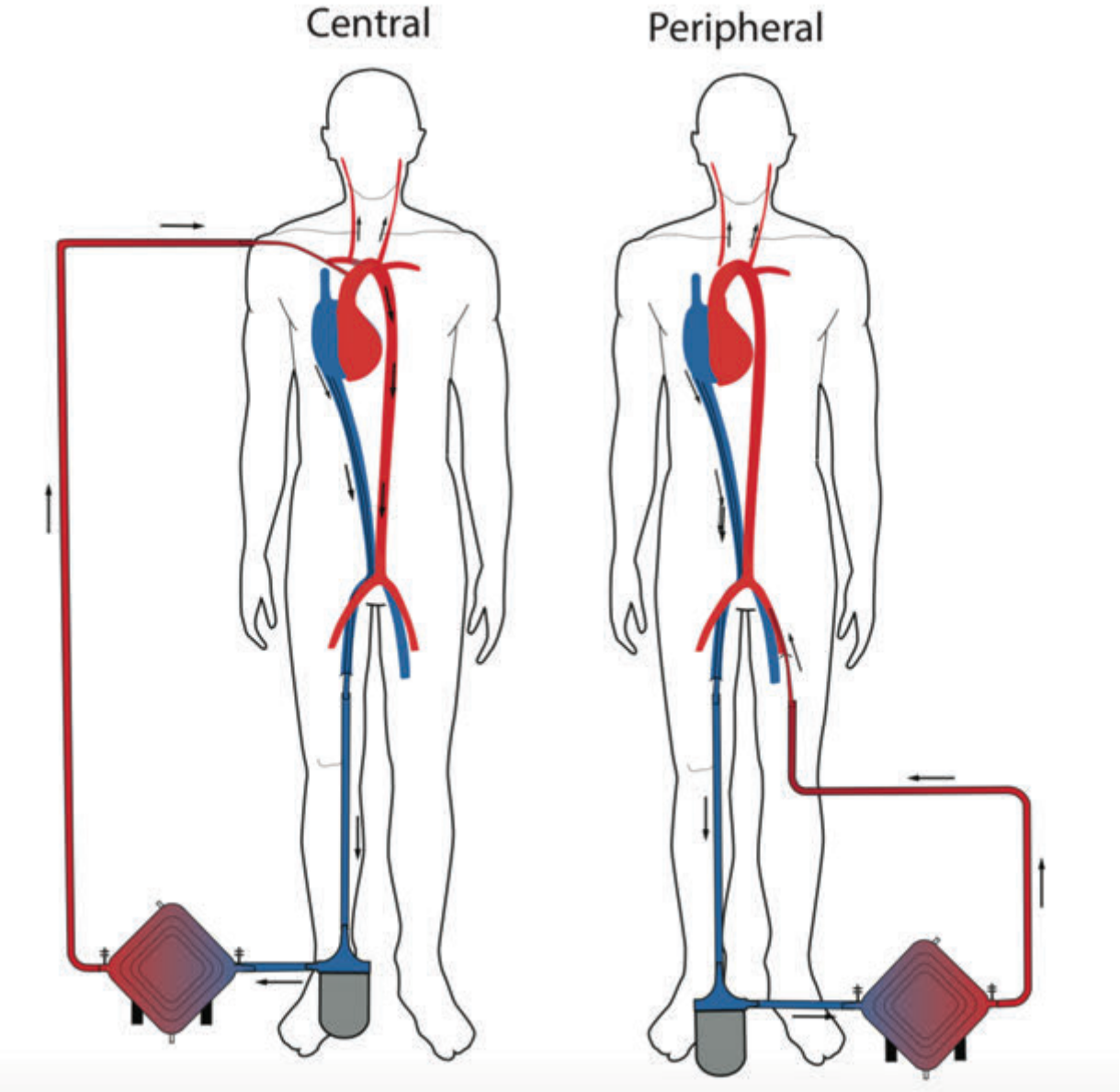
Return Cannula:

Surgically placed cardiopulmonary bypass cannula in ascending aorta. This will typically be tunneled and exit the temporarily closed chest via the suprasternal notch. Alternatively the chest may be left open.

Alternative Strategies:

Less commonly the drainage cannula used for cardiopulmonary bypass may be used, instead of a peripherally inserted femoral venous drainage cannula.
If femoral vein is deemed too small for the above sized drainage cannula, then a second drainage cannula could be considered in the right internal jugular.

VA ECMO – Central as Compared to Peripheral Arterial Cannulation (With Peripheral Venous Cannulation in Both Examples)



Veno-Arterial-Venous ECMO

Drainage Cannula:

Femoral Venous access using Maquet Multiport Venous Cannula.

Cannula Size:	patient **> 60kg**	29Fr or 25Fr
	Patient **< 60kg**	23Fr or 21Fr
Position:	Tip sitting in IVC at level of hepatic veins	

Return Arterial Cannula may be Central or Peripheral:

As described for central or peripheral VA ECMO.

Return Venous Cannula

Right Internal Jugular vein access using Maquet HLS Arterial Cannula for 'Return'

Cannula Size:	patient **> 60kg**	21Fr or 19Fr
	Patient **< 60kg**	19Fr or 17Fr
Position:	Tip sitting in proximal Right Atrium. Typically cannula is inserted to the taper	

Circuit Variations

The following sections discuss common variations on the usual VA and VV ECMO circuits.

Veno-Arterio-Venous (VAV) ECMO

VAV ECMO may be required in the following situations:

- when VA ECMO is instituted with peripheral cannulation for severe shock in the setting of severely impaired pulmonary function with type I respiratory failure. The goal in this situation is to avoid the problem of differential hypoxia.
- Following lung transplantation when mechanical circulatory support is required. Although central VA ECMO alone may be appropriate in this circumstance, VAV ECMO has the advantages of:
  - Helping to ensure oxygenated blood is traversing the pulmonary circulation (the patient has no bronchial circulation)
  - Facilitating a period of VV ECMO for primary graft dysfunction following removal of circulatory support
- In the setting of weaning from VA ECMO when the patient still requires VV ECMO support. Here, a transition to VAV ECMO may be appropriate prior to transitioning fully to VV ECMO.

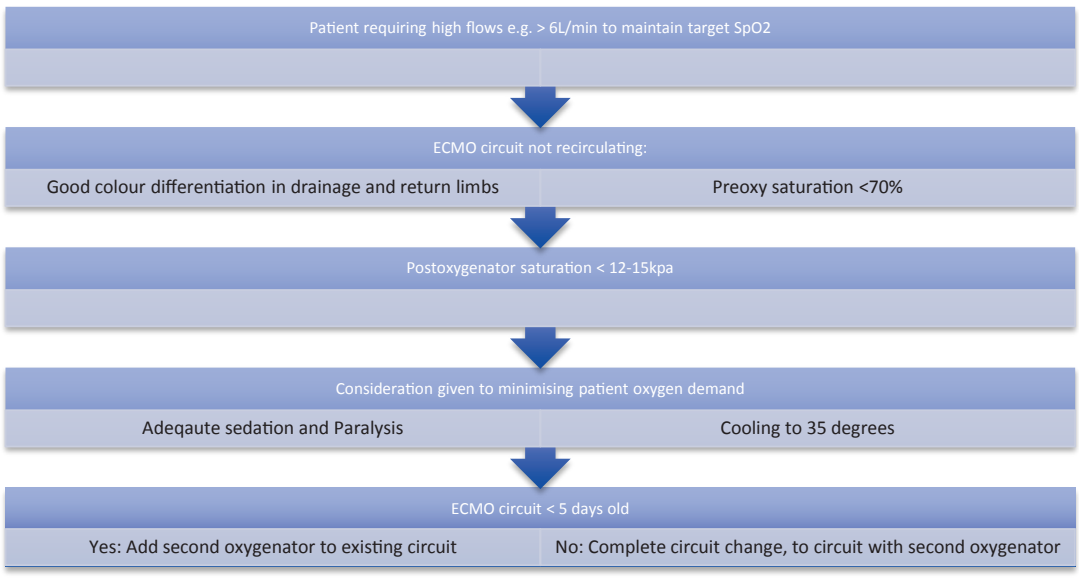
Points to note:

- Assuming severe pulmonary dysfunction, with VAV ECMO the FiO2 should be set to 1.0 to ensure the blood being returned to the right atrium is fully oxygenated.
- The proportion of flow down the arterial and venous return limbs can be manipulated with clamps on either limb. Flow down each limb can be measured with a flow meter attached to a cardiopulmonary bypass machine. Note however that this proportional flow will be dynamic, depending on variations in systemic vascular resistance over time.

Two Oxygenators

Typically on VV ECMO, increasing circuit flows will result in improved oxygenation. If there is a need to run very high circuit flows (> 6 L/min) the operating range of the oxygenator may be exceeded, necessitating an additional oxygenator in parallel with the first. The most common need to run high circuit flows is to match the demands of a hyperdynamic circulation, as might be seen in sepsis.

A decision making process for adding a second oxygenator is outlined below:



Full Circuit Change

The usual indication for a full circuit change is the need to replace the ECMO oxygenator or pump head.

For a discussion on when each of these might be considered, please refer to the anticoagulation document.

CVVH Use on ECMO

It is standard practice in CVICU to perform CVVH off the ECMO circuit. This avoids additional dialysis catheter placement in a patient at inherent risk of line-related bleeding and infection.

The principles that guide how CVVH is added to the ECMO circuit are as follows:

- The oxygenator provides a defence against emboli (air, clot, etc) entering the systemic circulation.
- The ECMO circuit pressures post oxygenator are lower than those pre-oxygenator. High ECMO circuit pressures can limit the use of CVVH being performed off the ECMO circuit.

VA ECMO

The main principle here is to avoid embolisation post oxygenator into the arterial circulation of the patient.

The CVVH circuit **must**

- access blood from the ECMO circuit pre-oxygenator
- return blood to the ECMO circuit pre-oxygenator

VV ECMO

To maintain standardization the preferred setup for the CVVH circuit is the same as for VA ECMO i.e:

- access blood from the ECMO circuit pre-oxygenator
- return blood to the ECMO circuit pre-oxygenator

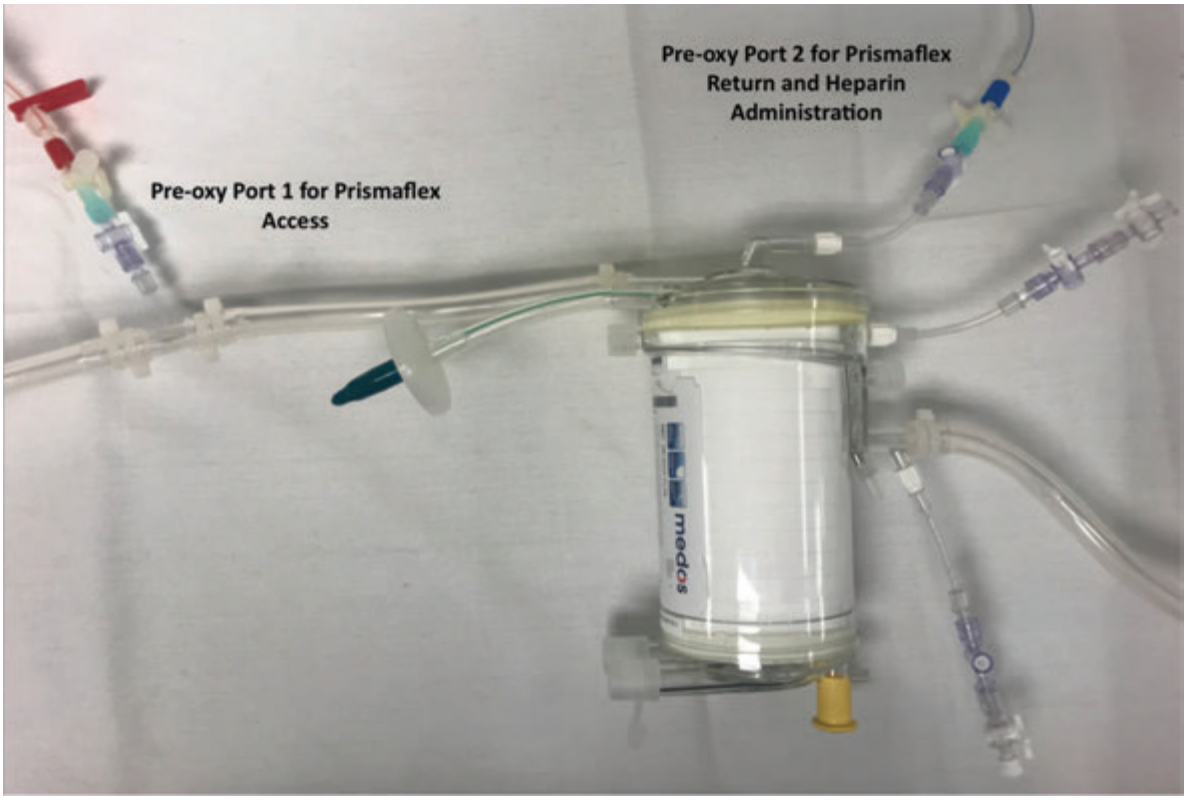
An alternative setup that can be done at CVICU consultant discretion is:

- access blood from the ECMO circuit pre-oxygenator
- return blood to the ECMO circuit **post**-oxygenator

This alternative setuup may be useful in the situation where the pressure in the CVVH return line in the pre-oxygenator position is too high for the CVVH machine to function. Of note however, new software on our CVVH machines has meant that the machines tolerate much higher return pressures than they used to. Points to note about this alternative setup are:

- Although the access port with the lowest circuit pressue is on the return cannula, access here risks breakage/shearing off of the port from the cannula which would pose signficant issues for ongoing circuit integrity. Thus, the best place to return blood from the CVVH circuit is at one of the access ports immediately post oxygenator
- The risk of embolisation to the patient on VV ECMO will not be much different to CVVH being provided through a normal central venous dialysis catheter.
- This configuration results in 200ml/min of blood bypassing the oxygenator. This is unlikely to be an issue, given that ECMO circuit flows are much higher than this.

