KK Women's and Children's Hospital
SingHealth

Paediatric and Neonatal Extracorporeal Life Support Programme

Revised as at 29 September 2017

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1 INTRODUCTION TO ECMO PROGRAM

1.1 Extracorporeal Membrane Oxygenation (ECMO)

ECMO is a therapy that is well established as a mode of cardiac and respiratory support in reversible cardiac and pulmonary failure, especially in the neonatal and paediatric cardiac patients.

1.1.1 What is ECMO?

Extracorporeal Membrane Oxygenation (ECMO) provides lifesaving support for children with refractory cardiorespiratory failure. ECMO is a cardiopulmonary bypass device that provides complete respiratory and cardiac support and is used in intensive care units (ICU) when conventional modes of support have failed. Mechanically, blood is drained from the venous system, pumped through an artificial lung where oxygen is added and carbon dioxide removed, and then, depending on the configuration of the circuit, returned to either the venous or arterial circulation.

Basic techniques

Two types of ECMO techniques are used:
1) Veno-Arterial ECMO
2) Veno- Venous ECMO

Veno-Venous ECMO is the technique of choice if cardiac function is adequate. In newborns with cardiac compromise, Veno- Arterial ECMO is preferred.

Veno-Arterial ECMO

The right atrium is cannulated via the right internal jugular vein. Blood is actively drained from the right atrium using a centrifugal pump and pumped out through the artificial lung into the aorta. The blood circulates through the artificial lung where gas exchange occurs against a filtered gas mixture of Oxygen and CO_2. Counter current flow of blood and gas on opposite sides of the membrane allows for effective diffusion of gases between the blood and gas phases. Oxygenation can be regulated by varying flow through the ECMO circuit to the extent that laminar flow will allow. The higher the volume of cardiac output diverted through the membrane lung, the better the oxygen delivery will be from the ECMO circuit. Blood is rewarmed to body temperature before returning to the patient via an 8 to 14 Fr catheter positioned in the aortic arch through a right common carotid artery cannulation.

Veno-Venous ECMO

This is achieved by using a double lumen catheter that allows ECMO support with cannulation of the right atrium alone. Desaturated blood is withdrawn from the right atrium through the outer fenestrated venous catheter wall, and oxygenated blood from the ECMO circuit is returned to the inner arterial catheter angled to direct blood across the tricuspid valve. Higher flow rates are required to maintain adequate oxygen delivery with VV bypass, because of recirculation of desaturated and oxygenated blood within the right atrial chamber. Advantages of VV ECMO include avoidance of carotid artery cannulation and maintenance of pulmonary blood flow. The major disadvantage is that unlike VA bypass, VV ECMO does not provide cardiac support. Oxygen delivery during VV bypass depends on native cardiac output.

1.2 ECMO Programme

The KKH Paediatric-Neonatal ECMO Programme was set up in January 2012 with the aims to establish a multidisciplinary ECMO team with defined roles and responsibilities as well as to formalise workflows, establish policies and procedures, formulate training, education and accreditation requirements for specialist ECLS nurses.

1.2.1 ECMO Team members and Responsibilities

The ECLS team comprises of:

a. ECLS Programme Director
b. ECLS Deputy Directors
   i. Paediatric intensive care unit (PICU) Deputy Director
   ii. Neonatal intensive care unit (NICU) Deputy Director
   iii. Surgical Deputy Director
c. ECLS Nurse Coordinator
d. ECLS Specialist Nurses
e. Specialist consultants – cardiologists, haematologists and neurologists

Roles and Responsibilities

a. ECLS Programme Director

The ECLS Programme Director shall oversee the development of the programme in terms of infrastructure, budgeting, equipment selection and quality assurance. He/she shall also provide advice to the ECLS Coordinator on the overall operation and development of the program as well as to serve as medical liaison between the ECLS Nurses and the Departments of Cardiothoracic Surgery, Paediatrics and Neonatology.

b. ECLS PICU Deputy Director

The ECLS PICU Deputy Director shall be a qualified paediatric intensivist appointed to the Department of Paediatric Subspecialties with a specific interest in the clinical management and development of the ECMO Programme. Primary responsibilities include but are not limited to the following:

- develop policies and procedures pertaining to ECLS in the PICU
- provide clinical advice on paediatric ECLS
- serve as medical liaison between the ECLS Program and the department of surgery, nursing services, the patient's family, and all medically related ECMO issues
- conduct and/or assist in conducting medical, clinical and research on paediatric ECMO

c. ECLS NICU Deputy Director

The ECLS NICU Deputy Director shall be a qualified neonatal intensivist appointed to the Department of Neonatology with a specific interest in the clinical management and development of the ECMO Programme. Primary responsibilities include but are not limited to the following:

- develop policies and procedures pertaining to ECLS in the NICU
- provide clinical advice on neonatal ECLS
- serve as medical liaison between the ECLS Program and the department of surgery, nursing services, the patient's family, and all medically related ECMO issues
- conduct and/or assist in conducting medical, clinical and research on neonatal ECMO

d. ECLS Surgical Director

The ECLS Surgical Director shall be a qualified cardiothoracic surgeon with interest in the application of clinical ECMO, its development and clinical research. Primary responsibilities include but are not limited to the following:

- provide surgical advice to the ECLS Program
- serve as the surgical liaison between the ECMO Program and nursing, patient's family, and other surgical related ECMO issues
- conduct or assist in conducting surgical research on ECMO techniques
- provide training to surgical house staff in ECMO techniques of cannulation and decannulation
- maintain adequate support coverage (personnel and equipment) from surgical services

e. ECLS Nurse Coordinator

The ECLS Deputy Nurse Coordinator will serve as the primary liaison between the ECLS team and perfusion services, nursing, pharmacy, laboratory and transfusion services. Primary responsibilities of the ECLS Nurse Coordinator include:

- Serve as liaison between ECMO team and the patient or patient's family on all ECMO related patient issues
- Provide clinical and technical support for the ECMO team
- Conduct equipment evaluations, make technical recommendations, and establish equipment related controls
- Coordinate the repair and maintenance for all ECMO equipment with the biomedical engineering department
- Maintain ECLS Nurse Specialist roster, ensuring adequate coverage for emergency and on-going ECMO cases
- Develop and maintain training and accreditation programme for the ECLS specialist nurses. This training and accreditation programme shall be in accordance to the guidelines put forth by the ELSO Registry for ECMO Specialists. He/she shall be responsible for the ongoing education and continual assessments of the ECLS specialist nurses

f. ECLS Specialist Nurses

The programme proposes the identification and training of a core group of PICU and NICU trained nurses to be cross-trained as ECLS Specialist Nurses. These specialist nurses shall be responsible for the management of the extracorporeal circuit and troubleshooting in patients on ECLS. They will be deployed upon activation of ECLS in either PICU or NICU and be responsible for the circuit during initiation, maintenance, weaning and decannulation. They will assume the role ECMO nurse specialists during such times. Routine ICU nursing care shall be taken care of by separate ICU nurses.

g. Specialist consultants

Various other inputs are crucial in the safety of a patient undergoing extracorporeal life support therapy. These include:

- Paediatric cardiology
- Paediatric haematology
- Paediatric neurology
- Paediatric anaesthetist

1.2.2 **ECMO Nurse Specialist Training Programme**

To qualify to become an ECMO Nurse Specialist, one must satisfy all the following criteria:

a. Be a credentialed nurse in Singapore;
b. Have a job classification of senior staff nurse or above;
c. Have at least 2 years of clinical experience in paediatric or neonatal critical care;
d. Be certified and maintain current certification in advanced life support training programmes
    i. Advanced Paediatric Resuscitation Course or equivalent

Once the above criteria have been satisfied, the candidate must:

a. Complete the ECMO Nurse Specialist Training Course which is a course based upon the Guidelines and Recommendation set forth by the Extracorporeal Life Support Organization (ELSO), designed by the ECMO team;
b. Complete 50 hours of supervised ECMO case management experience, and on completion;
c. Earn a satisfactory performance rating on an ECMO competency validation verified by the ECMO team, which comprises of simulation scenarios and wet lab viva

1.2.3 **ECMO Nurse Specialist Certification Programme**

On completion of the ECMO Nurse Specialist Training Programme stated in 1.2.2, the ECMO Programme will award the candidate the designation of “ECMO Nurse Specialist” and is required maintain the accreditation on a yearly basis (reviewed and re-accredited by 30th June of each calendar year).

The annual requirements to maintain the ECMO Nurse Specialist Certification are as spelt:

a. Obtain 50 hours of case management clinical hours with primary clinical responsibility for patient management OR 6 monthly wet lab sessions if the 50 hours of case management is not fulfilled;
b. Satisfactorily complete a yearly competency assessment validation conducted and validated by the ECMO Coordinator and ECMO Medical Director that includes an assessment of all advanced care procedures, point of care tests and pharmacologic agents administered during the course of ECMO management.