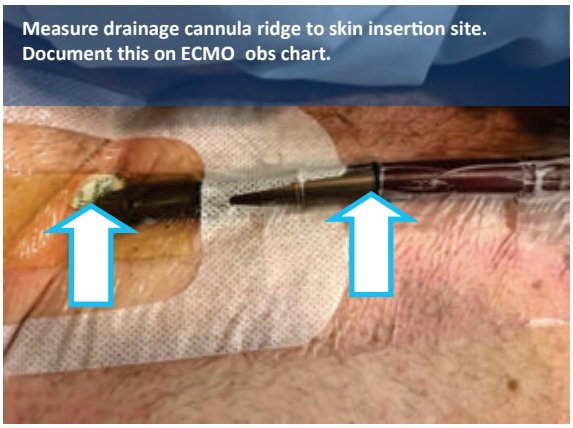
Standard CVVH Configuration for VA and VV ECMO



Routine Nursing Care of an Adult ECMO Patient

At the beginning of each shift

- **Obtain thorough handover from previous shift**
- **Check ECMO circuitry with previous shift (Eg: clots, CVVH)**
- **Complete safety check as per back of record sheet**
  - Check Parameter sheet
  - Check circuit for air & thrombus
  - Cannula site check
    - ensuring a measurement is taken and documented
    - If concerned about sutures securing the cannula being broken or coming undone, please inform SMO



- Displacement Plasma-Lyte® - 148 1000ml with 5000iu heparin changed q72hrs along with IV tubing for all patients
- Flow sensor gel available for the Jostra ECMO machine
- Emergency clamps present- Minimum of 2 spare non toothed clamps
- Notification form sent to Lab/Blood bank
- Blood Supplies- 4%HAS, RBC- Review what is currently in the blood fridge and order more if needed. You should have 1 units RBC and 2 Bottles of 4% HAS in the unit at all times
- Audible alarm on
- Flow alarm limits set
- ECMO Emergency Management Form charted by SMO and visible
- Adequate O2 & Air in cylinders- there should be at least 5000kPa of pressure in each cylinder. Change out cylinders if less than 5000kPa with perfusion or Technician. If cylinder 500-5000kPa put back onto rack in Technicians office with tag "In Use" showing
- Hand crank present and in correct position to move pump head quickly and easily in emergency situation
- Crossmatch due (72hrs)- check that crossmatch is current

For VA Circuits Only

- **Sats Monitor Calibration**
  - Remove SVO2 sensor from ECMO circuit by pushing down and twisting anticlockwise
  - Attach SVO2 sensor to Biotrend attachment on left side
  - Turn Biotrend off and on
  - Once Biotrend machine reboots the letters "CALIB" will show on the Biotrend
  - Press and hold the "CAL" button on the right hand bottom of the Biotrend until the screen on the Biotrend shows CAL
  - Wait until the screen shows all 0's then you can disconnect the SVO2 sensor from the Biotrend machine and reconnect to the connection port on the ECMO circuit
  - Take a Pre-oxy ABG
  - Once taken press "store" on the front of the Biotrend
  - When you have the results from your Pre-oxy ABG press "Recall" on the front of the Biotrend. This will select your HCT reading and allow you to adjusts it by pressing the arrow up or arrow down as required to set the number on the Biotrend the same as the result on your ABG
  - Press recall again. This will select the SVO2 reading and allow you to adjusts it by pressing the arrow up or arrow down as required to set the number on the Biotrend to the same as the result on your ABG
  - Once you have completed that the machine will then flick back into monitoring

Daily Checks For ECMO Nurse

Cannula assessment

- Sutures secure
- Cannula position in relation to skin unchanged (as above photo)
- Site is assessed for bleeding
- Cannula secured
- Any bleeding is reported to medical staff

Circuit assessment

- Connections secured- each connection has a cable tie
- Crank handle present and appropriately placed
- Display reading RPM
- Pump plugged into back wall not the pendant
- Alarms are set appropriately

Oxygenator assessment

- All gas line connections are secure
- Gas exhaust port unobstructed
- No air or foam present from oxygenator
- No clots are present in oxygenator
- Oxygenator is level or below inlet cannula
- Secured appropriately

Heat exchanger assessment

- Patient's temperature stable
- Water bath temperature is appropriate
- Circuit temperature is appropriate
- Water bath pump is never turned off (heater may be turned off)
- Blood temperature constantly monitored

Environment

- On call numbers listed - Know which perfusionist and SMO is on call
- Examine patient
- Check neurovascular observations in cannulated leg at least 4hrly and document
- Assess CNS status and maintain RASS aim
- Ensure double stopcocks on all ports and blind end bungs/smartsites present
- Check for adequate low range ACT cuvettes
- Check when next blood testing is due
- Discuss emergency management with bedside nurse and outline what each person would do during emergency procedures
    - E.g. Plan for suckdown should be discussed (what sedation/ neuromuscular blocker bolus, fluid set attached to appropriate line, positioning changes)

During each shift

- Consult SMO for any changes required that differ to parameters charted
- Assist bedside nurse with position changes/ linen changes / x-ray
- Assist bedside nurse with suctioning

Hourly	*Check circuit flow* *Complete record sheet* *Complete pupil check*
2hrly	*ACTs (Only if ACT's unstable)*
6hrly	*Complete circuit check* *ACT check* *ABG*
12hrly	*Plasma Hb* *FBC* *Pre-Oxy ABG for SvO2 for VA to calibrate Biotrend*
24hrly	*Coag* *U & E's ensuring Mg and Phosphate are tested* *CXR* *"Coughing" circuit to be done once a shift by perfusion, or at discretion of SMO*

Blood Testing

- All blood tests including plasma haemoglobin should be taken from the patient's arterial line rather than the ECMO circuit. An exception is the Pre-Oxy gas for mixed venous saturation cell calibration or a Post-Oxy gas when directed by the CVICU SMO. If the plasma Hb is high and there is concern that this could be a false positive, it can be repeated from the circuit at SMO discretion.

Circuit Cultures

- Not taken as routine, only if suspected sepsis. Confirm with SMO before sending

Infusion and sampling sites

The nurse should ensure that:

- Post pump head – use for sampling pre-oxygenator blood gas, circuit cultures
- Oxygenator inlet (Access port coming from the top of the oxygenator) – infuse heparin here
- Post oxygenator – post-oxygenator blood gases as needed, (ensure ABG's are taken with 15L/min of sweep, **and on an FiO2 of 1.0**). Please note that even for a patient on VA ECMO, the FiO2 needs to be turned to 1.0 for 10 minutes prior to taking a post-oxygenator blood gas to allow it to be interpreted correctly.

Line Changes

	24 hours	48 hours	72 hours	96 hours	1 week
Heparin infusion	X				
Heparin line			X		
Ventilator tubing					X
Displacement fluid			X		

Blood product Administration

Red Cells

To be given as the ECMO Nurse deems appropriate to maintain HCT above prescribed level. The ECMO Nurse does not need to get a prescription for this as long as the blood given is documented clearly on the CVICU 24hr Chart.

Platelets

To be given to maintain prescribed level on ECMO observation chart.

Procedures

X-ray

This should be done preferably in daylight hours (exception being post cannulation x-ray).

- X-rays will always be taken through the bed unless asked to be taken under the patient by the SMO. In this case for IJ cannulation a senior nurse level 3 or 4 should hold the cannulae and neck and control the lift and two nurses/HCA's/X-ray techs should lift the patient. A separate X-ray tech should insert the X-ray board. During the procedure the ECMO Nurse should watch ECMO Flows and ECMO lines and call a stop if unsafe at any time.

Pressure Injury Prevention

- Follow the CVICU Pressure Injury Bundle of Care for all ECMO patients with peripheral cannulation. The goal should be to turn them as per a standard CVICU patient at high risk of pressure injuries.
- If a patient has significant instability on turning (e.g. hypotension or hypoxia) despite judicious sedation bolus and paralysis, then they can be wedged on alternate sides until the situation is reviewed by an SMO. The decision to continue with only wedging the patient should be reviewed on each SMO ward round, with full turns reinstituted as soon as the patient condition allows.
- If the patient is on central VA ECMO, then the default is to not roll the patient however to alternate position using wedges under mattress. These patients should be managed as per the high risk bundle of care for pressure injury
- If a nurse is unable to wedge the patient, then this should be documented.

Lift (slat hoist)/bed change/NJ

This should be done during daylight hours if circumstances allow.

- SMO aware
- Preferably two ECMO nurses plus other nurses as designated

Prone/deproning positioning

- This should ideally be done during daylight hours.
- SMO/Senior Fellow will run prone/deproning
- Perfusion to be present for proning a patient at SMO discretion.
- When proning a patient, they must have preventative dressings in place as per the CVICU proning protocol.
- If there are any treatment injuries as a result of proning, then it is important that a datix, woundcare chart and ACC treatment injury form are completed.
- Ensure Clinical Nurse Coordinator observe/assist with proning

Transport of patient and circuit to CT

- Perfusionist
- Intensivist
- ECMO Nurse
- Patient Nurse
- Orderly

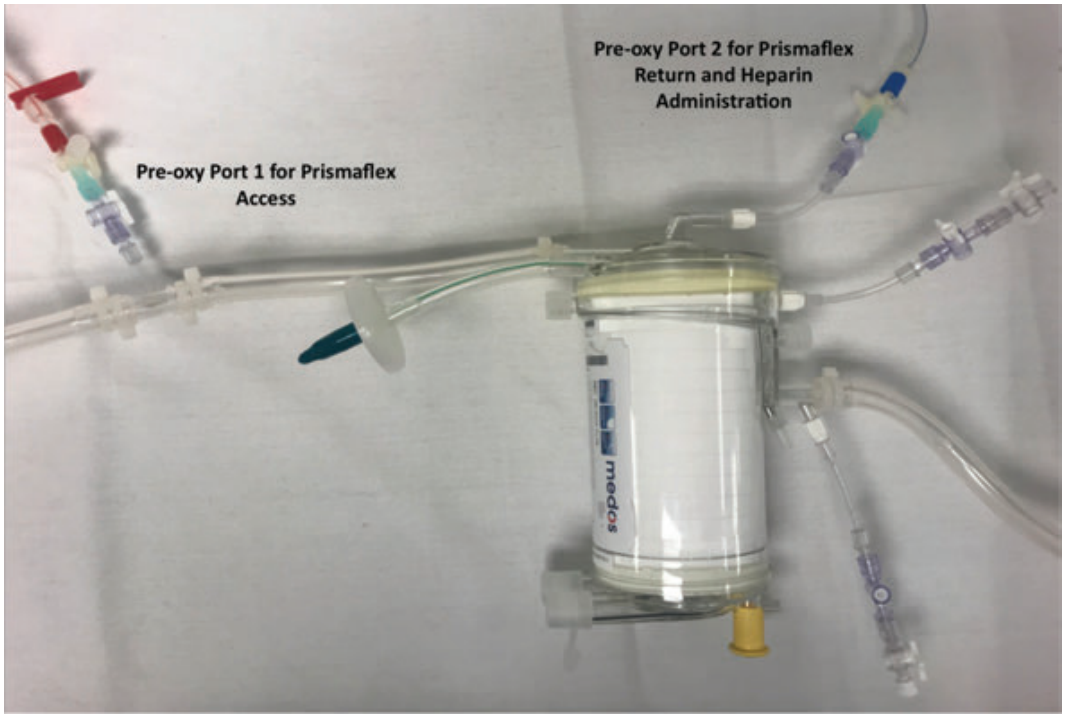
Procedures where perfusion must be present

- Changing of gel on maquet pump flow sensor
- Addition of CVVH to circuit **if** ECMO nurse not confident with procedure
- Circuit changes
- Conversion to/from VA/VV/VAV
- During emergencies such as air in the circuit or cardiac arrest, perfusion should be notified to attend as soon as possible and the emergency managed as appropriate by the ECMO nurse prior to their arrival.

Procedures to notify perfusion

- Decannulation and withdrawal of ECMO. Please note that Perfusion will usually attend if able. If they are unable to attend, then don't dispose of any of the circuit/ equipment before they arrive.
- Invasive procedures e.g biopsy (at SMO discretion)

Adult Prismaflex CVVH on ECMO Preferred Set Up:



The picture above is the preferred set up for CVVH in the CVICU. If these ports are unable to be used then discuss with SMO. Please refer to section on "Adult ECMO Cannulae and Circuit Variations" for more discussion on this. Citrate is the preferred substitution fluid. Heparin can be delivered via the port on the top of the oxygenator. Blood samples can be taken from the patient arterial line.

Dressing Change of Cannulae Site

- This should be done during daylight hours unless bleeding is a problem.
- Dressings to be changed in consultation with SMO. If ECMO Nurse comfortable they can change the dressing with sterile technique ensuring Chlorhex impregnated dressings are put back insitu. But if not comfortable dressing is to be changed by SMO. Any cannulation site with significant bleeding should be attended to by the SMO.

Discontinuation of ECMO

- Perfusion generally will be present for this. If perfusion are not present, once the circuit has been discontinued please place ends of the circuit in a yellow bag and contact perfusion to take the circuit and dispose of it. Don't throw any part of the circuit or other equipment away, as there have been issues in the past with expensive non-disposable equipment being lost. Perfusion will check the ECMO pump and ensure all parts are present.
- Send notification forms to Labs/Bloodbank of discontinuation of ECMO.
- Notify ECMO Coordinator via email.

The fine balance between thrombosis and anticoagulation in ECMO is difficult for a number of reasons.

Firstly, the disease process and its sequelae that have lead to the need for ECMO, as well as the treatment given prior to the establishment of ECMO may have caused a significant prothrombotic or antithrombotic state.

Secondly, exposure to the extracorporeal circuit tends to result in a prothrombotic state.

Thirdly, despite this prothrombotic state induced by the circuit, bleeding is a common complication with ECMO. Bleeding is not only due to anticoagulation, but also due to other factors such as thrombocytopaenia, fibrinolysis, uraemia and liver failure.

Factors Promoting Thrombosis

- **High fibrinogen**
- **High factor VIII**
- **Heparin resistance**
- **HIT**
- **Circuit**
  - Platelet and coagulation cascade activation
- **LV/LA stasis**
- **Immobile patient**

Factors Promoting Bleeding

- **Heparin**
- **Coagulopathy from and underlying condition**
  - DIC
  - Hepatic Failure
  - Uraemia
- **Platelets**
  - Consumption
  - Impaired function
  - Acquired von Willebrand Syndrome
- **Abnormal fibrinolysis**

Tests of Anticoagulation during ECMO

ACT:

- **A whole blood point of care test, that uses an activator to provide a global measure of haemostasis.**
- **It is prolonged in the presence of anaemia, hypofibrinogenaemia, thrombocytopaenia, and other coagulation factor deficienceies.**
- **Despite these limitations, it is the test most commonly used in CVICU to guide heparin therapy**

APTT:

- **A plasma based test that uses an activator, calcium, and phospholipids to measure the time to fibrin formation in the absence of cellular components.**
- **It is prolonged by lupus anticoagulant, factor VIII, IX, XI, XII deficiencies, von Willebrand disease.**

Anti Xa

- **Heparin binds to and confers a conformational change in antithrombin. This dramatically increases antithrombin's inhibition of factor Xa**
- **Measurement of Anti Xa levels is measuring the anticoagulant effect of the combination of heparin/antithrombin.**
- **It is a useful test, because it is not influenced by the factors that affect the ACT/ APTT described above, and may also be helpful in diagnosing true heparin resistance, as opposed to apparent heparin resistance as seen with the APTT/ACT.**

Platelet count

- **Normally target a platelet count greater than 80 x 10^9. If this is difficult to maintain (requiring lots of platelet transfusion) then a lower limit may be acceptable. If bleeding, then a platelet count over 100 x10^9 is usually targeted.**

Anticoagulation and Other Haematological Management for ECMO

Prior to Initiation of ECMO

In a non-emergent setting, baseline coagulation parameters should be obtained and attempts made to correct significant coagulopathy.

- **Reversal of previously administered anticoagulants if possible**
- **INR < 1.5, Plts > 100, Fibrinogen > 1.5**

Levels of Anticoagulation

The degree of anticoagulation on ECMO is a balance of risk of bleeding versus risk of thrombosis. The options when considering this risk-benefit evaluation are:

- **No heparin**
- **Heparin at fixed rate of 10 u/kg/hr. Heparin not increased to target an ACT, however is decreased if ACT > 160s**
- **Heparin to target an ACT of 140 – 160s**

Management of Heparin Infusion

- **Ensure baseline ACT has been done**
- **No bolus unless otherwise instructed by SMO**
- **Start infusion at 10 units/kg/hr (with the patient's weight rounded to the nearest 5 Kg. So weight 78 Kg is treated as 80 Kg). Only reduce this dose if the ACT > 160 seconds.**

Wt (Kg)	40 -	45	50	55	60	65	70	75	80	85	90	95	100+
Dose U/hr	400	450	500	550	600	650	700	750	800	850	900	950	1000
Rate mL/hr	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0

- **Do not adjust the heparin rate unless instructed to by the SMO. You may be instructed to adjust to target ACT of 140-160 seconds. If so follow the algorithm below unless instructed otherwise. Measure ACT using two channels on each occasion. If > 12s difference between the two results, repeat the measurements.**

Possible Dose Adjustments when targeting ACT:

ACT (s)	Stop infusion	Rate Change (u/hr)	Repeat ACT
< 120	0	+ 100	2hr after rate change
120 - 140	0	+ 50	2hr after rate change
140 - 160	0	No change	2hr after rate change
160 - 180	0	- 50	4 hrs
180 - 220	30 mins	- 50	2hr after rate change
> 220	60 mins	- 100	2hr after rate change

- **No bolusing of heparin when ACT is low.**
- **If the ACT > 220 on two consecutive ACTs then pause heparin for 120 mins and check ACT has fallen below 160 before restarting. Consult Registrar/SMO as to the rate.**
- **No change in heparin or heparin bolus when platelets are given**

Anticoagulation and Other Haematological Management for ECMO

Anticoagulation on VV ECMO

- In the absence of coagulopathy or increased risk of bleeding, heparin should be administered.