2 INDICATIONS FOR PAEDIATRIC ECMO

2.1. VA ECMO

VA ECMO provides near total cardiopulmonary support. VA ECMO allows control of the cardiac output through the flow rate generated by the ECMO pump. This mode of support allows time for the heart and/or the lungs to rest as a bridge to recovery.

The clinical indications for VA ECMO in the paediatric patients include:

a. Postoperative cardiac failure when patient is unable to be weaned off cardiopulmonary bypass in the operating theatre or in the ICU with severe cardiac failure defined by pressor and inotropic requirement, metabolic acidosis, decreased urine output for 6 hours (post cardiotomy ECMO);
b. Witnessed cardiac arrest with response to CPR but still unstable and no response to CPR direct massage underway for 5 minutes (ECPR);
c. Myocardial failure unrelated to operation: myocarditis, cardiomyopathy, toxic drug overdose.

The haemodynamic and metabolic parameters that may guide the decision to institute ECMO include:

- Oxygen index (OI) >40 on 2 or more arterial blood gases, where OI = (MAP xFiO_2 x100)/Pa O_2
- Pa O_2 < 40 mm Hg for 4 h in 100% O_2
- Intractable metabolic acidosis
- Intractable shock
- Progressive, intractable pulmonary or cardiac failure
- Inability to come off cardiopulmonary bypass at operation

There are no absolute parameters that define the indications for ECMO support, and the decision to place a patient on ECMO combines both numerical data and clinical setting.

Post Cardiotomy ECMO

Myocardial stun may occur after cardiotomy or from bypass myocardial injury. It is generally felt that this should resolve 4 to 6 days after the insult. Residual uncorrected anatomical lesions must be excluded before post cardiotomy syndrome is diagnosed. In such cases, central cannulation is often used.

Emergency Cardiac Life Support

VA ECMO may be deployed as an emergency cardiac life support in the event of reversible cardiopulmonary failure that is not responding to conventional support or in the event of sudden cardiopulmonary arrest (ECPR), with an aim to bridge towards recovery.

2.2 Veno-venous ECMO (VV ECMO)

2.2.1 Indications and Contraindications

A. Indications

While no absolute indicators are known, consideration for ECMO is best within the first 7 days of mechanical ventilation at high levels of support.

B. Contraindications

a. Recent neurosurgical procedures or intracranial bleeding (within 10 days). Grade II or III intracranial hemorrhage is a general contraindication.
b. Recent surgery or trauma: increased risk of bleeding. While ECMO has been performed successfully in these patients, use of heparinized circuits and/or oxygenators may limit bleeding initially. Care to maintain adequate coagulation factors, platelet counts and use of low ACT's (160-180) may be helpful.
c. Patients with severe neurologic compromise, genetic abnormalities (not including Trisomy 21).
d. Relative: endstage hepatic failure, renal failure, primary pulmonary hypertension.

3 INDICATIONS FOR Neonatal ECMO

3.1 Inclusion criteria:

I. Respiratory Entry Criteria

a) Aa DO_2	>605-620 for 4-12 hours
b) Oxygenation Index (0I)	>35-60 for 0.5-6hrs
c) PaO_2	<35 to <60 mmHg for 2-12 hours
d) Acidosis and shock	pH < 7.25 for 2 hrs or with hypotension
e) Acute deterioration	PaO_2< 30 to 40 mmHg

II. Gestational Age > 34 weeks
Intracranial hemorrhage risk increases dramatically in patients with GA < 34 weeks

III. Birthweight ≥ 2.5 kg
Cannulation is difficult in babies with birth weight less than 2 to 2.5 kg

IV. Reversible lung disease with length of mechanical ventilation < 14 days
Irreversible conditions such as Surfactant protein B deficiency and alveolar capillary dysplasia may not be detected prior to placement on ECMO. However, once on ECMO a definitive diagnosis can be made.

V. The absence of uncontrolled bleeding or coagulopathy
The heparinization needed to prevent clotting within the ECMO circuit will contribute to any coagulopathy and potentially create uncontrollable haemorrhage.

Correct coagulation abnormalities prior to placement on ECMO

VI. No intracranial hemorrhage ≥ grade III
Grade II IVH can be managed judiciously in selected cases.

VII. No uncorrectable congenital heart disease
A cardiac ECHO should be performed prior to cannulation

VIII. Failure of optimal medical management
High frequency oscillator ventilation, surfactant and INO have all been either utilized or determined to be not helpful

IX. Decision to provide full management support

3.2 Exclusion Criteria

Lethal anomalies such as Trisomy 13, 18 and documented severe irreversible brain injury.

<u>Indications for ECMO in CDH infants</u>

Inability to maintain preductal saturations >85% or
postductal saturations >70%.

- Oxygenation index ≥ 40 present for at least 3 h.

Peak inspiratory pressure >28 cm H 2 O or
mean airway pressure >17 cm H 2 O is required to achieve saturation >85%.

- Increased PaCO 2 and respiratory acidosis with pH <7.15 despite optimization of ventilator management

- Inadequate oxygen delivery with metabolic acidosis as measured by elevated lactate ≥ 5 mmol/l and pH <7.15

- Systemic hypotension, resistant to fluid and inotropic therapy, resulting in urine output <0.5 ml/kg/h for at least 12–24 h.

Indications for ECPR and Rescue ECMO (Activation of ECMO code)

1. Sudden deterioration of an infant with reversible decease process, meet the general inclusion criteria for ECMO and failure to respond adequately to standard resuscitation

2. Witnessed cardiac arrest with immediate institution of CPR and no or inadequate response to 5 minutes of CPR

3.3 Neonatal Conditions requiring ECMO

- CDH
- Meconium aspiration syndrome
- PPHN
- Sepsis
- RDS

Rarer indications for ECMO

- Viral pneumonia (herpes simplex and adenovirus)
- Cardiomyopathy
- Hydrops fetalis

Other Indications

Pre-operative ECMO can be used to stabilize infants who are believed to have repairable cardiac defects but who are deemed to be poor surgical candidates by virtue of their clinical instability. Indications for ECMO include arterial saturation < 60%, compounded by hypotension and metabolic acidosis, unresponsive to mechanical ventilation, pharmacologic support, inotropes and vasodilators.

ECMO is also used to support post-operative period of babies who undergo cardiac surgery under prolonged bypass.

3.4 Veno Arterial ECMO

The indications for VA ECMO are:

- CDH infants meeting ECMO criteria
- Infants with significant cardiac compromise
  (Minimum inotrope requirement is not a contraindication for VV ECMO. Most patients come off from inotrope support following initiation of ECMO, once oxygenation improves.)
- Infants who fail VV ECMO can be converted to VA ECMO

3.5 VV ECMO

- VV ECMO is associated with higher survivability and lower morbidity but it does not provide Cardiac Support. It remains dependent on native cardiac output
- Around 10% needs to get converted to VA bypass because of inadequate cardiac support.
- Higher ECMO flow rate are required to maintain adequate oxygen delivery
- It is the treatment of choice in Neonatal ECMO if cardiac support is adequate
- VV ECMO avoids carotid ligation and it has better outcome

3.6 Follow up of ECMO patients

Doppler studies of the carotid arteries should be done to ensure adequate forward flow and need to be repeated on follow up.

All ECMO patients should be followed up for Neurodevelopment assessment up to the age of 5 to 8 yrs with multidisciplinary team if required.

Early Intervention Program (EIP) referral should be done prior to discharge.

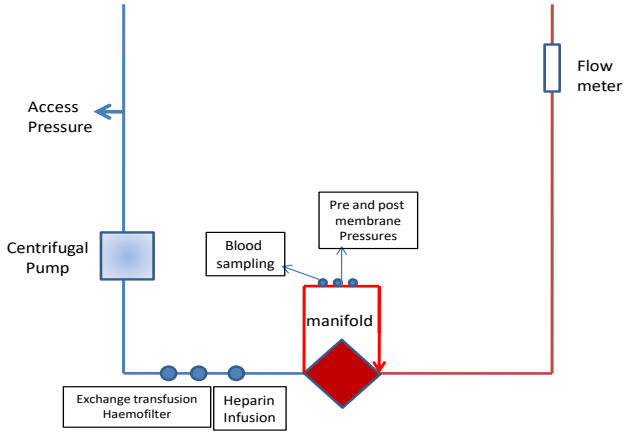
High Risk Hearing Screen should done at 3-4 months of age.