Institution of ECMO:

- As soon as cannulae are within appropriate vessels but prior to inserting ECMO cannulas, administer 1000 units of heparin as a bolus.

Ongoing anticoagulation:

- Commence heparin infusion at 10u/kg/hr when ACT < 200s following initial bolus at cannulation
  - Fixed dose heparin at 10u/kg/hr
  - ACT is monitored and maintained < 160s
  - Heparin dose is reduced if ACT > 160
  - Heparin dose is not increased above 10u/kg/hr, irrespective of the ACT value

Consider increasing heparin dose to target an ACT if:

- large thrombus burden within the circuit
- rising plasma Hb thought to be due to circuit thrombus
- In this circumstance, targeting an ACT of 140 – 160 or 160 – 180, depending on perceived risk of bleeding vs thrombosis may be appropriate

Anticoagulation in VA ECMO

Non-surgical patient

Institution of ECMO:

- As soon as cannulae are within appropriate vessels administer 5000 units of heparin as a bolus.

Ongoing Anticoagulation

- Commence heparin infusion at 10u/kg/hr when ACT < 200s following initial bolus at cannulation
- Target ACT of 140 – 160s
- Consider increasing heparin dose to target an ACT of 160 – 180s if:
  - large clot burden within the circuit
  - rising plasma Hb thought to be due to circuit clot
  - heart not ejecting well

Post Cardiothoracic Surgery

There are two scenarios that may occur here

1. Unable to wean patient from CPB
2. Able to wean from CPB but severe haemodynamic instability

Unable to wean patient from CPB

Institution of ECMO:

- Cannulate patient for ECMO and transition from CPB to ECMO.
- Once established on ECMO fully reverse heparin with protamine and then carry out surgical haemostasis.
- Once bleeding under control and acceptable transfer patient to CVICU.

Ongoing anticoagulation:

- Heparin will be started in CVICU once the clinical teams (ICU & Surgery) are satisfied risk of bleeding is minimal.
- This will usually be 24-48 hours post initiation of ECMO. During this time efforts to keep the heart ejecting a little will be made.
- Typically heparin will be started at a fixed dose of 5-10u/kg/hr for a period of time, and increased to target an ACT when satisfied there is no bleeding with the fixed dose heparin.
- The final ACT target will depend on risk of bleeding vs risk of thrombosis. Increased risk of thrombosis particularly when heart not ejecting well

Able to wean from CPB but severe haemodynamic instability

Institution of ECMO

- Fully reverse Heparin with protamine.
- Cannulate patient and establish on ECMO.
- No bolus or infusion of Heparin is given.
- Once bleeding under control and acceptable transfer patient to CVICU.

Ongoing anticoagulation

- Heparin will be started in CVICU once the clinical teams (ICU & Surgery) are satisfied risk of bleeding is acceptable.
- This will usually be 24-48 hours post initiation of ECMO. During this time efforts to keep the heart ejecting will be made.
- Typically heparin will be started at a fixed dose of 5-10u/kg/hr for a period of time, and increased to target an ACT when satisfied there is no bleeding with the fixed dose heparin.

- The final ACT target will depend on risk of bleeding vs risk of thrombosis. Increased risk of thrombosis particularly when heart not ejecting well

Issues With Anticoagulation During ECMO:

Thrombosis/ Difficulty achieving anticoagulation

Heparin resistance:

- Potential causes include:
  - Antithrombin III Deficiency
  - Increased heparin clearance
  - Increased levels of heparin binding proteins
  - Elevations of fibrinogen or factor VIII
  - Certain medications
    - Aprotinin
- All of the above causes can be overcome with more heparin, except for antithrombin III deficiency
- If unable to achieve a therapeutic ACT despite a heparin dose that would usually be adequate e.g. 35 – 40 u/kg/hr, then consider measuring:
  - Anti Xa level
    - As another marker the anticoagulant effect of heparin administration, to help confirm inadequate heparinisation
    - A level consistent with therapeutic anticoagulation would be 0.3 to 0.7 U/ml
    - Studies in management of VTE have shown that, when high doses of heparin are required to obtain a target APTT of 1.5-2.5 times normal, using Anti-Xa levels to guide therapy results in lower heparin dosing and no observed detrimental effects.
  - Antithrombin III level
- Antithrombin III deficiency can be congenital or acquired. Acquired causes include:
  - Disseminated Intravascular Coagulation
  - Acute thrombosis
  - Liver disease
  - Surgery and trauma
  - An extracotporeal circulation itself
  - Exposure to heparin
- ATIII levels < 30-40% of normal may account for clinically significant heparin resistance.
- Administration of ATIII concentrate for patients on ECMO has not been well studied. It's efficacy in reducing heparin resistance in patients (i.e. not definitely due to AT III deficiency) undergoing cardiopulmonary bypass has been demonstrated.
- In the presence of heparin resistance, low anti-Xa levels and ATIII levels < 30-40% of normal, discussion with a haematologist regarding recombinant ATIII administration is recommended.
- If planning on administration of ATIII, the heparin infusion should be lowered prior to ATIII administration in anticipation of an increased anticoagulant effect.

Circuit Thrombus:

Oxygenator Thrombus:

- **Suspicion for this generally rises in the presence of:**
  - Visible thrombus within oxygenator
  - Worsening oxygenator performance as evidenced by worsening post-oxygenator PaO2
  - Rising plasma Hb
  - Low fibrinogen levels
  - Note:
    - Trans-oxygenator pressure is not routinely measured in CVICU.
    - D Dimer is unlikely to be helpful, as it is commonly elevated in patients on ECMO in the absence of problematic thrombus
- Oxygenator or circuit change generally required when:
  - Post-oxygenator PaO2 < 15 - 20kPa (following "coughing" of oxygenator)
  - If trans-oxygenator pressure is measured as part of evaluation of potential thrombus, it should be < 10mmHg/L blood flow (and not > 50mmHg)

Pump Head Thrombus:

- Suspicion for this generally arises in the presence of:
  - Visible thrombus within pump head
  - Worsening circuit flows for a given rpm
  - Noisy pump head with palpable vibrations
  - Rising plasma Hb
  - Low fibrinogen levels
  - Note:
    - D Dimer is unlikely to be helpful, as it is commonly elevated in patients on ECMO in the absence of problematic thrombus
- **Circuit change generally required when:**
  - Plasma Hb > 500 - 1000 mg/L, in the context of some of the other factors described above being present

- Unable to achieve desired flows, when they could previously be achieved (?agree with this)

Bleeding:

Definitions:

- **Major bleeding:**
  - Volume of bleeding
    - Hb fall of greater than 20g/L in a 24 hr period
    - Transfusion of > 10ml/kg PRBCs in a 24 hr period
  - Nature of bleeding
    - Requires surgical intervention
    - Involves CNS
- **For Major Bleeding:**
  - Stop heparin infusion until bleeding resolved
  - Typical coagulation parameters to target whilst bleeding on ECMO
    - Platelets > 100
    - INR < 1.5 - 2.0
    - Fibrinogen > 2.0
  - A TEG will also prove useful to guide factor replacement, and to demonstrate evidence of fibrinolysis.
  - Consider antifibrinolytics
  - Factor VIIa has been used with severe bleeding refractory to surgical intervention and correction of coagulopathy. There is a risk of fatal circuit thrombosis with this however, so it should be used with extreme caution.
- **Bleeding around ECMO Cannula sites:**
  - Ensure cannula has not migrated out of patient
  - If this is a return cannula problem, ensure it is inserted so that the lip on the cannula is flush/snug with the skin
  - If issue remains unresolved, consider a purse string around cannula, although this has the potential to cause further bleeding from suture holes

Heparin Induced Thrombocytopaenia

This is a diagnosis that has major implications for anticoagulation management of the patient on ECMO, as it will require administration of an alternative (irreversible) anticoagulant

Apply the 4T score below:

Thrombocytopenia	Platelet count fall >50 % **and** nadir ≥20,000/microL	2 points
	Platelet count fall 30 - 50 % **or** nadir 10 to 19,000/microL –	1 points
	Platelet count fall <30 percent **or** nadir <10,000/microL	0 points
Timing of platelet count fall	Clear onset between days 5 and 10 **or** plt count fall at ≤1 day if prior heparin exposure within the last 30 days	2 points
	Consistent with fall at 5 to 10 days but unclear (eg, missing platelet counts) onset after day 10, **or** fall ≤1 day with prior heparin exposure within 30 to 100 days	1 point
	Platelet count fall at <4 days without recent exposure	0 points
Thrombosis or other sequelae	Confirmed new thrombosis, skin necrosis, **or** acute systemic reaction after intravenous bolus	2 points
	Progressive or recurrent thrombosis non-necrotizing (erythematous) skin lesions, suspected thrombosis that has not been proven	1 point
	None	0 points
Other causes for thrombocytopenia	None apparent	2 points
	Possible	1 point
	Definite	0 points

- Pretest probabilities for HIT are as follows:
  - 0 to 3 points – Low probability, 4 to 5 points – Intermediate probability, 6 to 8 points – High probability
- Only send a HIT screen if patient scores moderate or high in probability (there is an increased risk of a false positive HITs screen in the setting of low clinical probability)
- Involve haematology early
- If the diagnosis of HITs is felt to be highly likely, then heparin anticoagulation should be discontinued, and alternative anticoagulation commenced
  - **Fondaparinux:**
    - Dose: 2.5 – 5mg s/c daily
    - Monitoring: Anti Xa activity Q12H, Target 0.2 – 0.5u/ml
  - **Bivalirudin**

This section is written as a troubleshooting guide primarily for problems relating to the ECMO circuit. For each problem (e.g., hypoxaemia) the aetiology, diagnosis, and treatment options are presented. For a deeper understanding of the problems outlined below, refer to other sections in the manual ("The Physiology of ECMO", and "Anti-coagulation and bleeding". Problems and complications primarily related to the patient (e.g., sepsis, intracerebral haemorrhage, pneumothorax) are not addressed in detail.

Section 1: problems related to both VV and VA ECMO

Suction events

A suction event (or suckdown) is when there is an abrupt loss of circuit flow. Suction events are commonly preceded by chattering on the drainage limb and a short period of reduced flow for a given pump speed. The cause is collapse (suction) of the IVC onto the drainage cannula resulting in immediate loss of circuit flow.

Aetiology

The most common causes of suction events are patient agitation/movement and hypovolaemia. Less common causes include kinking of the drainage cannula/tubing, malposition of the drainage cannula, and raised intra-abdominal pressure.

Diagnosis

The diagnosis of a suction event is usually self-evident. Recurrent suction events, despite adequate sedation and intravascular volume status, are an indication for an echocardiogram to assess the position of the drainage cannula.

Treatment

To relieve the suction event, pump speed should be reduced to zero and then slowly increased back to normal. Concurrently, it is usually necessary to sedate and/or paralyse the patient. In addition, it may be appropriate to administer a fluid bolus.

Low flow/high pump speed

Low circuit flow/high pump speed refers to the requirement increased pump speed (i.e., RPM) to achieve the same circuit flow. It may develop over minutes to hours or more slowly, over a period of days.

Aetiology

When the problem arises over minutes-to-hours, it is akin to a 'slow' suction event. Causes include hypovolaemia, inadequate sedation or patient movement. When the problem arises over hours-to-days, an evolving obstruction within the circuit should be considered: thrombus in the oxygenator or pump head; thrombus on the cannulae; or cardiac tamponade (particularly in post-cardiac surgery VA ECMO).

Diagnosis
Like a suction event, the diagnosis of rapidly evolving low flow/high pump speed is usually self-evident. When the condition is slowly evolving, a careful search for signs of obstruction within the circuit should be made. This includes (1) measuring a post-oxygenator blood gas (oxygenator failure typically accompanies thrombotic obstruction within the oxygenator); (2) measuring the pressure drop across the oxygenator (> 100 mmHg suggests obstruction); (3) measuring the plasma haemoglobin (high levels may indicate obstruction within the pump head); (4) careful inspection of the circuit tubing looking for kinking or fibrin formation; (5) performing an echocardiogram looking for obstruction in and around the cannulae.

Treatment
Treatment is directed at the underlying cause. If a circuit problem is identified, it should be replaced.

High plasma haemoglobin

Aetiology
High plasma haemoglobin (Hb) occurs from blood trauma and most commonly reflects thrombus formation in the circuit, particularly the pump head.

Diagnosis
Plasma Hb is normally less than 100 mg/L. Values between 100-500 mg/L are not uncommon during ECMO support. A rapidly rising plasma Hb (over 24-hours) or a value > 800-1000 is suggestive of significant haemolysis. Other features associated with thrombus or haemolysis in the circuit should be sought (e.g., pink urine, DIC, coagulopathy, CVVH circuit issues). Additionally, evidence of problems with the pump head or the oxygenator should be sought. Such problems include (1) visible thrombus or stranding in the pump head or oxygenator; (2) increased resistance in the circuit (low flow/high pump speed); (3) an abnormal 'knocking' sound on auscultation of the pump head (rare).

Treatment
Circuit replacement, particularly if associated with circuit problems or patient bleeding. Replacing the CVVH circuit (if present) may also be helpful.

Plasma leak from gas phase of oxygenator

Aetiology
The implication of a plasma leak is that there is a breach in the oxygenator membrane allowing plasma to leak from the blood phase to the gas phase. This problem is rare with modern polymethylpentene oxygenators.

Diagnosis
The plasma leak itself is self-evident. Other signs of oxygenator failure should be sought such as a low post-oxygenator P_aO_2 and/or high post-oxygenator P_aCO_2 and an increased pressure gradient across the oxygenator.

Treatment
For mild plasma leaks, a watch and wait approach is appropriate. Very rarely, a severe leak necessitates exchanging the oxygenator/circuit. Excessive fluid accumulating inside the oxygenator will reduce its efficiency at gas exchange, so regular flushing of the circuit with higher gas flows (coughing the oxygenator) is recommended if a mild plasma leak develops

Bleeding

Aetiology

Causes of patient bleeding include excessive anticoagulation, inadequate surgical haemostasis, untreated coagulopathy, consumptive coagulopathy/DIC and HIT. The most common causes of consumptive coagulopathy are sepsis and circuit thrombus.

Diagnosis

Excessive anticoagulation, surgical bleeding, and untreated coagulopathy are diagnosed and treated in the usual manner. New sepsis or circuit thrombus should be suspected in a previously stable patient who develops late-onset cannula-site bleeding. Consider testing for HIT (always assess prior probability of HIT using the 5-Ts test before performing a HIT screen as there is a significant false positive rate with the heparin-PF4 antibody assay).

Treatment

Treatment depends on the underlying cause. For DIC associated with circuit thrombus, circuit exchange may be necessary.

Thrombus/haematoma in the patient

Patients supported by ECMO are at risk of both thrombosis and bleeding, and can develop both complications at the same time.

Aetiology

Thrombus/haematoma in the patient includes extravascular blood collections (pleural and pericardial, and retroperitoneal) and intravascular/intracardiac thrombi. Intravascular sites include the central and jugular veins, the deep veins of the legs, and thrombi associated with ECMO cannulae. Patients on VA ECMO with minimal LV ejection can develop intracardiac thrombosis.

Diagnosis

Diagnosis depends on which site of bleeding is suspected. Chest radiography plus echocardiography is usually indicated. For intravascular thrombus formation, always consider HIT.

Treatment

Treatment depends on the underlying cause and the site of thrombus.

Thrombus in the circuit

Aetiology

Thrombus most commonly develops in the oxygenator, and occasionally in the pump head.

Diagnosis and treatment

See sections above on low flow/high pump speed and high plasma haemoglobin.

Section 2: Problems specific to VV ECMO

Arterial hypoxaemia

Aetiology

Causes of hypoxaemia (P_aO_2 < 8 kPa) on VV ECMO include: (1) inadequate ECMO circuit flow; (2) high cardiac output (sepsis/SIRS/fever); (3) recirculation; (4) oxygenator failure; and (5) severe anaemia. Further deterioration in native pulmonary function may also contribute.