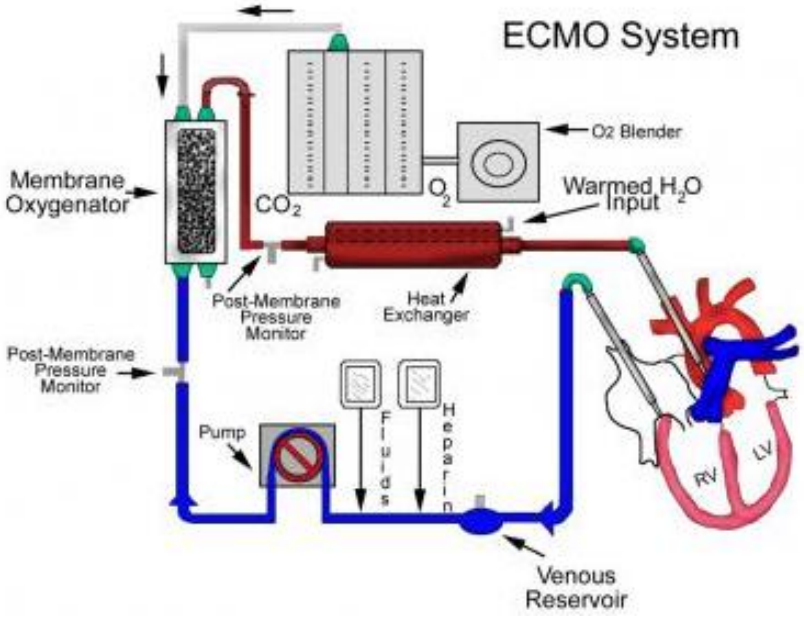
4 ECMO EQUIPMENT

Equipment required for Initiation of ECMO

- Hilite 2400 for patients less than 20kg
- Hilite 7000 for patients 20kg or greater
- Heparin coated Tubing packed ¼" in combination with Hilite 2400
- Heparin coated Tubing pack 3/8" in combination with Hilite 7000
- Rotaflow centrifugal pump or Delta Stream centrifugal pump
- Rotaflow console or Delta Stream console
- Blender
- ECMO supply cart with sterile instrument
- Albumin box
- Cannulation cart

4.1 ECMO Circuit





1. Centrifugal pump

2. Oxygenator

3. Flow transducer

   - Electromagnetic transducer
   - Placed distal to shunts
   - More accurate measurement of flow going to the patient

4.2 Oxygenator

4.2.1 Hilite 2400 LT by Medos

Paediatric hollow fibre oxygenator with diffusion membrane:

Specifications

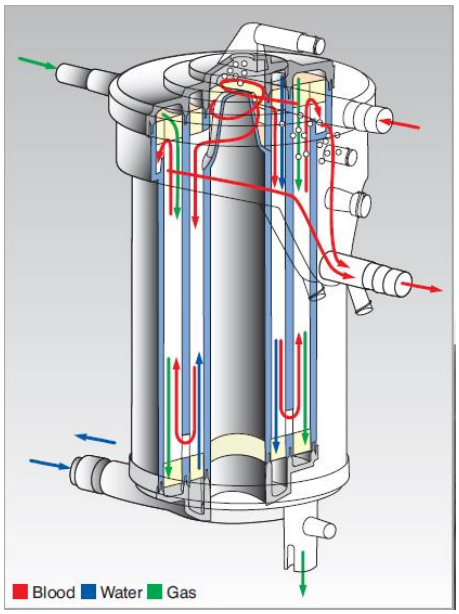
Max. blood flow	2,4 l/min
Static priming volume	95 ml
Gas exchanger	
Material:	Polymethylpentene
Type:	Plasma tight hollow fibre
ID/OD:	200/380 µm
Surface:	0,65 m^2
Heat exchanger	
Material:	Polyester
Type:	Hollow fibre
Surface:	0,16 m^2
Heat exchanger performance:	63%

4.2.2 **Hilite 7000 LT by Medos**

Adult hollow fibre oxygenator with diffusion membrane

Specifications

Blood flow rate	1-7 l/min
Static priming volume	275 ml
Gas exchanger	
Material:	Polymethylpentene
Type:	Plasma tight hollow fibre
OD:	380 μm
Surface:	1.9 m^2
Heat exchanger	
Material:	Polyester
Type:	Hollow fibre
Surface:	0.45 m^2



4.3 Centrifugal pump

4.3.1 Rotaflow Centrifugal pump

Technical Data	ROTAFLOW Centrifugal Pump RF-32 (USA)
Priming volume	32 ml
Surface	190 cm^3
Diameter of rotor	50 mm
Flow rate	0 – 10 l/min
Connectors	3/8˝
Material	Polycarbonate

4.3.2 Delta Stream DP3

deltastream® DP3

Pump

Flow	0 – 8 L/min
Speed	up to 10.000 rpm
Pressure	0 – 600 mmHg
Priming volume	approx. 16 ml
Size L, Ø	approx. 77 mm, 50 mm
Weight	38 g
Connector	3/8”

5 ECMO CANNULAE

5.1 Arterial Cannulae

Bio-Medicus Pediatric One Piece Arterial Cannula non-vented with ¼" connector & overall length 19cm				
Code	Fr	mm	Flow (l/min) @ 60mmHg	Max Wt
CB96825-008	8	2.7	0.6	Up to 3kg
CB96825-010	10	3.3	1.0	Up to 6kg
CB96825-012	12	4	1.6	Up to 16kg
CB96825-014	14	4.7	2.3	Up to 20kg

Bio Medicus Pediatric One Piece Arterial Cannula vented with 3/8" connector & overall length 43.2cm (with guidewires)			
Code	Fr	mm	Max Wt
CB96530-015	15	5	Up to 35kg
CB96530-017	17	5.7	Up to 70kg
CB96535-018	19	6.3	>50Kg

Maquet ECMO Arterial Cannula with 3/8 connector			
BE PAS 1515	15	5.0mm	Up to 35kg
BE PAS 1715	17	5.7mm	Up to 70kg
BE PAS	19	6.3mm	>50kg

5.2 Venous Cannulae

Biomedicus One Piece Venous Cannula non-vented with ¼" connector & overall length 19cm (with stylet)				
Code	Fr	mm	Flow (l/min) @ 40mmHg	Max Wt
CB96835-008	8	2.7mm	0.45	Up to 3kg
CB96835-010	10	3.3	0.875	Up to 5kg
CB96835-012	12	4.0mm	1.125	Up to 12kg
CB96835-014	14	4.3	1.875	Up to 18kg

Maquet ECMO Venous Cannula with Tip Length 80mm (with connector)			
Code	Fr	Flow (l/min) @ 40mmHg	Max Wt
BE-PVS-1938	19		

Biomedicus Adult One Piece Femoral Venous Cannula vented with 3/8" connector & overall length 43.2cm (with guidewires and dilator)			
Code	Fr	mm	Max Wt
CB96605-015	15	5	Up to 25kg
CB96605-017	17	5.7	Up to 40kg
CB96605-019	19	6.3	> 40kg

Double Lumen Venous Cathether

Desired flow for VV ECMO: 120-140 ml/kg/min

Double Lumen cathether is not used for patient < 2.5kg

Avalon Elite Cannula			
Weight of patient	Fr	Connection (")	Flow (L/min)
2.5 to 5	13 Fr	1/4	0.5
4 to 9	16 Fr	1/4	0.9
9 to 12	19 Fr	1/4	1.2
12 to 15	20 Fr	3/8	1.5
15 to 20	23 Fr	3/8	2
20 to 65	27 Fr	3/8	3.5

5.3 Central Cannulae

Central Cannulae			
Arterial		Venous	
Size	l/min	Size(Fr)	l/min
2.6mm	0.75	12	0.9
3mm	1	14	1.44
3.5mm	1.25	16	1.75
4mm	1.7	18	2
18Fr	3.3	20	2.5
20Fr	4	22	3.6
22Fr	5	24	4.26

6 CIRCUIT FLOW RATES AND CIRCUIT PRIME

6.1 Circuit Flow Rates

Wt	Flow Rates
0-3 kg	200 mls/kg/min
3-10 kg	150 mls/kg/min
10-15 kg	125 mls/kg/min
15-30 kg	100 mls/kg/min
> 30kg < 55 kg	75 mls/kg/min
> 55kg	65 mls/kg/min

6.2 Circuit prime

Drug Item	Dosing	Route	Special instructions
Albumin 20% Solution (50mL)	200 ml	Others	DO NOT ADMINISTER TO PATIENT
Calcium Chloride 10% (5.5mmol/10mL) Injection	1.5 mmol	IV	Administer to patient once ECMO flows established
Heparin Sodium 1,000 unit/mL Injection	1 unit/ml of plasmalyte A	Others	DO NOT ADMINISTER TO PATIENT; to inject into plasmalyte A
Heparin Sodium 1,000 unit/mL Injection	1 unit/ml of 20% Albumin	Others	DO NOT ADMINISTER TO PATIENT; to inject into 20% albumin
Heparin Sodium 1,000 unit/mL Injection	1 unit/ml of PRBC	Others	DO NOT ADMINISTER TO PATIENT; to inject into packed red cells
Sodium Bicarbonate 8.4% (1mmol/mL) Injection (20mL)	20 mmol	Others	DO NOT ADMINISTER TO PATIENT
Plasmalyte A solution	1 Litre	Others	DO NOT ADMINISTER TO PATIENT

7 RESCUE ECMO INITIATION GUIDELINES

7.1 Definition

Rescue ECMO is the rapid deployment of a pre-assembled ECMO, in an effort to improve outcomes for patients that suffer sudden cardiac arrest from various forms of myocardial dysfunction or respiratory failure.