Diagnosis

Check the pre-oxygenator (i.e., 'venous') oxygen saturation. A low value (< 50-60%) suggests high cardiac output/anaemia; a high value (>75%) suggests recirculation. Check the post-oxygenator ('arterial') PO_2 (check the F_iO_2 on the ECMO gas blender is set to 1.0 first). A low value (< 10-15 kPa) suggests oxygenator failure. An echocardiogram should be performed to check the cannulae positions and assess for recirculation.

Treatment

If the problem is recirculation, the cannulae positions may need to be adjusted. If the problem is high cardiac output consider the following: (1) active cooling +/- maintenance of neuromuscular blockade; (2) blood transfusion; (2) reducing inotropic support; (3) aggressive treatment of sepsis. Occasionally a beta-blocker may be useful to reduce cardiac output. If the problem is oxygenator failure, first 'cough' the oxygenator, then consider changing the circuit. If the problem is the requirement for high ECMO circuit flows that are exceeding the capacity of the oxygenator, then consider adding in a second oxygenator in parallel with the first (if the circuit is more than 3-5 days old, then this will also involve changing the whole circuit. See also "CVICU Adult ECMO Cannulae and Circuit Variations" for further discussion about the decision process around adding a second oxygenator) Oxygenator function is flow dependant, so reducing blood flow through the circuit (if possible) will increase the post-oxygenator PO_2

Increasing mechanical ventilation above rest settings may be useful.

Hypotension

Aetiology

VV ECMO does not directly affect the circulation (after the initial period following establishment of ECMO). Thus, the causes of hypotension during VV ECMO are the same for any hypotensive patient. Consider pump failure, vasoplegia/SIRS, hypovolaemia, and obstructed venous return (tension pneumothorax, patient-ventilator dyssynchrony, and massive haemothorax).

Diagnosis and treatment

Diagnosis and treatment should be directed at the underlying cause. Probably the most common cause of hypotension in patients receiving VV ECMO is vasoplegia/SIRS due to sepsis. Aggressive treatment of sepsis and vasopressor therapy are essential in this circumstance. A chest radiograph should be performed to rule out a tension pneumothorax. The patient should be sedated and paralysed. It is important to ensure the ventilator settings are not contributing to obstructed venous return. An echocardiogram should be performed to rule out a cardiac cause. A volume challenge should be considered.

Section 3: Problems specific to VA ECMO

Upper body hypoxaemia (Harlequin syndrome, differential hypoxaemia)

Aetiology

Upper body hypoxaemia arises in patients on *peripheral* VA ECMO who have (or develop) impaired pulmonary function in association with good (or improving) cardiac function. Then, oxygen delivery to the upper body (limbs, brain, heart) is via blood that has passed through poorly functioning lungs and been ejected from the left ventricle (LV). By contrast, the lower body is supplied by oxygenated blood that has passed from the ECMO return cannula positioned in the femoral artery.

Diagnosis

The diagnosis is confirmed by finding a low S_aO_2 in the upper body but normal S_aO_2 in the lower body.

Treatment

Simple measures involve either improving native pulmonary function (which may be as simple as ventilating the lungs normally) or reducing native cardiac output (e.g., by increasing ECMO circuit flow, stopping inotropes, giving a beta-blocker). More complicated treatments involve initiating VAV ECMO or changing to VV ECMO (to provide oxygenated blood to the lungs). Occasionally, changing from peripheral to central VA ECMO is indicated.

Hypoxaemia (whole body)

Aetiology

A key cause of (whole body) hypoxaemia during VA ECMO is a patient with previously good pulmonary function who then develops impaired pulmonary function for whatever reason while on ECMO. Patients on VA ECMO who have good pulmonary function and are receiving 'normal' mechanical ventilation typically require very little sweep gas flow to maintain normal gas exchange. If such a patient then develops a lung problem (e.g., atelectasis/mucus plugging/pulmonary oedema/VAP etc.) they will become hypoxaemic.

Diagnosis and treatment

In patients on peripheral VA EMCO, it is important to first check that hypoxaemia is not just affecting the upper body by checking the oxygen saturation in the lower limbs (which will be the same as in the upper limbs). Then, once the diagnosis is confirmed, assessment and treatment of pulmonary function is as for any critically ill patient (i.e., chest radiograph, bronchoscopy, antibiotics, regular suctioning, diuretics, etc.). Increasing the sweep gas and circuit flow (so that the ECMO circuit is providing most of the patient's oxygen delivery) may be necessary.

A particular problem that can occur is the necessity to use very low sweep gas flows (< 2 L/min) to avoid causing hypocarbia (as, in patients with good pulmonary function, CO_2 clearance may be achieved to a large extent by the patient's native pulmonary function). This can lead to water vapour building up within the gas phase of the oxygenator reducing its oxygen transfer capabilities. The diagnosis is confirmed by finding a reduced post-oxygenator PO_2 that normalises with 'coughing' the oxygenator. This scenario is best dealt with by bleeding CO_2 in the patient's ventilator (e.g., 1 L/min), which allows both normal ventilation and normal sweep gas flows to be maintained.

Hypotension

Aetiology

Hypotension may be due to inadequate cardiac output or vasoplegia. Causes such as inadequate circuit flow, cardiac tamponade, sepsis, and SIRS should be considered.

Diagnosis

Assessment of S_vO_2 (an inline oximeter is usually present on a VA ECMO circuit) is a useful first step. A low value (< 50%) suggests inadequate cardiac output; a high value (> 60%) suggests vasoplegia; however, this distinction is not completely reliable. If low cardiac output is suspected it is important to determine if there is a circuit problem (see the section on low flow/high pump speed above) or a patient problem (e.g., deteriorating native cardiac output, tamponade, vasoplegia). An echocardiogram can be useful to help determine the cause.

Treatment

Treatment is directed at the underlying cause. Inadequate cardiac output is treated by increasing circuit flow or, if there is a circuit problem, exchanging the circuit. Early diagnosis and treatment of cardiac tamponade is essential. Untreated tamponade can lead to blood stasis within the heart and intracardiac thrombus formation, which is usually fatal. Vasoplegia is treated with a vasopressor with or without methylene blue *and* by increasing circuit flow. Blood transfusion may be beneficial if the haemoglobin concentration is low (< 80-90 g/L).

Non-pulsatile arterial waveform

Aetiology

In patients with severe cardiac dysfunction, especially in the early phase of fulminant myocarditis, may develop a non-contractile LV. In this circumstance, the aortic valve may remain closed leading to a non-pulsatile arterial waveform. This situation is not ideal as there may be ongoing left-heart return (from the right heart, the bronchial circulation, Thebesian circulation, a degree of aortic regurgitation) causing marked LV distension. (Note compared to an LVAD, LV decompression with VA EMCO is less efficient; consequently, non-pulsatile waveform is more acceptable in a patient supported by an LVAD.) Severe LV distension can further damage the heart and can lead to torrential pulmonary oedema and pulmonary failure. There is also a risk of thrombus formation in the left-heart, even with adequate anticoagulation.

Diagnosis

Patients with a non-pulsatile arterial waveform should undergo an echocardiogram. Features on the echocardiogram that confirm the diagnosis are: failure of opening of the aortic valve, severe LV distension, non-contraction (or minimal contraction) of the LV, severe mitral regurgitation (which may occur in both systole and diastole). The presence of spontaneous echo contrast or frank thrombus formation is especially concerning.

Treatment

The goal is to achieve some LV ejection (manifest by return of pulsatility on the arterial waveform) and to decompress the left-heart. Useful strategies are to increase inotropic support, increase circuit flow (to ensure no blood returns to the left-heart via the pulmonary circulation), and to physically decompress the LV, either by an atrial septostomy or surgical decompression. Other alternatives include venting the pulmonary artery or insertion of an IABP.

LV Distension

There are 2 potential mechanisms for this occurring.

- An imbalance between blood entering the LV via the pulmonary circulation and blood leaving the LV via the aortic valve
- Blood entering the LV via an incompetent aortic valve

An imbalance between blood entering the LV via the pulmonary circulation and blood leaving the LV via the aortic valve

Conditions that predispose to this are:

- LV dysfunction significantly worse than RV dysfunction
- No LV ejection

The RV output accumulate and result in raised LV and LA pressures. This has the potential to cause problems via:

- LV damage related to distension
- Pulmonary oedema and lung injury
- Differential hypoxia could then develop and result in further hypoxic myocardial injury

Initial management strategies include:

- Lower the MAP
- High PEEP if appropriate (up to 20mmHg could be considered)
- Consider altering inotropes
  - *A reduction in inotropic support could improve the problem if they are resulting in RV output >> LV output*
  - *An increase in inotropic support could improve the problem if LV ejection can be significantly increased*
- Reduce ECMO flows if able
- Consideration of IABP
  - *This may encourage LV emptying enough that further invasive strategies are not needed*
  - *If this is inserted, the plan would be to remove it once LV distension is no longer an issue i.e. not planning on leaving it until ECMO decannulation*

More invasive strategies may be required to vent the LV:

- This involves consideration of the following:
  - *Perceived risk of ongoing LV distension in that patient*
  - *Risk of LV venting strategy being considered*
    - *Procedural risk*
    - *Increased circuit complexity in some instances*
  - *Predicted duration until myocardial recovery*
    - *If shorter duration, then less permanent options may be preferable*
    - *If longer duration, particularly if bridging to VAD or transplant, then more definitive and effective management may be indicated*
- Options include:
  - *Balloon Atrial Septostomy*
  - *Percutaneous transeptal LA venting*
  - *Percutaneous transaortic LV venting*
  - *Percutaenous LA venting*
  - *Thoracotomy with LV venting*
  - *Impella device*

Blood entering the LV via an incompetent aortic valve

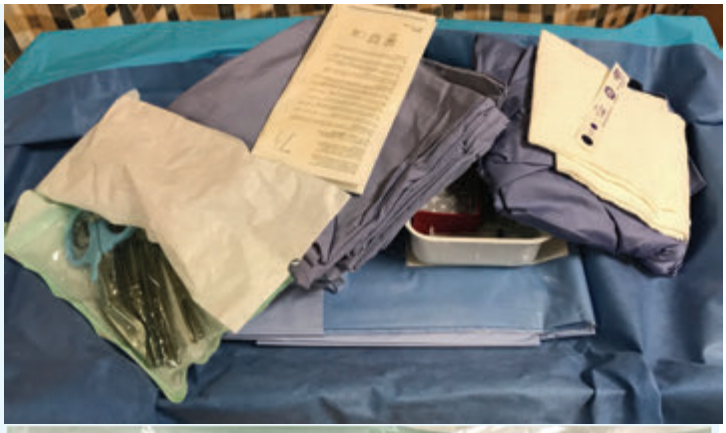
In the case of minimal or absent LV ejection, this has the potential to result in rapid increases in LV cavity pressure, with consequent increases in pulmonary capillary pressures. Florid pulmonary oedema, pulmonary haemorrhage can result and can be fatal.

Although temporising measures may be utilised (lower MAP, lower flows, adjusting inotropes , more definitive measures to drain the LV are likely to be urgently required.

ECMO 2nd oxygenator

Equipment

- CVL pack
- Gown and gloves
- 2 packs of Sterile drapes
- 2 packs of occluding clamps (contain sterile shears)
- Chlorhexidine
- Sterile swaps for cleaning circuit
- 2 x 3-way connectors
- Primed oxygenator and circuit tubing
- 50ml syringe (ideally slip nozzle)
- Plenty of saline
- Emergency drugs
  - Atropine
  - Dilute adrenaline



Patient Preparation

- Volume line available
- Appropriately sedated and paralysed

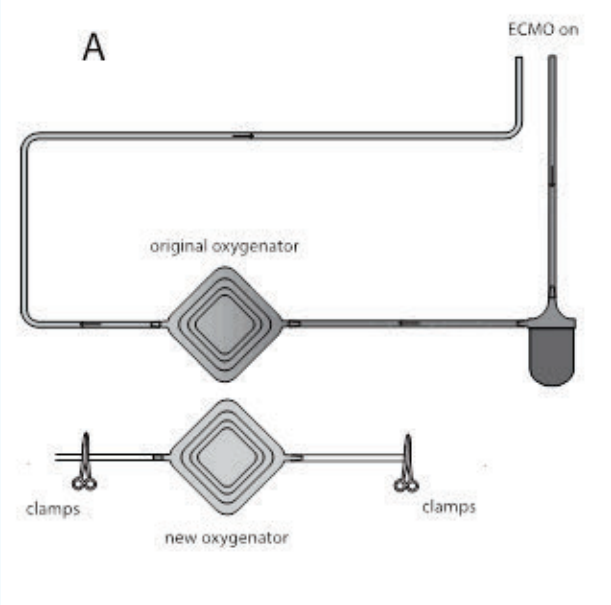
Personnal

- 2 proceduralists scrubbed
- Perfusionist
- 1 hands off leader (can be nurse) to watch observations during procedure
- Available personnel for drug administration and fetching equipment as available

Ventilator Settings

- Set to maximize oxygenation during periods where circuit is clamped.
- FiO2 of 1
- PIP 30cmH2O
- PEEP 10

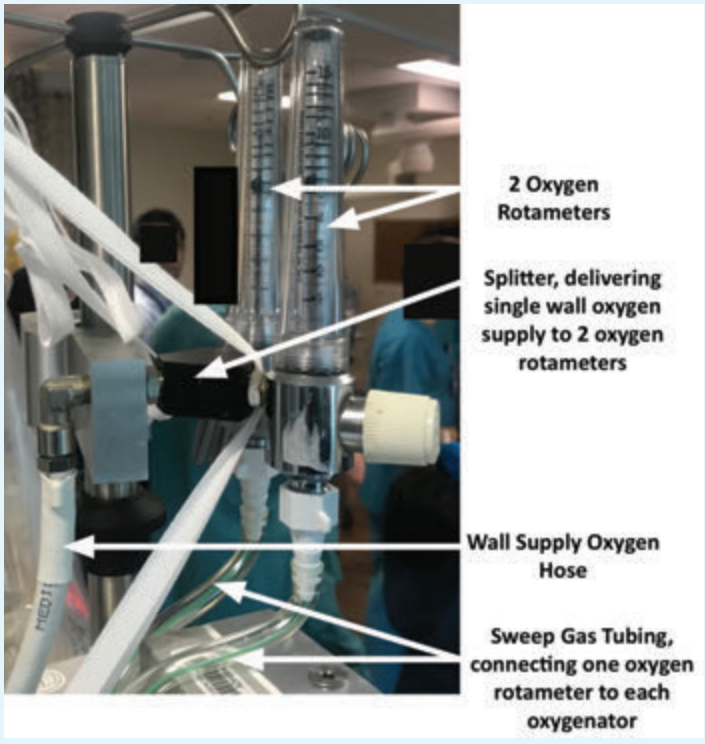
Stage 1: Prepare 2nd Oxygenator



ECMO 2nd oxygenator

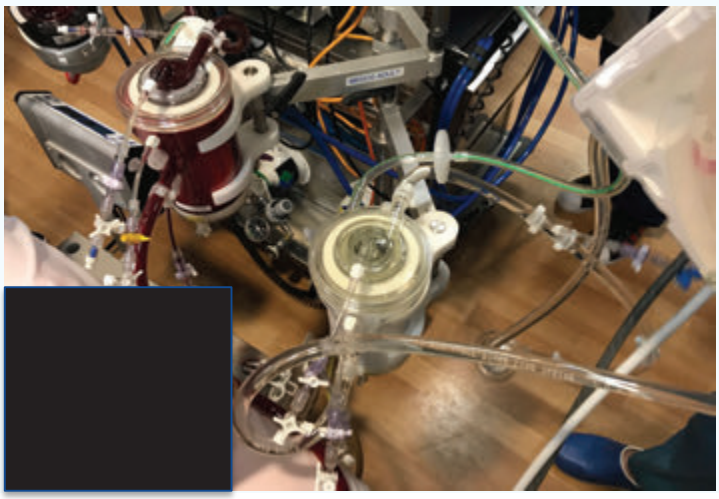
Set up to allow sweep gas flow to both oxygenators

- Oxygen hose from wall outlet feeding a splitter that supplies two rotameters.
- Each rotameter then supplies sweep gas flow (100% oxygen) to one oxygenator.



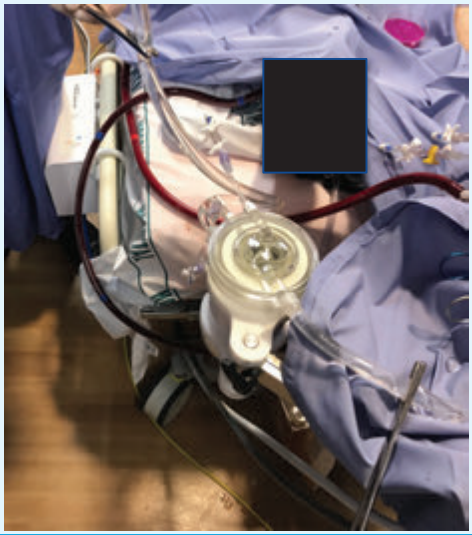
Primed Second Oxygenator

- Sitting in second oxygenator mount
- Sweep Gas Tubing connected to the oxygenator and oxygen running

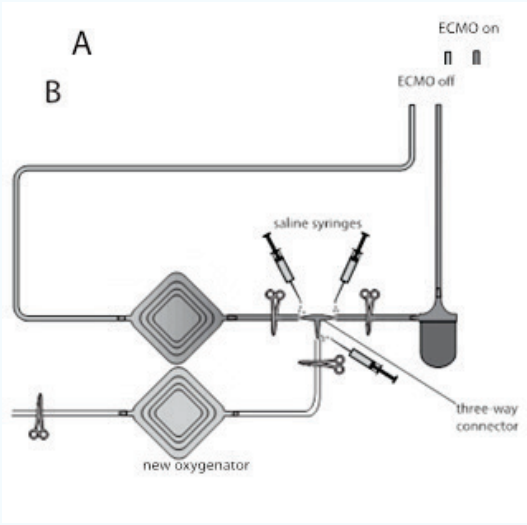


Clamp and Separate 2nd Oxygenator

- Separate primed 2nd oxygenator from the rest of the primed circuit.
- Clean the tubing attached to the 2nd oxygenator with chlorhexidene solution
- Rest the clamped, cleaned oxygenator tubing on sterile drapes



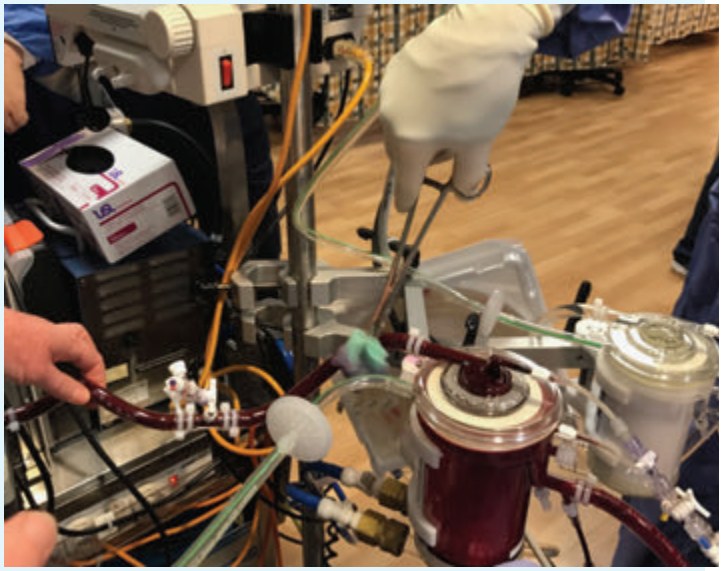
Stage 2: Incorporate 2nd Oxygenator into Existing Pre-oxygenator Circuit

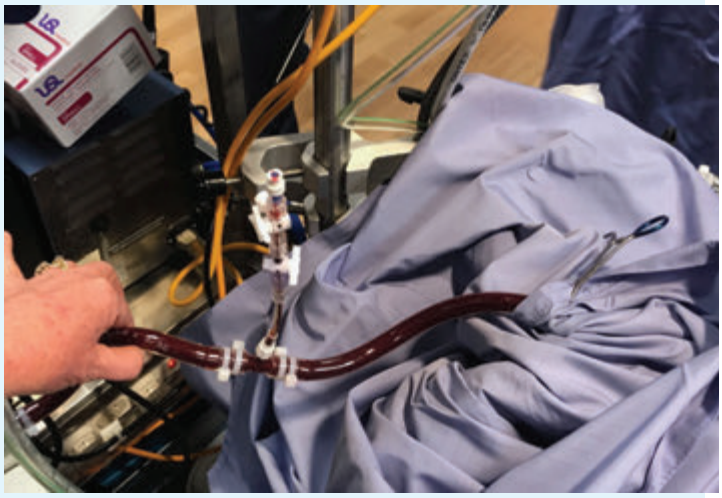


ECMO 2nd oxygenator

Prepare Existing Circuit Preoxygenator

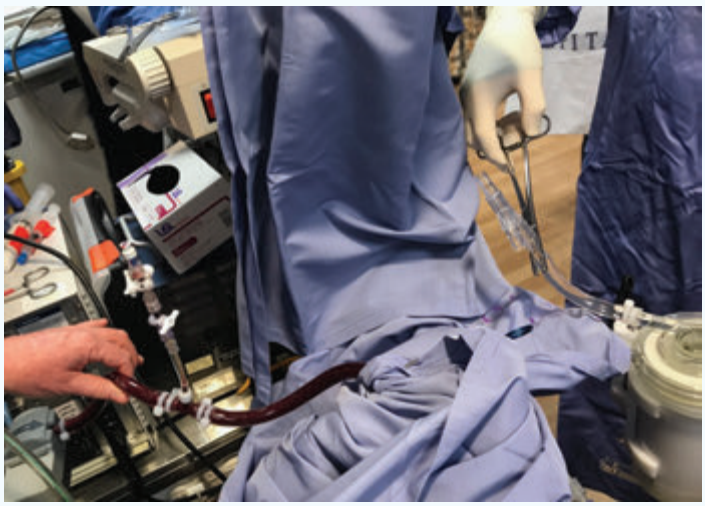
- Identify the area of tubing pre-oxygenator that is going to be divided (Usually between existing connector and oxygenator)
- Clean this area thoroughly with chlorhexidine
- Apply a drape to this area to maintain a sterile field





3 Way Connector to 2nd Oxygenator

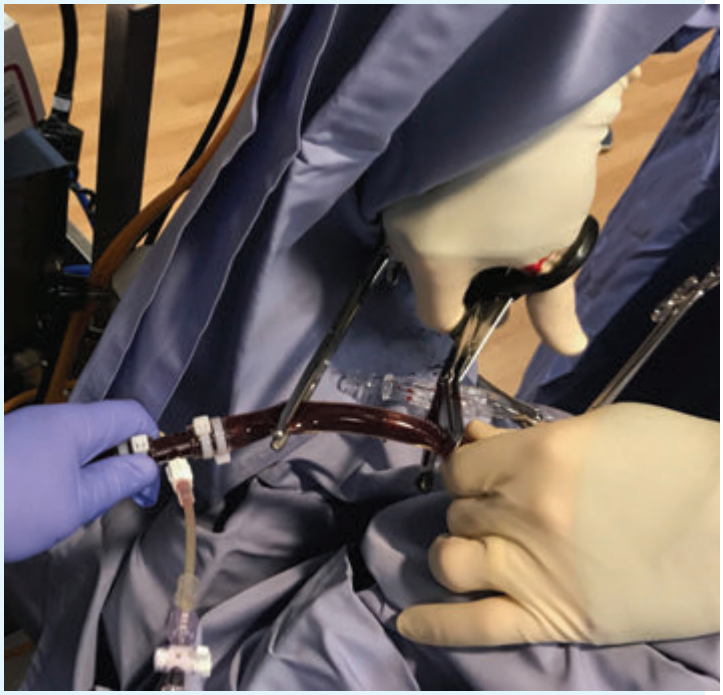
- Insert 3 way connector into Pre-oxygenator tubing of second oxygenator
- Ensure it is in the correct orientation



ECMO 2nd oxygenator

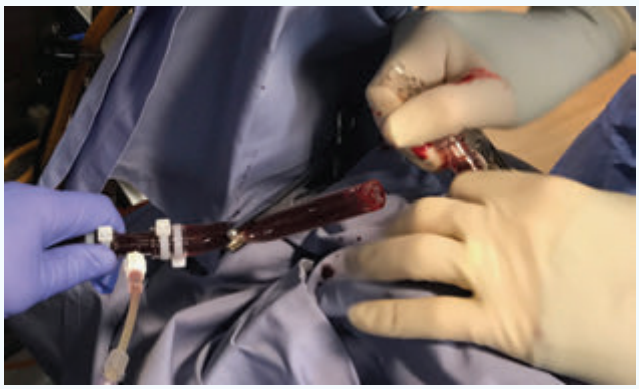
Dividing Circuit Pre-Oxygenator

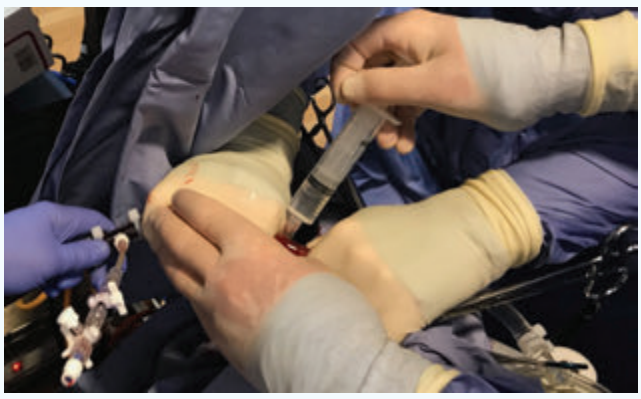
- Line up where in the existing pre-oxygenator circuit is ideal to insert the 3 way connector
- **Announce your plan and ensure all equipment and personnel are ready, including:**
- Your assistant is ready with a 50ml syringe of saline
- You have clamps and shears in easy reach
- Perfusion are ready for circuit to be clamped
- Team ready to monitor for deterioration and manage as required
- **Then:**
- Warn perfusionist and clamp the circuit 3-4cm either side of planned point of division
- Divide the circuit



Incorporating 2nd Oxygenator Tubing into Pre-oxygenator Circuit

- Connect other “trouser leg” of 3-way connector to distal limb of cut pre-oxygenator circuit (I.e. the limb of cut circuit closest to existing oxygenator).
- Whilst assistant fills 3 way connector and proximal limb of cut circuit with saline, reconnect the proximal limb of the circuit to the 3 way connector. Ensure no air bubbles in circuit once connected.

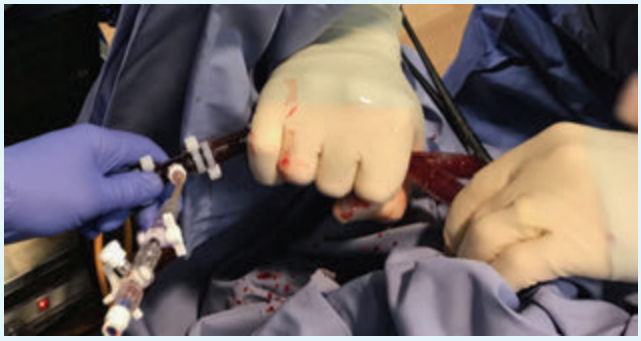


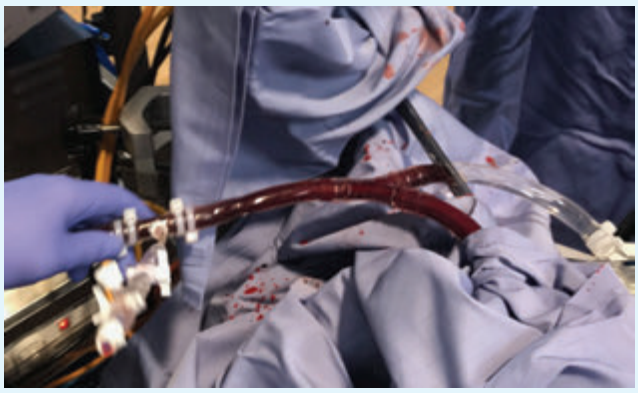


ECMO 2nd oxygenator

Release Clamps To Existing Oxygenator

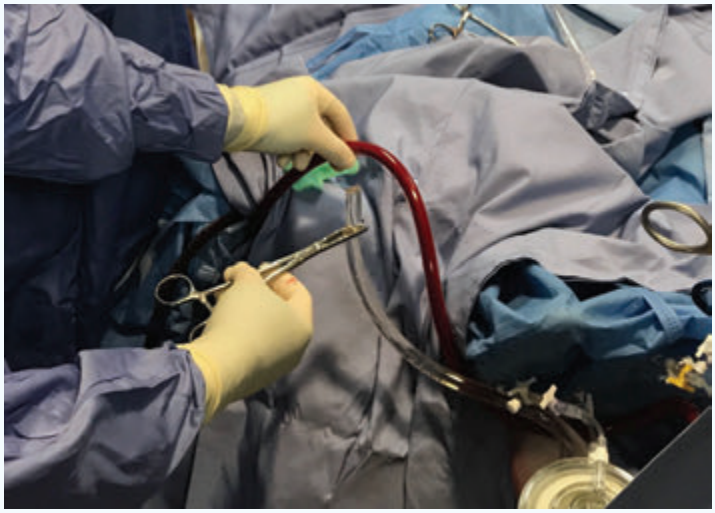
- Release clamps to existing oxygenator and ask perfusionist to increase flows back to normal.
- Keep clamp on the area of circuit leading into the second oxygenator
- Await recovery of any deterioration in patient observations whilst circuit has been clamped, and manage as appropriate

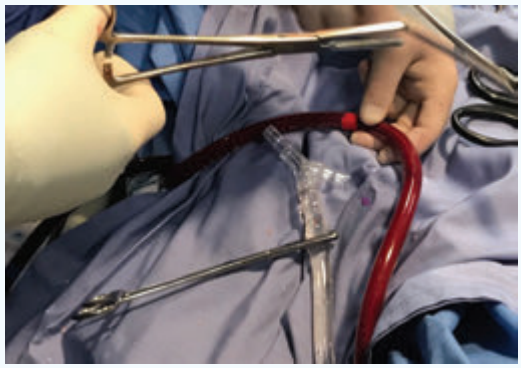




Prepare Existing Circuit Postoxygenator

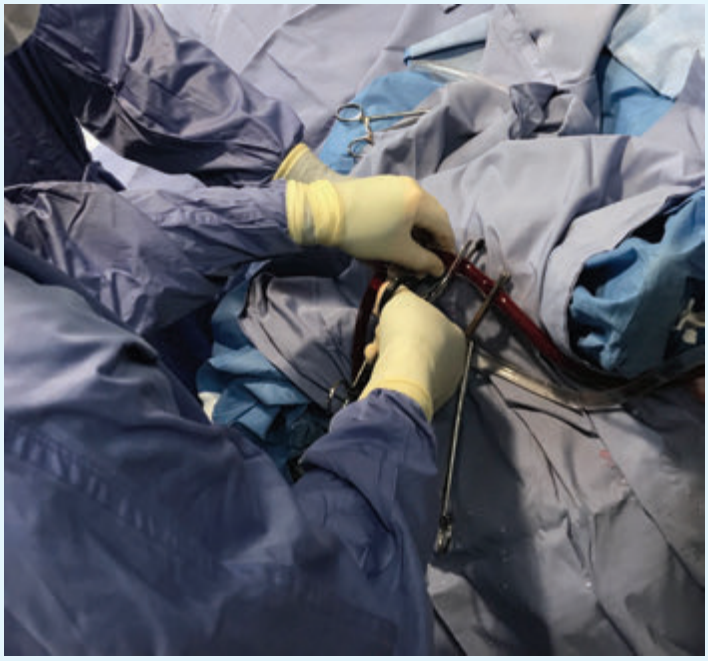
- Ensure the Post oxygenator limbs of both 1st and 2nd oxygenators are cleaned, and that the sterile field is appropriately prepared
- Insert 3-way connector into post-oxygenator limb of 2nd oxygenator