7.2 Indications

The indications for rescue ECMO include:

- Sudden/ unexpected cardiopulmonary arrest
- Reversible disease process or organ failure
- Provide temporary resuscitative support
- Bridge to organ recovery or transplantation

7.3 Goals of ECLS

The goals of ECLS are:

- To provide immediate cardiac support, organ perfusion and tissue oxygenation
- To correct acidosis and hypoxaemia
- To provide mild hypothermia to lower metabolic demands and neuroprotection

7.4 Extracorporeal CardioPulmonary Resuscitation (ECPR)

ECPR may be applied in the setting of a witnessed cardiopulmonary arrest in the hospital with effective resuscitation instituted without delay. The cause of the arrest must be deemed as potentially reversible and ECMO provided as a bridge to recovery. The decision for ECPR is a joint decision made by the NICU or the PICU consultant as the code leader with the cardiothoracic surgeons and/or cardiologists. In such circumstances, ECMO code will be activated in the respective ICU.

7.5 Rescue ECMO System

- Identify patient as candidate for crash ECMO by ICU consultant
- ICU MO will call operator to activate “Attention all medical staff. ECMO team to _____” at the location of the patient
- “ECMO Code” Team comprising of the personnel stated below will respond to the code:
  - ICU consultant – code leader
  - ICU registrar
  - ICU MO
  - Anaesthetist
  - CTS surgeon on call
  - ECMO Nurse Specialist
  - ICU code nurse and bedside nurse

- A “handover” round will be given by the ICU consultant to the ECMO code team. The ICU registrar will give the “handover” if the ICU consultant has not arrived at the bedside

- Consent for ECMO will be taken by the ICU consultant +/- the cardiothoracic surgeon

7.6 Initiation Procedure

7.6.1 Equipment

The following equipment should ready and procedures performed:

During Emergency

- ECG monitor
- Airway secured and ventilation initiated
- Emergency cart
- ECMO cart
- Portable head light
- ECMO bloods for blood prime
- 2D echo bedside
- GXM,FBC,ABG, PT/PTT, ACT
- Establish lines (central and peripheral IV catheters)

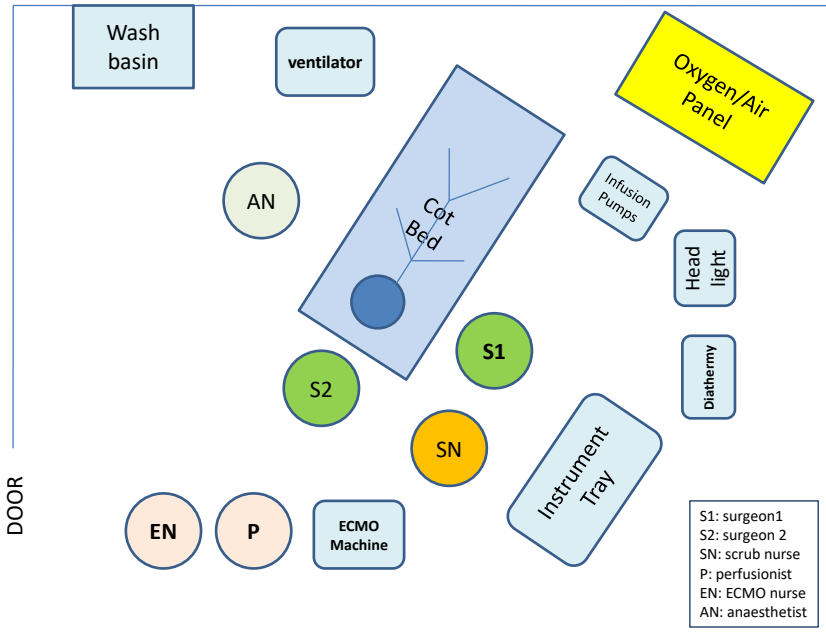
In addition (Elective ECMO Cannulation)

- Cranial ultrasound completed for neonates (except for emergency ECMO)
- NG tube inserted
- Foley catheter inserted

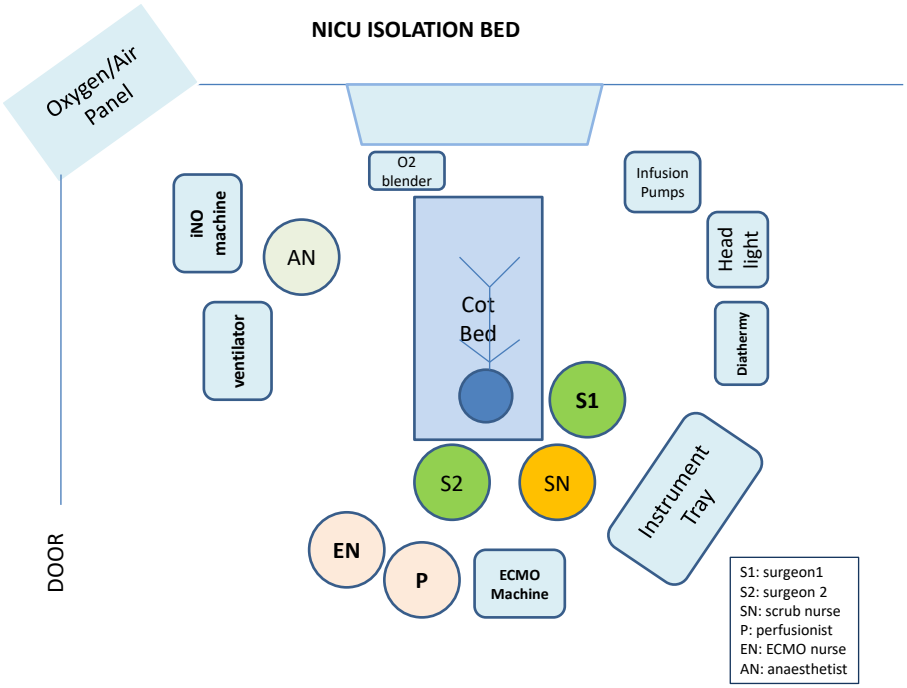
7.6.2 **Positioning**

Position child with neck extended (towel rolled under scapulae) and head turned to left.

CICU ISOLATION ROOM 16



NICU ISOLATION BED



7.6.3 **Blood products**

- Blood products used in ECMO should preferably be leucoreduced and less than 7 days old. Irradiated or washed blood may be requested for neonates if ECMO is anticipated and cannulation is expected in >4 hours

- Blood products required for ECMO circuit prime must be obtained according to the weight of the patient as below:

Weight of patient	**<10kg (Neonatal Pack)**	**> 10kg (Paediatric Pack)**
Packed red cells (leucodepleted) for **CIRCUIT PRIMING**	**COLLECT**: 1 adult unit	**COLLECT**: 1 adult unit
	STANDBY: 1 adult unit	**STANDBY**: 1 adult unit
Packed red blood cells (cross-matched), not leucodepleted. **FOR PROCEDURE**	0 unit	1 unit (STANDBY unless specified)

- Inform Blood bank (tel no: 63941376) to state need for ECMO **(Neonatal or Paediatric blood – matched or unmatched)** with the location of the patient

- In the event that leucodepleted blood packed red blood cells are not available, blood bank will provide a **leucocyte filter**. The cells will be filtered prior to use.

EMERGENCY ECMO (Both Neonatal and Paediatric)

- If EMERGENCY ECMO is initiated, please inform Blood Bank that **"ECMO (paediatric or neonatal) pack un-crossmatched"** is needed
- ICU MO to fill up blood product requisition form and **emergency blood request form**
- ICU MO will run to the Blood Bank with the forms and the ice box to collect the emergency ECMO pack
- For emergency change of ECMO circuit, the same emergency acquisition protocol applies

NON-EMERGENCY (ELECTIVE) ECMO IN PICU

- If NON-EMERGENCY (ELECTIVE) ECMO is initiated, please inform Blood Bank that **"Crossmatched ECMO (paediatric or neonatal) pack"** is needed
- ICU MO to fill up blood product requisition form
- Blood Bank will crossmatch the leucoreduced red cell concentrate in the ECMO pack
- This will take about 30 minutes, provided there is a valid group and match specimen for the patient
- Blood Bank will inform ICU when the blood is ready for collection
- ICU will have to arrange for a porter to collect the blood from Blood Bank with the blood requisition form
- For non-emergency change of ECMO circuit, blood products will need to be arranged with the Blood Bank for proper group and match

NON-EMERGENCY (ELECTIVE) ECMO IN NICU

- If NON-EMERGENCY (ELECTIVE) ECMO is initiated, please inform Blood Bank that **"Crossmatched ECMO (paediatric or neonatal) pack"** is needed
- Send the sample of blood from baby and mother to blood bank for cross matching
- ICU MO to fill up blood product requisition form
- Blood Bank will crossmatch the leucoreduced red cell concentrate in the ECMO pack
- Order 2 paediatric units of packed red cells [leukoreduced and fresh(<7days) red cells]