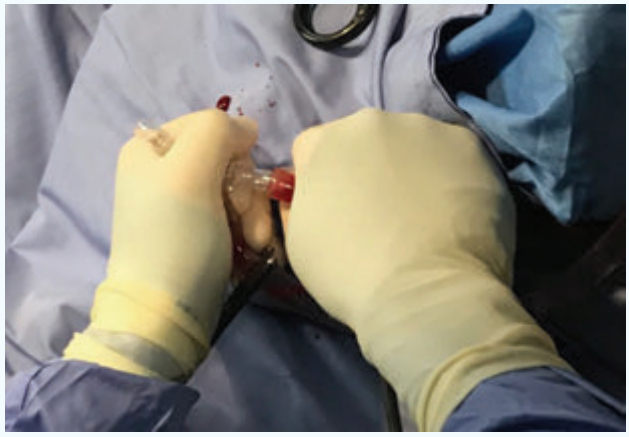
Dividing Circuit Postoxygenator

- Line up where in the existing post-oxygenator circuit is ideal to insert the 3 way connector
- **Announce your plan and ensure all equipment and personnel are ready, including:**
- Your assistant is ready with a 50ml syringe of saline
- You have clamps and shears in easy reach
- Perfusion are ready for circuit to be clamped
- Team ready to monitor for deterioration and manage as required
- **Then:**
- Warn perfusionist and clamp the circuit 3-4cm either side of planned point of division
- Divide the circuit

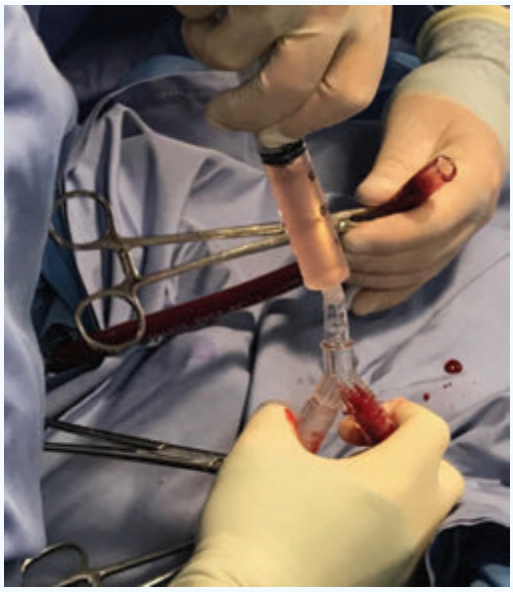


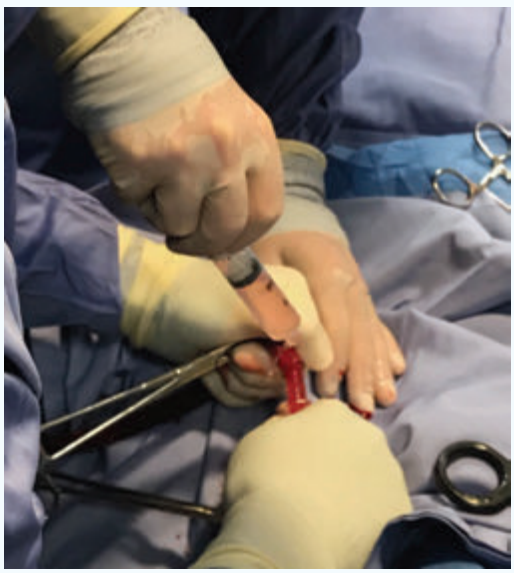
Incorporating 2nd Oxygenator Tubing into Post-oxygenator Circuit

- Connect other “trouser leg” of 3-way connector to proximal limb of cut post-oxygenator circuit (I.e. the limb of cut circuit closest to existing oxygenator).
- Whilst assistant fills 3 way connector and distal limb of cut circuit with saline, connect the distal limb of the circuit to the 3 way connector. Ensure no air bubbles in circuit once connected.



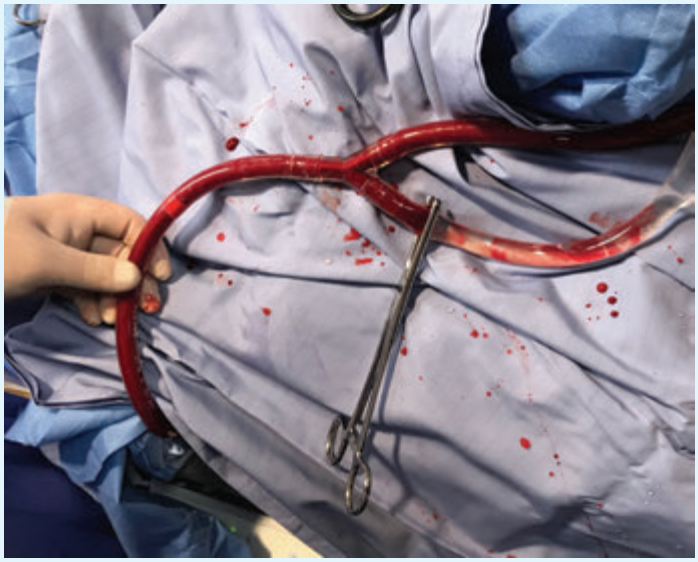
ECMO 2nd oxygenator





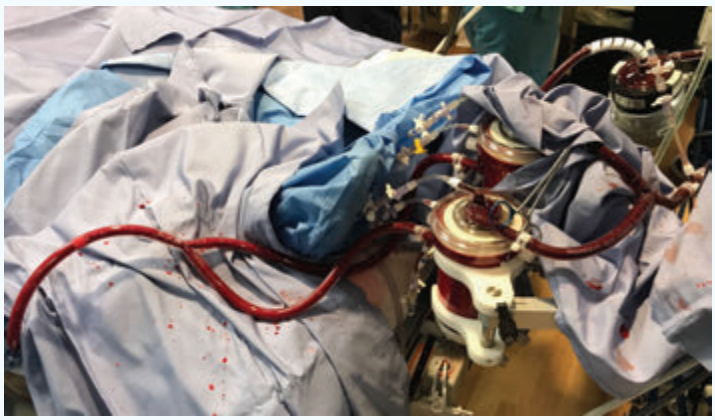
ECMO 2nd oxygenator

- Release clamps to allow flow through existing oxygenator and ask perfusionist to increase flows back to normal.
- Keep clamps on the area of circuit leading out of the second oxygenator
- Await recovery of any deterioration in patient observations whilst circuit has been clamped, and manage as appropriate



Release Clamps And Allow Flow Through Second Oxygenator

- Ensure that sweep gas tubing has been connected to the second oxygenator and that sweep gas (100% oxygen) is flowing
- Observe for any changes in patient status. Patient's oxygenation should gradually improve beyond what it was previously
- Procedure is now complete
- Ensure all clamps are gathered up and sent to CSSD for fast tracking.



ECMO Circuit change

Preparation

- **Equipment:**
  - Gloves/ gown/ mask
  - 2 x Number 10 scalpels (if connecting new circuit directly onto cannulae)
  - Sponge set + sponge holder + chlorhexidine wash
  - 2 packs of occluding clamps (contain sterile shears). At least 6 clamps are required (4 for old circuit and 2 for new circuit).
  - 2 x 50ml syringes for deairing as you connect
  - Sterile drapes
  - Sutures (if connecting new circuit directly onto cannulae)
  - 2 x end to end circuit connectors (+ 1 spare) if **not** connecting new circuit onto old cannulae

- **Emergency precautions:**
  - Adrenaline 10mcg/ml
  - Calcium
  - Blood
  - Large bore IV access and Volume line

- **Personnel**
  - 2 proceduralists – one for each limb of the circuit
  - 1 person to assist with deairing whilst connecting to the new circuit
  - 1 perfusionist
  - 1 hands off leader (can be one of the proceduralists)
  - 1 person available to administer drugs/ IVF if needed

- **Ventilator Settings**
  - Set to maximize oxygenation during periods where circuit is clamped.
  - FiO2 of 1
  - PIP 30cmH2O
  - PEEP 10

Overall procedure

There are two potential methods for changing the ECMO circuit. These differ by where the break is made in the existing circuit

- Cutting the existing circuit from the cannulae themselves and reattaching the new circuit at this point
- Clamping the drainage and return limbs of the circuit tubing and using a 2 way connector to attach the new ECMO circuit to existing tubing from the old ECMO circuit

- **Clean and Prepare areas of old circuit where clamping and division is planned.**
  - Apply glove, gown and masks
  - If connecting new circuit onto cannulae:
    - *Wash both cannula sites, existing cannulae, and proximal circuit tubing with chlorhexidine wash, to ensure both areas are as clean as possible*
    - *Release suture that holds each ECMO cannula into white cannula holder. You don't need to release any sutures securing the white cannula holder to the leg.*
    - *Drape the area to form a sterile field*
  - If connecting new circuit to existing circuit tubing:
    - *Wash both areas of tubing around where clamping and division planned*
    - *Drape the are to form a sterile field*
- **Prepare new ECMO circuit tubing**
  - Get clean circuit from perfusionist and lay out in sterile field. Align new red/blue with old red/blue lines.
  - Cut and clamp new tubing with sterile shears so that there is the right length for each cannula
  - Remove curls from tubing and ensure the two limbs aren't looped around each other
  - If connecting the new circuit to existing circuit tubing, then insert an end to end connector into each free end of the new circuit and fill with saline. Wet the free end of these circuit connectors to make them easier to slip into the tubing when performing the circuit change.
- **Preparing to change circuit**
  - One proceduralist in charge of each limb of circuit
  - Outline plan for deairing via syringe method where saline is flushed via syrnge into both free ends of tubing as they are connected, ensuring

no air enters the circuit. An extra person needs to be nominated to help with this.
- Identify the 2 places you are going to clamp to isolate the point that you plan to cut in the new circuit
- If connecting the new circuit to the cannulae themselves, then carefully incise the existing tubing that fits over the cannula ends in a lengthwise fashion. The aim is to not cut all the way through the tubing, but enough so that the tubing can be broken off the cannula connector when flexed. Care should be taken to not score the underlying cannula ridges (will lead to leak when new circuit connected).

Checklist prior to performing circuit change:

- Each proceduralist has 2 clamps, and clamp sites identified for the existing circuit.
- Plan for deairing cannula connections made
- Identified individual in charge of drug administration.
  - emergency drugs at hand,
  - line available to inject through
  - volume line available in case rapid volume administration needed
- New ECMO circuit:
  - *Gas connected and rotameter set at 6l/min*
  - *Power on*
- Announce overall plan for sequence of events

Simultaneously for return and inflow line:

- Apply proximal and distal clamps to existing circuit
- Varies between methods:
  - *If connecting the new circuit to the cannula connectors themselves, then break off the old circuit from the cannula connector via the lengthwise incision previously made*
  - *If connecting the new circuit to existing circuit tubing, then cut at the identified point between the two clamps*
- Attach new circuit to connector
  - *Syringe in saline to get rid of air*
- Remove clamps from line

Perfusionist and ECMO circuit

- Ensure flush bag clamp closed
- Clamp released from drainage limb first (risk of cavitation if return limb clamp released first)
- Pump set to 1500 RPM
- Turn on gasflow in blender
- Release return limb clamp
- Look for bright red blood in return line and dark red blood in drainage line

During recommencement of ECMO

- Hypotension:
  - *Treat with calcium chloride +/- volume +/- low dose adrenaline*
- Desaturation:
  - *This is usual during a circuit change for VV ECMO.*
  - *May be associated with significant bradycardia (HR < 40) and hypotension*
    a. Treat with atropine in 1st instance
    b. Adrenaline 50mcg if refractory

Once patient established on new circuit:

- If you have connected new circuit to cannulae directly:
  - *Secure new circuit in white circuit holders with new suture tie*
  - *Clean skin and reapply dressings*
- Apply cable ties over new circuit connections
- Dispose of sharps
- Return non disposable equipment including all clamps to perfusion

Auckland City Hospital

0800 ADULT ECMO

CVICU ECMO Referral Form

REFERRING HOSPITAL DETAILS

Date | Time

Referring Doctor | Cellphone

Referring Hospital

PATIENT DETAILS

First Name | Surname

NHI | DoB (DD / MM / YYYY) | Age | Gender (M / F) | Weight

Blood Transfusion Limitations (eg religion, antibodies etc) (YES / NO) | Height

CLINICAL DETAILS

Working Diagnosis | Allergies

Preg Test | Smoking | Alcohol

Clinical Summary

Research Studies Enrolled in/screened for

RESPIRATORY DETAILS

Intubation Date | Time

Ventilation — Mode | PEEP | PIP | PLAT

RR | TV | FiO2 | Sats

Adjuncts — Steroids | Proned | iNO

Current ABG — pH | pCO2 | pO2

BE | HCO3 | Lactate

Duration FiO2 > 80% ____ days

CXR/CT Findings

Chest Drains/Pneumothoraces

Known Underlying Respiratory Disease

Radiology sent Electronically to ADHB PACS

CARDIOVASCULAR DETAILS

Vitals	HR		MAP		CVP		CO	
Inotropes	Adr		Norad		Dopamine		Other	
Fluid balance daily/Cumulative					Feeding	NG / NJ / TPN .....mls/hr		
Urine Output			RRT		Ischaemia/mottling			
Echo findings								
Cardiac Arrest		ROSC		CNS function post arrest				
Vascular access/sites								

NEUROLOGY DETAILS

Neurology status pre-sedation		Pupil size & reactivity	
Current sedation/Paralysis			

INFECTION DETAILS

Confirmed Infection	
Current Antibiotic/Anitfungal Anitviral	

BLOOD RESULTS

Haematology	Hb		WCC		Plts			
	INR		APTT		Fib			
Biochemistry	Na		K		Creat		Urea	
	Bili		ALT/AST		Albumin			

REFERRAL OUTCOME

Accepted		Mode of Transport		Team Departure Time	
Additional Notes					

Please Fax to (09) 307-4906

ECMO Emergency Management Plan

Patient Label:

Call 777

- CVICU/PICU Intensivist on call
- Perfusionist YES / NO
- Surgeon YES / NO

Chest compressions YES / NO

Ventilation

- Disconnect from ventilator YES / NO
- Manual bagging YES / NO
- Emergency Ventilator Settings

FiO2 _____ *Default: 100%*
Mode _____ *Default: PCV+*
Peak pressure _____ *Default: 30cmH2O*
Rate _____ *Default: 18*
PEEP _____ *Default: 10cmH2O*

Other:

Signature: _____

Name (SMO): _____ Date: _____

ECMO Equipment Contingency plan

Version 1.0 | 22nd June 2017

Welcome *Haere Mai* | Respect *Manaaki* | Together *Tūhono* | Aim High

AUCKLAND DISTRICT HEALTH BOARD
Te Toka Tumai

1 Introduction

1.1 Purpose

This Extracorporeal membrane oxygenation (ECMO) equipment contingency plan establishes procedures to ensure the continuity of ECMO service is maintained, in the event of increased demand for the use of ECMO equipment. This plan is established to ensure following objectives are achieved:

- ✓ Maximise the effectiveness of contingency operations through an established plan that consists of the following phases:
  - Notification/Activation to detect and assess damage and to activate the plan
  - Recovery to restore temporary operations and recover from damage
  - Reconstitution of systems and normal operations
- ✓ Identify the critical activities, resources, and procedures needed to carry out operations during prolonged interruptions to normal operations
- ✓ Assign responsibilities to designated personnel
- ✓ Provide guidance for recovering operations during prolonged periods of interruption to normal operations
- ✓ Ensure coordination of contingency planning between stakeholders and staff responsible.

The intended audience of the ECMO Equipment Contingency Plan is the Service Clinical Director CVICU, Chief Perfusionist, Lead Intensivist, Lead Perfusionist, Clinical Director Cardiothoracic Surgery (Adult & Pediatrics) and any senior leaders whose support is needed to carry out a contingency plan. The final ECMO contingency plan document will be endorsed by the ECMO governance group

1.2 Applicability

The ECMO Contingency Plan applies to the functions, operations, and resources necessary to restore and resume normal ECMO Service operations at Auckland & Starship Hospitals.

1.3 Scope

1.3.1 Planning Principles

Various scenarios were considered to form a basis for the plan, and some assumptions were made. The applicability of the plan is predicated on:

A total number of functional ECMO machines present in the unit (7 ECMO Machines & 1 Transport ECMO Machine).

1.3.2 Equipment

Currently, there are two different types of centrifugal pumps used at Auckland District Health Board, Medtronic 560 and Maquet Rotaflow. There are three (3) Medtronic 560 centrifugal pumps and five (5) Maquet Rotaflow centrifugal pumps. Seven (7) of the pumps are on portable bypass system carts; one (1) is dedicated to ECMO transport and is permanently fixed with the ECMO transport stretcher.

Three Medtronic 560 systems and Maquet Rotaflow pumps are owned by the Greenlane Perfusion and two of the Maquet Rotaflow pumps have been bought by the Paediatric Intensive Care Unit.

The liver transplant service owns a Medtronic 560 pump and this is dedicated to liver transplantation services. Following is the list of equipment current at (May 2018).

Current Equipment list

	Owner	Site	Cart	Pump	Adaptor	Flow probe	Gas supply	Heater
1	GLPERF	ACH	PBS	Medtronic 560	Y	Adult	Sechrist	HCU35
2	GLPERF	ACH	PBS	Medtronic 560	Y	Adult	Sechrist	HCU35
3	GLPERF	ACH	PBS	Medtronic 560	Y	Adult	Sechrist	HCU35
4	GLPERF	ACH	PBS	Jostra	N/A	N/A	Sechrist	HCU35
5	GLPERF	ACH	PBS	Jostra	N/A	N/A	Sechrist	HCU35
6	PICU	SSH	PBS	Jostra	N/A	N/A	Sechrist	HCU35
7	PICU	SSH	PBS	Jostra	N/A	N/A	Sechrist	HCU35
8	GLPERF	ACH	Transport	Jostra	N/A	N/A	Transport	NA
9*	ACH LIVER	ACH	Trolley	Medtronic 560	Y (spare)	Adult (L)	Sechrist (spare)	HCU35

2 Concept of Operations

Adult and Paediatric services share the ECMO machines on a first come first basis and as required. The adult ECMO service is the major user of the ECMO equipment. The majority of the cases requiring ECMO are cannulated percutaneously either on-site or off-site, depending on the location of the patient. Historically there has been only one situation where the department had to borrow an extra pump from a regional unit as most of the ECMO pumps were all in use. This occurred during the H1N1 epidemic.

As the ECMO service has become busier and more organised it is warranted that a contingency plan is put in place to allow for an improved process during periods of high demand.

Currently, there are two ECMO machines set up and primed with paediatric and neonatal circuits. These carts are permanently kept in the starship perfusion room. The perfusion room in Auckland city hospital holds the other four ECMO machines and a dedicated transport ECMO set up. The adult service has one primed ECMO setup, which lasts for a month and is always ready to be used.

2.1 ECMO Insertion process

Once a decision is made to put a patient on ECMO one of the machines either from paediatric or adult service is used and a replacement one is set up accordingly.

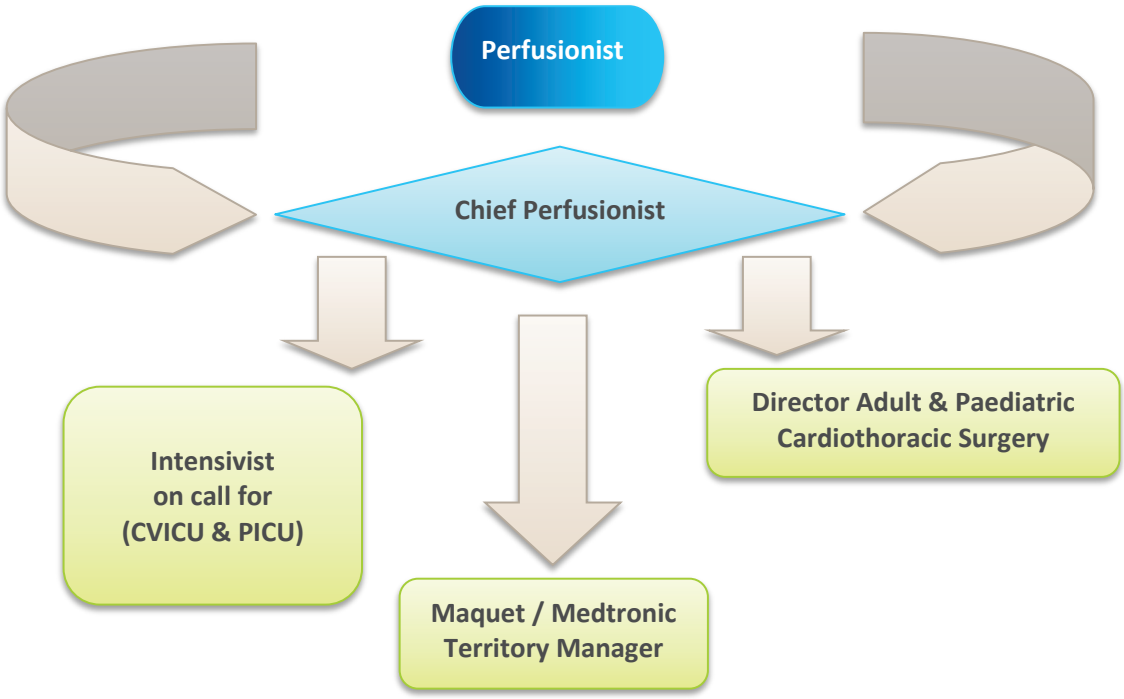
2.2 Responsibilities

The maintenance and stocking of the ECMO machines are undertaken by the perfusion department. All the consumables are the part of the perfusion department's budget. Chief Perfusionist oversees the maintenance of the stock levels and ECMO machine backup in conjunction with adult and paediatric cardiothoracic departments and intensive care departments.

Transport ECMO service is maintained by Air Ambulance Director in conjunction with perfusion department including equipment maintenance and consumables restocking.

3 Notification and Activation

In the event of only two (2) ECMO machines being available excluding the transport ECMO the following people should be contacted immediately as per the flow chart below. This means when the 4th ECMO machine is in use.



The perfusionist using the 4th ECMO machine will notify the chief perfusionist. Chief Perfusionist will, in turn, inform the on-call intensivist for PICU and CVICU. The on-call intensivists will inform the Medical Directors of Adult and Pediatric Intensive care units as appropriate and Cardiothoracic Surgery about the current level of the ECMO machines availability.

Chief Perfusionist will also inform the Medtronic / Maquet territory managers about the possibility of getting a Loan ECMO machine urgently as a backup option.

(Currently, there is no agreement with the service companies with regard to getting a unit on loan, however, if one of the current pumps is broken, the companies are happy to provide a loan pump until the broken one gets fixed).

In the event, if a loan pump cannot be sourced from the companies; the possibility of using the Liver Service ECMO machine should be considered. There is no agreement in place at present for this, so it would need to be discussed with the Director of the NZLTU. This should only be a short-term basis until another machine can be sourced with the expedite process.

4 Recovery Operations

Scenario 1: ECMO machine out for service.

Name: Perfusionist On-Call, Perfusion Coordinator

Contact Information: Contact Centre

Responsibility: Ensure Chief Perfusionist is informed.

Other: Medical Director ICU, PICU and on duty Intensivist, Service Manager Cardiac, Surgical Director Cardiothoracic Paeds / Adults.

Plan of Action: *Chief Perfusionist will ensure we have two pumps plus the transport ECMO machine available. If the companies have agreed to keep a spare machine in the country then a period with only one spare pump plus the transport pump is acceptable If not t organise a loan unit until the machine is serviced and operational.*

Scenario 2: Only two spare ECMO Machines available excluding the transport ECMO machine.

Name: Perfusionist On-Call, Perfusion Coordinator.

Contact Information: Contact Centre

Responsibility: Ensure Chief Perfusion is informed.

Other: Medical Director ICU, PICU and on duty Intensivist, Service Manager Cardiac, Surgical Director Cardiothoracic Paeds / Adults.

Plan of Action: *Chief Perfusionist will organise to get the loan unit from Medtronic / Maquet.*

Scenario 3: No ECMO available excluding the transport ECMO machine.

Name: Perfusionist On-Call, Perfusion Coordinator.

Contact Information: Contact Centre

Responsibility: Ensure Chief Perfusion is informed.

Other: Medical Director ICU, PICU and on duty Intensivist, Service Manager Cardiac, Surgical Director Cardiothoracic Paeds / Adults.

Plan of Action:

- *Discuss with NZLTU the possibility of short-term use of their pump.*
- *Urgently discuss the availability of loan pumps with companies*
- *Review patients currently on ECMO.*
- *Consider recertifying the decommissioned transport pump*

5 Return to Normal Operations

5.1 Plan Deactivation

Deactivation Procedure: Once the Number of spare ECMO machines reached two (if companies are keeping a spare pump in the country).

Name: Perfusionist On-Call, Perfusion Coordinator.

Contact Information: Contact Centre

Responsibility: Ensure Chief Perfusion is informed.

Other: Medical Director ICU, PICU and on duty Intensivist, Service Manager Cardiac, Surgical Director Cardiothoracic Paeds / Adults.

Appendix A: Contingency Plan Approval

The undersigned acknowledge they have reviewed the ECMO Equipment Contingency Plan and agree with the approach it presents. Changes to this Contingency Plan will be coordinated with and approved by the undersigned or their designated representatives.

Signature: _____ Date: _____

Print Name: _____

Title: _____

Role: _____

Signature: _____ Date: _____

Print Name: _____

Title: _____

Role: _____

Signature: _____ Date: _____

Print Name: _____

Title: _____

Role: _____

Appendix B: Personnel Contact List

Appendix C: Vendor Contact List

Manager: Alan Cavell
Phone: 0800 1438 4643
Mobile: 021 874 882
Email Address: acavell@maquet.com.au

Manager: Lesley Palmer
Phone: 021 339 910
Mobile: 021 339 910
Email Address: Lesley.palmer@metronic.com

Appendix D: Equipment and Specifications

Medtronic 560 Ecmo Machine

Maquet Rotaflow Ecmo Machine

Appendix E: Service Level Agreement

Maquet Rotaflow Common Error Messages

MAQUET
GETINGE GROUP

8 Messages

8.1 High-priority Alarms

All physiological and technical alarms of the ROTAFLOW System generate a high-priority alarm.

NOTE

Alarm settings are automatically saved after 30 seconds.

8.1.1 Physiological Alarms

Affected unit	Visual message	Acoustic alarm	Pump stop	Cause/Error source
Status display	[FAULTBUB]	Yes	Yes	Error in the integrated bubble sensor. Only occurs if the ROTAFLOW System is operated as a stand-alone device ("STAND AL" mode) and bubble intervention is activated. ■ Reapply ultrasonic contact cream (⇨ "Reapplying Ultrasonic Contact Cream", page 61).
Status display	[FAULTLEV]	Yes	Yes	Level monitoring error
Status display	[STOP ???]	Yes	Yes	Pump stopped for an as yet unknown reason, e.g.: ■ Communication error if monitoring system has been switched off ■ Immediately after reprogramming of ROTAFLOW ICU Console
Status display	[STOP BUB]	Yes	Yes	Pump stopped by bubble monitoring
Status display	[STOP LEV]	Yes	Yes	Pump stopped by level monitoring
Status display	[STOP PRX]	Yes	Yes	Pump stopped by pressure monitoring [X] (1 to 4)
Status display	[STOP-INP]	Yes	Yes	Monitoring intervention

Status display	[NO COMM.]	Yes	Yes	Communication error with HL 20 (⇨ ""ART" and "ART PULS" Modes: Communication Error with HL 20", page 63)

8.1.2 Technical Alarms

Affected unit	Visual message	Acoustic alarm	Pump stop	Cause/Error source
All displays	[ERROR! HEAD]	Yes	Yes	Drive was removed or connected with console switched on. Device was damaged. ■ ⇨ "Send Device to Authorized Service Point", page 77 Centrifugal pump was magnetically uncoupled when removed or inserted. ■ Switch console off and on to clear error. Drive and inserted centrifugal pump were shaken at a speed of 0 rpm, and this caused magnetic uncoupling of the centrifugal pump. ■ Switch console off and on to clear error.
Speed/flow display	[ERROR!]	-	-	Error, see status display for more information
Speed/flow display	[NO SEL.]	Yes	Yes	Console control module in the HL 20
Speed/flow display	[RUN-AWAY]	Yes	Yes	"Run-away": Speed is more than 20% faster than the set value (above 1000 rpm) ■ Turn rotary knob to 0 to clear error. Reaction time: ■ with continuous pumping: approx. 5 seconds ■ with pulsatile pumping: approx. 15 seconds, above 6000 rpm approx. 1.5 seconds.

Speed/flow display	[VALVE?]	Yes	-	Confirmation required that suitable systems or methods are available to prevent a reverse flow (⇨ "Switching on the Console, Self-test", page 39).
Speed/flow display	[LOW BAT.]	Yes	No	Battery operation, low battery capacity (⇨ "Battery Operation", page 29).
Speed/flow display	[BAT FAULT]	Yes	No	Battery operation, battery charging error
Speed/flow display	[BAT XX.X]	Yes	No	Battery operation, [XX.X] = Current battery voltage (⇨ "Battery Operation", page 29)
Speed indicator	[⇐⇐]	-	-	Recommendation to turn push-and-turn knob to zero.
Speed indicator	[⇑⇑⇑⇑]	Yes	No	Speed over upper speed limit (HLIM)
Speed indicator	[⇓⇓⇓⇓]	Yes	No	Speed below lower speed limit (LLIM)
Speed indicator	[!!!!]	Yes	Yes	More than one run-away [RUNAWAY] within 20 seconds. ■ Switch off pump to clear error.
Flow display	[- * * -]	-	-	Flow sensor not connected
Flow display	[---]	Yes	No	Invalid flow value
Flow display	[⇑⇑⇑⇑]	-	-	Flow > 10 lpm The ROTAFLOW ICU Console stops the pump at 12 lpm and emits an acoustic alarm.
Flow display	[⇓⇓⇓⇓]	Yes	No	Flow < lower flow limit (FLIM)
Flow display	[????]	Yes	Yes	Flow sensor error
Flow display	[DEL.]	Yes	Yes	Delay line of flow sensor
Flow display	[ERR]	-	-	Error: Flashes together with a further message
Flow display	[RAM]	Yes	Yes	Flow sensor memory error

Flow display	[SIG!]	Yes	No	Error in the integrated flow/ bubble sensor, possible incorrect flow display. ■ The ROTAFLOW Centrifugal Pump continues to function. ■ Reapply ultrasonic contact cream (⇨ "Reapplying Ultrasonic Contact Cream", page 61). ■ If the error occurs during LPM mode, the ROTAFLOW ICU Console switches automatically back to RPM mode.
Flow display	[STAT]	Yes	Yes	Flow sensor status
Flow display	[TEMP]	Yes	Yes	Flow sensor temperature
Flow display	[TXRX]	Yes	Yes	Flow sensor transmission receiver
Status display	[TEMP B⇑⇑]	No	No	Battery temperature > 50°C
Status display	[TEMP C⇑⇑]	No	No	Electronics temperature > 60°C
Status display	[TEMP M⇑⇑]	No	No	Temperature of HL 20 Drive > 50°C
Status display	[B TEMP]	Yes	Yes	Battery temperature > 60°C
Status display	[C TEMP]	Yes	Yes	Electronics temperature > 70°C
Status display	[M TEMP]	Yes	Yes	Temperature of HL 20 Drive > 70°C
Status display	[-12VTEST]	Yes	Yes	Internal power supply outside valid range
Status display	[+12VTEST]	Yes	Yes	Internal power supply outside valid range
Status display	[+5VTEST]	Yes	Yes	Internal power supply outside valid range
Status display	[AD-CONV]	Yes	Yes	A/D converter error
Status display	[ARITHMET]	Yes	Yes	Micro controller error

Status display	[EEPROM]	Yes	Yes	EPROM error
Status display	[HEAD]	Yes	Yes	Tachometer
Status display	[ILL.ERR]	Yes	Yes	Other error
Status display	[ILL.MODE]	Yes	Yes	Memory for mode
Status display	[KEYSTUCK]	Yes	No	Button pressed for longer than 15 seconds
Status display	[LAMPTEST]	Yes	Yes	Display error
Status display	[OFFSET]	Yes	Yes	Offset voltage too high
Status display	[RAM]	Yes	Yes	Internal data memory error
Status display	[REFERENC]	Yes	Yes	Internal voltage reference outside valid range
Status display	[ROM]	Yes	Yes	Internal program memory error
Status display	[SEL-LINE]	Yes	Yes	Reprogramming
Status display	[UNEXPECT]	Yes	Yes	Software error

8.2 Self-test

Affected unit	Visual message	Meaning
Flow display	[EX.X]	[X.X]: Software version
Status display	[RFC XXXX]	[XXXX]: ROTAFLOW ICU Console: Operating hours since last servicing
Status display	[RFDMXXXX]	[XXXX]: ROTAFLOW Drive: Operating hours since last servicing
Status display	[RFDS——]	Slave ROTAFLOW Drive not connected
Speed indicator, status display	[–OK– EX.X PUMP OK]	Self-test completed without errors

8.3 Temperatures

Battery

If the battery temperature exceeds 45°C, battery charging is stopped to prevent damaging the battery (⇨ "Battery Operation", page 29).