PLATELETS, FFP AND CRYOPRECIPITATE

- 1 unit of fresh frozen plasma and 2 units of apheresed paediatric platelets are available at KKH Blood Bank
- Requests for FFP and platelets are based on individual indications and the requisition process is as per KK Hospital protocol
- If cryoprecipitate is required, ICU MO will call Blood Services Group (BSG) MO for approval and inform Blood Bank to fetch the cryoprecipitate from Blood Services Group

7.6.4 **Medications**

Drug Item	Dosing	Route	Special Instructions
Rocuronium Br 50mg/mL injection	Loading dose: 0.6-1 mg/kg/dose Repeat doses: 0.2 mg/kg/dose	IV	
FentaNYL 100cmg/2mL injection	Dosing range: 1-2 mcg/kg/dose	IV	Slow bolus over 10 minutes
Morphine Sulfate 10mg/mL Injection	0.1 mg/kg/dose	IV	
Heparin Sodium 1,000 unit/mL injection	Loading dose: 50 unit/kg/dose Repeat loading dose: 10-50 unit/kg/dose	IV	Confirm with CTS surgeon re: dosing PRIOR to administration. Repeat loading doses to titrate based on ACT.
Heparin Sodium 1,000 unit/mL injection	Infusion: 10-40 unit/kg/hr (see online orderset for dilution guidelines)	IV	Continuous infusion to start once ECMO flows established and ACT < 220 seconds. Titrate to ACT range.
Adrenaline 1: 10,000 (1mg/10mL) injection	0.01 mg/kg/dose (0.1mL/kg of 1: 10,000 solution)	IV	
Albumin 5% Solution (250mL)	10mL/kg	IV	
Sodium Chloride 0.9% inFUSion bottle (500mL)	10ml/kg	IV	
Phenyephrine HCL 10mg/mL injection	Dose range: 2 – 10 mcg/kg	IV	Administer to large vein to prevent extravasation. Dilute to 10mcg/ml for neonates <5kg, 100mcg/ml for children >5kg
Cefazolin Injection	Term neonate < 7 days, > 2kg: 25mg/kg/dose Q12H Term neonate > 7 days, > 2kg: 25mg/kg/dose Q8H Paediatrics: 25mg/kg/dose Q6H	IV	

7.6.5 **Prepare ECMO Circuit**

- ECMO Nurse to check and verify patient's weight in clinical notes and CLMM.
- To prepare infant/paeds circuit if patient's weight <20kg
- To prepare adult circuit if patient's weight > 20kg
- Primed circuit to bedside
- Plug pump and heater/cooler in – ensure O_2 and Air gas lines plugged in
- Add one bottle of sterile water for irrigation into heater/cooler
- Set heater/cooler Temp @ 37^{o}C
- Pump on circulate at 2000 RPM (Rotaflow pump) and 3000 RPM (Delta Stream pump)
- Ensure integrity of circuit – no leaks, connections secure
- Gas line attached to oxygenator and back of flow meter **gas flow – 200ml/min and 30% FiO_2**
- Zero flow probe, access pressure, pre and post membrane pressure
- Ensure alarms are functional and limits set

Priming Solution

- Add Heparin Sodium 1000unit and Sodium Bicarbonate 8.4% 20ml into 1litre of Plasmalyte A.
- Add Heparin Sodium 200unit into the last 50ml syringe of 200mls Albumin 20%
- Add Heparin Sodium 200unit into the last 50ml syringe of 200mls Pack Cells
- Prepare 1.5mmol (2.7ml) Calcium Chloride 10% to be administered at the time of initiation of ECMO flow, to be given by anaesthetis/CICU Physicians. In the absence of a central venous line, this can be administered into the ECMO circuit by the perfusionist under the instruction of the CICU Consultant.
- Prepare Heparin Sodium 25unit/kg x 2 syringes to be administered by CICU Physicians according to patient's ACT.

Cannulation

- Select cannulae and connectors in collaboration with CTS surgeon
- Clamp arterial and venous lines distal to bridge, circulate through bridge
- Open sterile wrap around arterial line, surgeon will double clamp line using sterile clamps then cut
- Repeat the same procedure with venous line
- **Secure both venous and arterial lines to bed**
- Surgeon connects arterial and venous lines to appropriate cannula ensuring NO AIR is in the circuit

Initiation

- Prior to initiation do a final visual check
- Commence ECMO by removing clamps from arterial and venous lines
- Increase RPM to achieve desired flow, observe access pressure
- **Establish gas flow at a 1:1 blood:gas flow ratio and FIO2 30-50%**
- Send arterial blood gas and ACT within 10 minutes of initiation
- Continue monitoring of ACT every 30 minutes until ACT approaches therapeutic range (200-220 sec)
- Start heparin infusion once ACT approaches desired level of 200 seconds,
- Begin heparin infusion at 10 IU/kg/hr and titrate to effect
- Begin exchange transfusion of PRBC to increase HCT
- Restore Coagulation factors – platelets, cryoprecipitate

7.6.6 **Roles and responsibilities**

ECMO NURSE

- Prepare priming solutions
- Collect ECMO cannula, circuit, ACT cart
- Prepare and initiate ECMO clear prime in the case of an emergency
- Run ACT

ICU CONSULTANT

- Acts as ECMO code leader

ICU REGISTRAR

- Secure airway and ventilation until anaesthetist arrives
- CPR or delegates CPR
- Prepares heparin or delegates preparation

ICU MEDICAL OFFICER

- Inform perfusionist and cardiologist on call (Refer to white board for numbers)
- Fills up blood requisition form
- Bring along the blood requisition form, a cooler box with a block of well frozen ice to blood bank for emergency Neonatal, Paediatric or Adult ECMO package and 2 units of packed cells for standby in blood bank
- Calls and collects blood products

CODE NURSE / BEDSIDE NURSE

- Positions medication cart as close as possible to ordering doctor
- Draws blood and send for ABG, GXM, FBC, U/E/Cr, Ca/Mg/PO4
- Primes remote medication line with 3-way tap
- Delegates retrieval of morphine, muscle relaxant and antibiotics, warm saline
- Prepares medication and bolus fluids
- Label and double check all medications and fluids
- Ensure patient in proper position (flat, board under patient)
- Communicates with ward clerk to make necessary calls
- Prepares equipment for intubation
- Records meds and events

SCRUB NURSE

- Instruct PSA to bring cautery and headlamp
- Connects cautery to patient. Ensure appropriate size pads are placed on patient
- Plugs in head lamp
- Assist surgeon in opening ECMO tray, ECLS pack and surgical preparation

ANAESTHETIST

- Sets up oxygen, bag and mask
- Manages airway and breathing
- Fluid and drug administration
- Preparation and administration of blood products
- Administration of heparin
- Records events and medications in anaesthetic chart

NURSE MANAGER / NURSE IN CHARGE

- Brings defibrillator to bedside, plugs in ECG leads and defib pads
- Brings crash cart to bedside
- Brings and connect ventilator/ delegate to RT if available
- Assigns another RN to watch over other patients
- Ensures all equipment are available
- Ensure all communication loops are closed

PERFUSIONIST

- Primes ECMO circuit
- Prepares Cannula from ECMO cart
- Supply central cannulas from OT during an open chest cannulation
- Hands over circuit tubings to surgeon/ scrub nurse when requested by surgeon
- Runs ACT
- Manages circuit flows, sweep gas, FiO2 and heparin infusion accordingly to ACT and ABG
- Charts ECMO prime, circuit events and changes
- Ensure power supply is connected to UPS, oxygen and air supply are connected securely to wall source.
- Handover to the ECMO Nurse In-Charge prior to departure

7.6.7 Cannula position

Cannula position is checked immediately after the initiation by 2D echocardiogram. In neck cannulation, the tip of the arterial cannula should sit be at the aortic arch and the venous cannula at the SVC-RA junction or in the right atrium. In femoral cannulation, the tip of the venous cannula should be at the IVC-RA junction or in the RA. The arterial cannula tip should sit in the common femoral artery.

Chest X-ray is also performed to assess ECMO cannula position and ETT position post cannulation.

8 NEONATAL ICU INITIATION GUIDELINES

Once the decision to initiate ECMO is made (both Surgical and Neonatal team in agreement), initiate the following sequence:

1. Obtain consent from parents
2. Blood bank should be notified as early in the process as possible (see section 4.6.3)
3. Cardiac ECHO
4. Cranial ultrasound
5. Chest and abdominal x-ray
6. Order following blood tests, FBC, PT, PTT, DIC screen, U&E, Creatinine, Ca and Glucometer
7. Place patient on surgical warmer (open care cot)

8.1 Staff required

- Cardiothoracic Surgeon
- OT Nurse (*confirm with OT Sister*)
- Neonatal Consultant, Associate Consultant/Registrar and Medical Officer
- ECMO Nurse Specialist and 2 *NICU Staff Nurses*
- Perfusionist

8.2 Equipment and supplies

These equipment and supplies must be made available prior to cannulation

- Theatre instruments – to be prepared by OT Nurses
- Diathermy - from OT
- Head light - from OT
- ECLS cannula - from ECLS cart,
- ECLS cannula size Baby weight 2 to 5 kg
- Venous cannula 10-16 F
- Arterial cannula 8-14 F
- Double lumen cannula 12-14 F-Only for VV cannulation

ECMO machine – to be primed by perfusionist and ECMO Nurse Specialist.