Electronics

If the temperature of the electronics exceeds 45°C, the ventilator switches to full speed. If the pump stops because the temperature is too high, the ROTAFLOW ICU Console cannot be started again until the temperature has fallen.

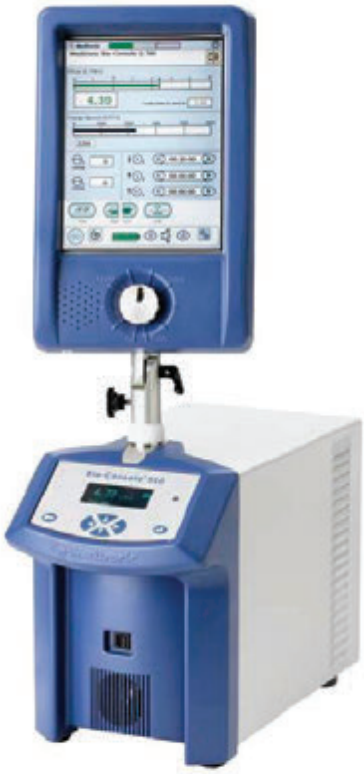
No temperature messages should appear under normal operating conditions. However, if this does happen, contact the authorized service (⇨ "Send Device to Authorized Service Point", page 77).

Medtronic

BIO-CONSOLE® 560

Extracorporeal Blood Pumping Console

Biomedicus Pump Troubleshooting and Error Messages



Checklist and Troubleshooting A

This section describes common situations that may occur when using the Bio-Console and corrective actions that may resolve these situations. If the actions recommended in this section have been followed and the situation is not resolved, consult a Medtronic service technician.

Quick Start Guide

This is a short summary of steps detailed in Chapters 3 through 5 of this manual.

	Item	Activity
1.	Be sure the Bio-Console is turned OFF before attaching components to the back panel.	■ Turn the Power On/Standby switch to OFF.
2.	Connect the components to the back panel of the Base Unit.	■ Connect the User Interface cable to the User Interface and the Base Unit. ■ Attach the pump motor cable to the back of the Bio-Console. ■ Lock the centrifugal blood pump into the external pump receptacle with the outlet positioned away from the top center. ■ Connect the flow transducer cable to the FLOW connector on the back of the Bio-Console. ■ Connect a 3-way stopcock and a fluid barrier to the male luer lock PRESSURE connector on the back panel of the Base Unit. ■ Attach optional safety systems, if desired. ■ If desired, attach a computer cable to the RS 232 digital output interface on the back of the User Interface.
3.	Check the internal batteries.	■ Turn the Power On/Standby switch to ON. ■ Turn OFF the AC power switch on the back panel. ■ With a primed Bio-Probe blood flow monitoring system attached to a centrifugal pump, turn the RPM to the highest setting for **10 seconds.** ■ Make sure the battery status indicator remains green. ■ Turn ON the AC power switch on the back panel.
4.	Check the functionality of the pump drive motor.	■ Turn the RPM knob to MAX RPM and back to the clicked OFF position. While doing this, make sure the PUMP SPEED and RPM display and graph show appropriate values.

	Item	Activity
5.	Connect, prime, and zero the pressure transducer.	■ Attach the pressure tubing with a fluid barrier and a 3-way stopcock to the PRESSURE connector on the back of the console. ■ Prime the pressure tubing. ■ Turn the 3-way stopcock so that the pressure transducer is exposed to air. ■ Press the Pressure Zero button on the User Interface Settings Screen until **0 mm Hg** is displayed.
6.	Assemble the Bio-Probe blood flow monitoring system.	■ Attach the arterial tubing to one side of the insert and the centrifugal pump outlet tubing to the other side. **Note:** Make sure an adult insert (DP-38) is used with an adult transducer (TX-50); similarly, use a pediatric insert (DP-38P) with a pediatric transducer (TX-50P). ■ Align the insert (under the transducer cover) according to the fluid path direction shown on the transducer cover. ■ Prime the centrifugal pump, insert, and tubing as described in the instructions included with the Bio-Pump centrifugal pump.
7.	Zero the flow transducer.	■ Clamp the tubing on the outlet of the centrifugal blood pump. ■ Press the Flow Zero button on the User Interface Settings Screen until **0.00 L/min** is displayed.
8.	Check the flow range and flow alarm.	■ Press the appropriate Flow Range Display button on the User Interface Settings Screen. ■ Press the upper and lower Flow Alarm Limit buttons on the User Interface Settings Screen until the desired limits are displayed.
		THE CONSOLE IS READY FOR USE

AC Power and External Motor Troubleshooting

	Situation	Checklist for Resolution
1.	No AC power to the Bio-Console.	■ Verify AC power cord is plugged into an electrical outlet. ■ Verify AC power cord is plugged into the back panel of the Base Unit. ■ Verify both the AC power switch on the back panel and Power On/Standby switch on the front panel are turned ON. If pump motor function is not restored, use a Model 150 handcrank or transfer the centrifugal blood pump to a standby Bio-Console.
2.	The pump motor does not spin.	■ Turn the knob to zero for a minimum of one (1) second, then turn the knob to the desired RPM value. ■ Verify the pump motor cable is properly connected to the back panel of the Base Unit. If power to the Bio-Console is not restored, use a replacement pump drive, Model 150 handcrank, or transfer the centrifugal blood pump to a standby console.

Bio-Pump Centrifugal Blood Pump Troubleshooting

	Situation	Checklist for Resolution
1.	The disposable pump rotates but flow is not indicated.	■ Verify flow transducer is installed with proper flow orientation and is plugged into the Bio-Console. ■ Verify the centrifugal blood pump is primed. ■ Verify all clamps are removed from flow circuit. ■ Verify RPM is sufficient to overcome the outlet resistance. ■ Verify flow circuit is free of occlusions. ■ Verify flow transducer is zeroed. (Flow value will flash if transducer is not zeroed.) If the flow display still does not function, use a standby flow transducer.
2.	The disposable pump vibrates when the RPM is increased.	■ Verify the centrifugal blood pump is placed securely in the remote drive receptacle. ■ Verify there are no foreign objects on the centrifugal blood pump or drive magnets. If the centrifugal blood pump still vibrates, replace it.

Flow Troubleshooting

	Situation	Checklist for Resolution
1.	The flow value is flashing dashes.	■ Verify the flow transducer cable is properly connected to the Bio-Console. If the flow display is still flashing dashes, use a standby transducer.
2.	The flow value is flashing.	■ Verify the flow transducer has been zeroed. ■ Verify the insert is placed correctly into the transducer. ■ Verify the insert pins are dry. ■ Verify the transducer cover is latched securely. ■ Is the system primed with either a balanced electrolyte solution or normal saline solution (not 5% Dextrose in Water [D5W] or sterile water)? ■ Verify there is no intermittent electrical interference present. When interference stops, the flow value will stop flashing. If the flow value is still flashing, use a standby transducer.
3.	The flow value flashed for a moment.	This is normal operation. (The flow changed abruptly, eg, the RPM knob was turned very quickly or a clamp was placed or removed quickly.)

	Situation	Checklist for Resolution
4.	The centrifugal pump is revolving but a flow value is not displayed.	■ Verify the flow transducer is installed with proper flow orientation and plugged into the Bio-Console. ■ Verify the centrifugal blood pump is primed. ■ Verify all clamps are removed from the flow circuit. ■ Verify the RPM is sufficient to overcome outlet resistance. ■ Verify the flow circuit is free of occlusions. ■ Verify flow transducer is zeroed. (Flow value will flash if transducer is not zeroed.) If the flow value is still not displayed, use the standby transducer or plot the RPM and difference in pressure between the inlet and outlet of the centrifugal blood pump on the charts in Appendix B.
5.	The centrifugal pump is revolving but a negative flow value is displayed.	■ Verify the fluid flow direction is aligned with the arrow on the transducer. ■ Verify the RPM is adequate to achieve positive flow.
6.	The flow transducer will not zero.	■ Verify the circuit tubing is clamped and the flow is zero. ■ Verify no electrical interference is present. ■ Verify no system errors are present. ■ Verify the transducer cover is securely closed. ■ Verify the insert pins (inside the flow transducer) are dry. If the transducer will still not zero, use the standby transducer.
7.	The displayed flow differs from the expected values.	■ Verify there are no flow circuit occlusions. Flow resistance affects the flow rate. ■ Verify the transducer is zeroed correctly.

RPM Troubleshooting

	Situation	Checklist for Resolution
1.	The RPM display is flashing.	Minor User Interface malfunction, but the RPM value is valid. Call a Medtronic service technician.
2.	The RPM display is flashing dashes.	■ Verify the pump motor is connected. If the pump motor is connected, there is a system failure. Use a backup Bio-Console. Call a Medtronic service technician.
3.	The RPM display indicates zero.	Turn the knob clockwise. If the RPM is still displayed as zero, use a standby console.
4.	The RPM knob will not turn below 2,000.	Normal operation for the RPM knob. To reduce the RPM below 2,000, press the black button on the RPM knob while turning the knob.
5.	When using the batteries, RPM is insufficient.	The battery charge is low. Prepare to use a standby Bio-Console or a handcrank.

Battery Power Troubleshooting

	Situation	Checklist for Resolution
1.	The internal batteries are not charged.	■ Verify the AC power switch is turned ON. ■ Verify the charger LED on the Console face panel is flashing. **Note:** Battery charging requires 18-24 hours. If batteries are not charged after 24 hours, call a Medtronic service technician.

Digital Output Troubleshooting

Refer to Appendix D in this manual for complete instructions.

	Situation	Checklist for Resolution
1.	The computer does not receive data.	■ Verify the cable is connected to the RS 232 interface on the back of the User Interface and to the computer. ■ Verify the baud rate and handshake method are appropriate for the device.

Safety Systems Troubleshooting

	Situation	Checklist for Resolution
1.	Cannot get green light status on the System Status Indicator when safety systems are connected.	■ Verify no system errors are present. ■ Verify all safety systems are enabled and configured. **Note:** All safety systems that are plugged in must be enabled and configured to achieve green light status except for the upper level sensor.
2.	The level sensor reports low fluid level when fluid level is normal.	■ Verify sensor is firmly fixed to reservoir. ■ Verify target on sensor is at or below the fluid level. ■ Verify red light on sensor is lit (red light is lit when fluid is present within sensor target). If sensor is properly applied and fluid is present, replace sensor cable.
3.	The level sensor reports adequate fluid level when fluid level is low.	■ Verify sensor is positioned correctly. ■ Verify red light on sensor is not lit (red light is lit when fluid is present within sensor target). ■ Remove sensor from reservoir and verify it does not detect fluid. If fluid is detected when sensor is not attached to reservoir, replace sensor cable.

	Situation	Checklist for Resolution
4.	The bubble detector reports bubbles when no bubbles are present.	■ Verify tubing is properly seated in bubble detector. ■ Verify tubing size is compatible with bubble detector. ■ Reposition bubble detector to a known bubble-free section of tubing. If bubbles are still falsely detected, disable or replace bubble detector.
5.	The bubble detector fails to report bubbles when present.	■ Verify bubble detector reports bubble when removed from tubing. ■ Reposition bubble detector. ■ Verify tubing size is compatible with bubble detector. If bubbles are still not detected, disable or replace bubble detector.
6.	AutoClamp will not open when Open Clamp button is pressed.	■ Verify RPM is >2000 when Open Clamp is pressed. ■ Verify air pressure is adequate. ■ Verify AutoClamp cables are securely attached to interface module. If AutoClamp still does not open, manually open the clamp to remove the tubing and replace clamp.
7.	AutoClamp will not close.	■ Verify AutoClamp is enabled and configured. ■ Verify bubble detector and level sensors are configured to stop the pump and are enabled. **Note:** The AutoClamp will close for pump stop or backflow or both conditions, depending on the configuration.
8.	AutoClamp malfunction error message appears.	■ Verify air pressure is adequate. ■ Verify AutoClamp cables are securely attached to interface module. If clamp malfunction error remains, manually open the clamp to remove the tubing and replace clamp.

Alert and Alarm Message Priority

Priority	Text-line 1	Text-line 2	Color
1	Communication to Base Unit Lost	Call Service	Red
2	Bubble Detected	Press Bubble Detector Button To Acknowledge	Red
3	Motor Disconnected		Red
4	Reservoir Low (Lower Sensor)	Bio-Pump Stopped — Clamp Closed	Red
5	Reservoir Low (Upper Sensor)	Bio-Pump Stopped — Clamp Closed	Red
6	Reservoir Low (Lower Sensor)	Bio-Pump Stopped	Red
7	Reservoir Low (Upper Sensor)	Bio-Pump Stopped	Red
8	Biopump Stopped — Clamp Closed	Turn Knob To 0 To Restart	Red
9	Biopump Stopped	Turn Knob To 0 To Restart	Red
10	Backflow — Clamp Closed	Press “Open Clamp” Button To Open	Red
11	Clamp Closed	Low Clamp Air Pressure	Red
12	Clamp Closed	Press “Open Clamp” Button To Open	Red
13	Backflow		Red
14	Reservoir Low (Lower Sensor)	Bio-Pump Coasting	Red

15	Reservoir Low (Lower Sensor)		Red
16	Bio-Pump Coasting	Lower Knob Speed To Disengage	Red
17	Low Battery		Red
18	Flow Transducer Disconnected		Red
19	Reservoir Low (Upper Sensor)	Bio-Pump Coasting	Yellow
20	Reservoir Low (Upper Sensor)		Yellow
21	High Flow		Yellow
22	Low Flow		Yellow
23	P1/2 High Pressure		Yellow
24	P1/2 Low Pressure		Yellow
25	AC Power Failure	Press AC Power Failure Button To Clear Alert	Yellow
26	Low Clamp Air Pressure		Yellow
27	Flow System Interference Detected		Yellow
28	Motor Controller Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
29	Flow System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
30	Pressure Monitor 1/2 Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
31	Pressure Monitor 1/2 Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
32	Clamp Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
33	Bubble Detector Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
34	UL/LL Sensor Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
35	Servo System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
36	Safety System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
37	UPS Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
38	Motor Controller Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
39	Flow System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
40	Pressure Monitor 1/2 Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
41	Pressure Monitor 1/2 Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
42	Clamp Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
43	Bubble Detector Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
44	UL/LL Sensor Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow

45	Servo System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
46	Safety System Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
47	UPS Malfunction	Press Service (Wrench) Button to Acknowledge	Yellow
48	Clamp Disabled		Yellow
49	Bubble Detector Disabled		Yellow
50	LL Sensor Disabled		Yellow
51	Medtronic Bio-Console 560		Green

CVICU Adult ECMO Manual

February 2019

AUCKLAND DISTRICT HEALTH BOARD
Te Toka Tumai

Welcome *Haere Mai* | **Respect** *Manaaki* | **Together** *Tūhono* | **Aim High** *Angamua*