8.3 Blood products (see section 7.6.3)

8.4 Medications

Item	Route	Calculated Dose Info	Order Details / Instructions
Lignocaine (P/Free) 1% (50mg/5mL) Injection	subcutaneous	3 mg/kg	
Rocuronium Br 50mg/5mL Injection (loading dose)	IV bolus	0.6 mg/kg/dose	loading dose
Rocuronium Br 50mg/5mL Injection (repeat dose)	IV bolus	0.3mg/kg/dose	repeat dose
FentaNYL 100mcg/2mL Injection	IV bolus	5 mcg/kg	Slow bolus over 10mins
Morphine Sulfate 10mg/mL Injection	IV bolus	0.1mg/kg	total of 2 doses required
Heparin Sodium 1,000 unit/mL Injection (loading dose)	IV bolus	50 units/kg	loading dose
Heparin Sodium 1,000 unit/mL Injection (loading dose)	IV bolus	75 units/kg	loading dose
Heparin Sodium 1,000 unit/mL Injection (loading dose)	IV bolus	100units/kg	loading dose
Heparin Sodium 1,000 unit/mL Injection (repeat loading dose)	IV bolus	10 units/kg	repeat loading dose
Heparin Sodium 1,000 unit/mL Injection (repeat loading dose)	IV bolus	25 units/kg	repeat loading dose
Heparin Sodium 1,000 unit/mL Injection	IV continuous	10 units/kg/hr	maintainance dose (max=40U/kg/hr)
Adrenaline (adrenaline bitartrate) 1:10,000 (1mg/10mL) Injection	IV bolus	0.01 mg/kg	Dose range: 0.01mg-0.03mg/kg (0.1 mL-0.3mL/kg of 1:10,000 solution)
Albumin 5% Solution (250mL)	IV Intermittent	10ml/kg	30-60mins, up to 4ml/min
Sodium Chloride 0.9% InFUSion Bottle (500mL)	IV bolus	10ml/kg	

Antibiotics

Medication Name	Order Details	Route	Frequency	Calculated Dose Info	Infuse Over	Rate
Cloxacillin Injection for Meningitis (Weight <2kg)	PNA 0-7 days	IV Intermittent	Q12H	100mg/kg/day		
	PNA >7 days	IV Intermittent	Q8H	150mg/kg/day		
Cloxacillin Injection for Meningitis (Weight ≥ 2kg)	PNA 0-7 days	IV Intermittent	Q8H	150mg/kg/day		
	PNA >7 days	IV Intermittent	Q6H	200mg/kg/day		
Cloxacillin Injection for Others (Weight <2kg)	PNA 0-7 days	IV Intermittent	Q12H	50mg/kg/day		
	PNA >7 days	IV Intermittent	Q8H	75mg/kg/day		
Cloxacillin Injection for Others (Weight ≥ 2kg)	PNA 0-7 days	IV Intermittent	Q8H	75mg/kg/day		
	PNA >7 days	IV Intermittent	Q6H	100mg/kg/day		
Gentamicin IV or IM	PMA ≤ 29 weeks (or significant asphyxia, PDA or treatment with indomethacin) & PNA 0-7 days	IV Intermittent	Q48H	5mg/kg		
	PMA ≤ 29 weeks (or significant asphyxia, PDA or treatment with indomethacin) & PNA 8-28 days	IV Intermittent	Q36H	4mg/kg		
	PMA ≤ 29 weeks (or significant asphyxia, PDA or treatment with indomethacin) & PNA ≥29 days	IV Intermittent	Q24H	4mg/kg		
	PMA 30-34 weeks & PNA 0-7 days	IV Intermittent	Q36H	4.5mg/kg		
	PMA 30-34 weeks & PNA >8 days	IV Intermittent	Q24H	4mg/kg		
	PMA ≥35 weeks & PNA ALL	IV Intermittent	Q24H	4mg/kg		
Penicillin G (Crystalline Benzylpenicillin) for Bacteremia	PMA ≤29 wks & PNA 0-28 days	IV Intermittent	Q12H	50,000 IU/kg/dose	30	minutes
	PMA ≤29 wks & PNA >28 days	IV Intermittent	Q8H	50,000 IU/kg/dose	30	minutes
	PMA 30-36 wks & PNA 0-14 days	IV Intermittent	Q12H	50,000 IU/kg/dose	30	minutes
	PMA 30-36 wks & PNA >14 days	IV Intermittent	Q8H	50,000 IU/kg/dose	30	minutes
	PMA 37-44 wks & PNA 0-7 days	IV Intermittent	Q12H	50,000 IU/kg/dose	30	minutes
	PMA 37-44 wks & PNA >7 days	IV Intermittent	Q8H	50,000 IU/kg/dose	30	minutes
	PMA ≥45 wks & PNA ALL days	IV Intermittent	Q6H	50,000 IU/kg/dose	30	minutes

Penicillin G (Crystalline Benzylpenicillin) for GBS Infection (Bacteremia)	PMA ≤29 wks & PNA 0-28 days	IV Intermittent	Q12H	200,000 IU/kg/day	30	minutes
	PMA ≤29 wks & PNA >28 days	IV Intermittent	Q8H	200,000 IU/kg/day	30	minutes
	PMA 30-36 wks & PNA 0-14 days	IV Intermittent	Q12H	200,000 IU/kg/day	30	minutes
	PMA 30-36 wks & PNA >14 days	IV Intermittent	Q8H	200,000 IU/kg/day	30	minutes
	PMA 37-44 wks & PNA 0-7 days	IV Intermittent	Q12H	200,000 IU/kg/day	30	minutes
	PMA 37-44 wks & PNA >7 days	IV Intermittent	Q8H	200,000 IU/kg/day	30	minutes
	PMA ≥45 wks & PNA ALL days	IV Intermittent	Q6H	200,000 IU/kg/day	30	minutes
Penicillin G Inj (Crystalline Benzylpenicillin) for Meningitis	PMA ≤29 wks & PNA 0-28 days	IV Intermittent	Q12H	500,000 IU/kg/day	30	minutes
	PMA ≤29 wks & PNA >28 days	IV Intermittent	Q8H	500,000 IU/kg/day	30	minutes
	PMA 30-36 wks & PNA 0-14 days	IV Intermittent	Q12H	500,000 IU/kg/day	30	minutes
	PMA 30-36 wks & PNA >14 days	IV Intermittent	Q8H	500,000 IU/kg/day	30	minutes
	PMA 37-44 wks & PNA 0-7 days	IV Intermittent	Q12H	500,000 IU/kg/day	30	minutes
	PMA 37-44 wks & PNA >7 days	IV Intermittent	Q8H	500,000 IU/kg/day	30	minutes
	PMA ≥45 wks & PNA ALL days	IV Intermittent	Q6H	500,000 IU/kg/day	30	minutes
Penicillin G Inj (Crystalline Benzylpenicillin) for Congenital syphilis	PNA ≤ 7 days	IV Intermittent	Q12H	50,000 IU/kg/dose		
	PNA > 7 days	IV Intermittent	Q8H	50,000 IU/kg/dose		

8.5 Anaesthesia

The infant is anaesthetised with fentanyl and muscle relaxation maintained. Ensure good access to airway. Hand ventilation tubing should be long enough to reach the baby. Inhaled nitric oxide should be attached if this is required by the baby.

8.6 Venous access

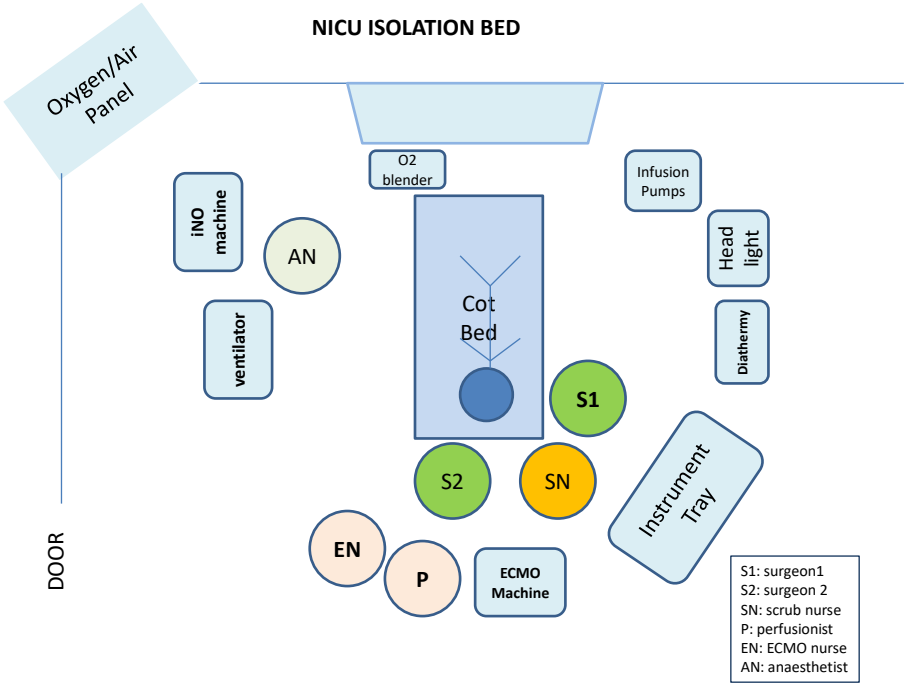
Ensure adequate venous access which is not close to the site of cannulation. Central line access is preferable and must be available **before** draping for ECMO cannulation and heparinisation. Venous access must be accessible throughout cannulation beyond the surgeons drapes by using an extension line of minimum 150 cm.

Prepare all the venous access to the leg side of the patient – Upper half will be totally covered by drapes as the chest need to be kept clear in case of emergency sternotomy.

Ensure emergency volume is drawn up, and emergency drugs are available at the bedside.
Arterial monitoring is **essential during** cannulation for ECLS and an arterial line must be in place before draping for cannulation and heparinisation.

8.7 Patient position / preparation

The patient will be placed in the open cot with head inwards foot end of the cot (Open End). Place a roll under the shoulders to extend the neck and turn the infants head to the left to expose the right side of the neck for ECLS cannulation. (Kindly see the figure for positioning of Ventilator, Nitric oxide set, Anaesthetist, 2 CTS surgeons, Scrub Nurse and Perfutionist.) All blood access should be in-situ prior to heparisation, including nasogastric tubes and urinary cathethers. Care should be taken to ensure that the ET tube is in a good position prior to cannulation (check CXR) and that it is not dislodged or kinked when positioning the head. If the patient is oscillated this may need to be discontinued and hand ventilation initiated during the cannula insertion (Oscillation is continued if CTS is comfortable with movement from vibration).



8.8 Surgical technique

The skin is prepared and covered with **drapes,** as for any surgical procedure.

8.9 VA ECMO cannulation

A skin collar incision is made on the right side of the neck. The incision is made to the border of the sternocleidomastoid muscle, preferably to the anterior border of the clavicular head of the sternocleidomastoid muscle which is retracted laterally. The carotid sheath is exposed and opened, and the carotid artery and internal jugular vein are isolated over a distance of over 2 cm. Silastic vessel loops are placed round each vessel in preparation for cannulation**.**

Having obtained absolute haemostasis, heparin 50-100 units/kg is given, as directed by the surgeon performing the cannulation, at least 3 minutes before the cannula is inserted. Heparin should be given into central access where possible & flushed with at least 5 mls of normal saline. Perfusionist performs the final check of the heparin bolus.

For veno-arterial ECLS the carotid artery is cannulated first . The cannula is cannulated with purse string on the common carotid artery. Having connected the arterial cannula into the circuit, the venous cannula is then placed in the internal jugular vein in the same fashion. In general, the largest venous catheter possible is used as venous return will then be facilitated. Having connected the venous cannula to the ECLS circuit, ECLS support may commence. The cannulae are secured with at skin level as well as on the bed and absolute haemostasis is achieved at the cannulation site.

For veno-arterial ECLS the carotid artery is cannulated first . The carotid artery is ligated distally and cannulated proximally. Having connected the arterial cannula into the circuit, the venous cannula is then placed in the internal jugular vein. In general, the largest venous catheter possible is used as venous return will then be facilitated. Two ligatures are placed proximally for each vessel and tied over a small piece of vessel loop to facilitate later removal. Having connected the venous cannula to the ECLS circuit, ECLS support may commence. The cannula are secured with several strong sutures to the skin of the neck, and absolute haemostasis is achieved at the cannulation site.

For veno-venous perfusion, a minimal surgical technique is used and a 12- 14 F double lumen catheter placed in the internal jugular vein.

8.10 Immediately after cannulation

The correct positioning of cannulae is checked with echocardiogram on table immediately following cannulation. The aim is to have the tip of the arterial cannula at the aortic arch which usually requires the cannula to be inserted 2 to 3 cm, depending on the size of the child (rib 3). The venous catheter must be inserted between 5 and 8 cm so that the tip of the cannula lies in the right atrial-IVC junction or in right atrium(rib 8-9). Echocardiogram is also an effective way of assessing the direction of blood flow in veno-venous ECLS using colour flow Doppler. A plain chest X-ray is also performed immediately following cannulation. This serves as a guide to the cannulae position after echocardiogram confirmation with subsequent follow up chest X-rays.

Straighten the child's head where possible after cannulation to aid left sided cerebral venous drainage. Incorrect cannula position usually causes blood flow problems (although not always immediately). Likewise apparently 'good' cannula positioning which does not permit full flows must be fully investigated. Surgical team is present till optimal flow is achieved.

9 RENAL REPLACEMENT THERAPY ON ECMO

9.1 Ultrafiltration

Fluid can be removed by ultrafiltration through a haemofilter attached to the ECMO circuit. In ultrafiltration, minimal solute is removed. The fluid removal rate is to be determined by the volume status of the child. The actual amount of fluid removed should be manually measured per hour.

9.2 Continuous renal replacement therapy (CRRT)

CRRT is the filtration of blood through a hollow fiber, semi permeable membrane outside of the body (extracorporeal circuit). CRRT is a slow, continuous (24 hours/day) therapy and is indicated for solute and/or fluid removal. The different modes of CRRT used are: slow continuous ultrafiltration, continuous venovenous haemodialysis, continuous venovenous haemofiltration and continuous venovenous haemodiafiltration. The indications for CRRT are:

- Fluid removal for fluid overload resistant to diuretic therapy
- Solute removal in the setting of acute kidney injury
  - Hyperkalaemia
  - Acidosis
  - Hyperphosphataemia
  - Uraemia
- Solute removal in setting of intoxication with dialyzable toxins
- Solute removal in setting of hyperammonaemia

CRRT during ECMO is done by creating a shunt from the ECMO to the PrismaFlex machine via the ECMO circuit before the oxygenator. The guidelines for CRRT is per the CRRT Policies and Procedure.

9.3 Continuous venovenous haemodialysis (CVVHD)

In continuous venovenous dialysis, blood is removed from the patient via one lumen of the dual-lumen catheter and pumped through the tubing circuit and haemofilter. Solute is removed by diffusion from the blood (higher concentration) to the dialysis solution (lower concentration) that runs countercurrent to the blood flow.

9.4 Continuous venovenous haemofiltration (CVVH)

In continuous venovenous haemofiltration, blood is removed from the patient via one lumen of the dual-lumen catheter and pumped through the extracorporeal circuit and haemofilter. Solute is removed via a convective process. In this mode of therapy, fluid replacement is required.

9.5 Continuous venovenous haemodiafiltration (CVVHDF)

In this process, solute removal is by both diffusive and convective process. Both dialysis solution and replacement solution are required.

9.6 Initiation of Ultrafiltration (UF)

Prime the appropriate filter (Infant <20kg; Adult >20kg), ensure all tubing are fully primed through with NaCl 0.9% and all air bubbles expelled. Connect the UF filter access port (red) to the three-way stopcock POST-PUMP then connect the return port (blue) to the three-way stopcock PRE-PUMP. Secure the ultrafiltration filter using the UF holder with red side facing upwards.

9.7 **Initiation of CRRT**

Prime the appropriate filter as per the CRRT Policies and Procedure. Connect the haemodialysis access port (red) to the three-way stopcock PRE-PUMP then connect the return port (blue) to the three-way stopcock POST-PUMP. A shunt is required for ECMO Adult Circuit , prime the shunt with NaCL 0.9% using aseptic technique. Connect one end to the 3-way stopcock pre-pump and the other end to the 3-way stopcock post-pump.

10 ANTICOAGULATION (*REFER TO SEPARATE DOCUMENT)

11 ECMO DAILY MANAGEMENT

11.1 ECMO Clinical Parameters

In general, patients on VA-ECMO should maintain ECMO perfusion flows at levels that achieve:

- Mixed venous oxygen saturation of >65%
- PaO_2 > 100 mmHg
- $PaCO_2$ 35-40 mmHg

In certain subgroup of patients, eg. patients with cyanotic heart conditions VA ECMO via femoral routes or VV-ECMO, goals may be different and should be reflected on the daily ECMO goals, set by the ECMO team on a daily basis.

DAILY ECMO GOALS AND GUIDELINES

Weight: _____ kg
Height: _____ cm
BSA: _____ m^2

PHYSIOLOGICAL PARAMETERS AND LABORATORY GOALS

Date/ Time					
ECMO DAY					
SBP (mmHg)					
MAP (mmHg)					
CVP (mmHg)					***Default target:***
Temp (^oC)					*35.5 - 37.0*
pH (patient)					*7.35 - 7.45*
paCO2 (patient)					*35 - 45*
paO2 (patient)					*>100*
SvO2 > %					*>65*
Haemoglobin (g/dL)					*(10-12)*
Platelet (x10^9/mm3)					*(80-120)*
Fibrinogen (g/L)					*1.5 - 4.0*
ACT (s)					*180-220*
Pump flow (ml/kg/min)					

FLUID BALANCE GOALS

SCUF **net** rate (ml/h)				
CVVH/D **net** rate (ml/h)				

11.2 Investigations during ECMO

11.2.1 Daily blood tests

	6am	12pm	6pm	12am
ABG (patient)	√	√	√	√
ABG (pre and post membrane)	√			
FBC	√		√	
PT/PTT	√		√	
Fibrinogen	√			
U/E/Cr	√			
Plasma free Hb	√			

- ACT every 1-2 hourly for 1st 24 hours, more frequently if out of range or heparin turned off. Following this, and if patient stable, reduce frequency of monitoring to q2-4H
- Bilirubin as indicated
- Blood culture if sepsis suspected
- Blood investigations and targets are ordered daily during the morning rounds

11.2.2 Echocardiogram

- At the time of cannulation
- Prior to decannulation
- PRN when volume status need to be ascertained or bleeding

11.2.3 Chest X-ray

- Post cannulation, chest & neck x ray (1 hour)
- Xray to access lung recovery (clearing) - Daily
- Post chest exploration for cardiac tamponade

11.2.4 Emergency Neck and Chest X-ray

Emergency x ray of neck and chest is ordered when venous drainage through venous cannula is significantly reduced or interrupted which is not rectified by:

- Positioning of babies head and neck
- Administering fluid volumes
- X ray chest and neck aims to exclude pneumothorax, pleural or pericardial effusion, accidental decannulation

11.3 Transfusion Guidelines

The table below outlines the transfusion targets and the transfusion requirements to achieve the targets. The targets may differ based on clinical assessment and are reviewed every morning during the ECMO rounds.

Transfusion Triggers	Blood product
Haemoglobin < 10g/dL	Leucoreduced Packed RBC (10ml/kg)
Albumin < 20g/L	0.5-1g/kg 20% albumin
Platelet count < $80x10^9$/L	Platelets 4U/m^2 of paediatric apheresed platelets (APP)
Fibrinogen < 1.5 g/L	Cryoprecipitate 5ml/kg

11.4 Haemolysis

11.4.1 Diagnosis

- Increased plasma free haemoglobin (>0.1g/dL)
- Pink colouration of the urine
- Continuing drop in the haematocrit levels without obvious signs of bleeding

11.4.2 Causes of haemolysis during ECMO

Poor flow dynamics in the ECMO circuit which may be a result of:

- Clot in circuit - check for high D-dimer level
- High RPM to achieve calculated flow
- Cannula too small for calculated flow
- Excessive negative pressure

11.4.3 Risk to the patient

Haemolysis can result in:

- Haemoglobin induced acute kidney injury
- Anaemia resulting in reduced oxygen carrying capacity of the blood
- Hyperkalaemia

11.4.4 Blood sampling for plasma free haemoglobin

Plasma free haemoglobin is tested on a daily basis for patients on ECMO. Blood samples must first be taken and sent to the laboratory for centrifugation. The centrifuged (plasma) sample is then tested for free haemoglobin using the point-of-care measurement. The workflow for centrifugation is instructed below

Instruction for centrifugation of ECMO blood specimen

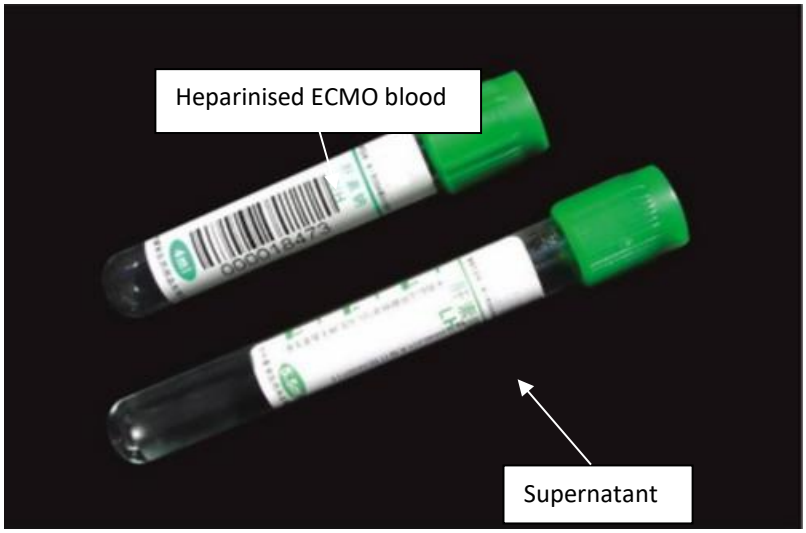
To fill in required patient info on the request form as shown below.

Request for centrifugation of ECMO blood specimen	
Attention: .Ms Ang Soh Hong Haematology Laboratory Tei. no: 63941373 From: Name of ECMO specialist i/c:_____ Location: _____ Contact no: _____	*Paste Patient ID sticker label here*

Lab use:

Date received:	_____ Day / Month / Year
Time received:	_____Hr.
Signature:	_____
Blood specimen (heparinized) centrifuged:	**10 mins. at 3,000 rpm** (Hettich Rotofix 32A Centrifuge)
Appearance of plasma:	Clear / Turbid / Haemolysed *(Please delete accordingly)*
If plasma is turbid, centrifuge supernatant for another 10 mins.	
Appearance of re-centrifuged plasma:	Clear / Turbid / Haemolysed *(Please delete accordingly)*
Performed by:	Lab Staffsignature: _____
	Time completed: _____ Hr.
	Time aliquot collected by porter: _____Hr.

1. Inform porter to bring to Lab Reception the request form and the packet
2. Packet must be labelled with 1“heparinised” ECMO blood tube + 1 labelled empty tube for Lab to put in the centrifuged supernatant.



3. Tell porter that after his/ her delivery, to return to Lab 20 mins later to pick up the tube of centrifuged supernatant

11.4.5 **Management of haemolysis**

The management of the haemolysis during ECMO involves the identification and correction of causes.

In the case of high plasma free haemoglobin levels (>0.1g/dL) alone, consider changing the pump head.

In the case of high plasma free haemoglobin levels (>0.1g/dL) with consumptive coagulopathy (low fibrinogen, high D-dimers), consider changing the pump and circuit.

11.5 **Routine Management**

- Neurological
  - Monitor level of consciousness, pupil size, equality and response to light every hourly
  - Monitor anterior fontanelle for size in infant
  - Monitor for any signs of seizures
  - Ultrasound head for neonates and infants
  - Train of four once daily for patients with pharmacological paralytic agents

- Cardiovascular
  - Continuous cardiac monitoring (rhythm,capillary refill time, peripheral pulses, central and peripheral color, signs of edema)
  - Assess peripheral perfusion with femoral cannulation using circulation chart
  - Maintain adequate cardiac preload with volume (e.g. Albumin, blood products) readily accessible
  - Avoid increased SVR (hypothermia and excessive inotropic agents)

- Pulmonary
  - Decrease ventilator settings to allow lung rest
  - Maintain functional residual capacity to facilitate oxygenation of pulmonary blood flow without over ventilating the lungs
  - Gentle pulmonary toilet to avoid bleeding

- Gastrointestinal

- Asses for presence of bowel sounds, abdominal distention
- Assess gastric drainage & stool output, monitor for bleeding
- Ranitidine or Omeprazole as indicated
- Provide parental nutrition as indicated and promote early enteral feeding

- Fluid & Nutrition
  - Strict I/O
  - Oliguria is common during first 24 to 48hours
  - Diuretics to promote patient diuresis as appropriate
  - Hemofiltration or hemodialysis may be added to ECMO circuit if renal failure does not improve

- Infection
  - Usual indicator for sepsis are unreliable since platelets are routinely destroyed by the circuit and temperature is controlled by the heat exchanger.
  - Signs: glucose instability, peripheral vasodilation or vasoconstriction, wound infection
  - Routine monitoring of FBC +/- inflammatory markers (eg. CRP and/or procalcitonin)
  - High index of suspicion for infection
  - No role for routine antibiotics
  - Consider fungal prophylaxis in neonatal ECMO patients

  * Fungal Prophylaxis on ECMO
    - Consider in all high risk patients
      - ➔ Neonates: Preterm < 37 weeks, Suspected DiGeorge/ other immunocompromised states, Open chest
      - ➔ Paediatric: Known immunodeficiency, Post-transplant, Open chest
    - Start within 24 hours of ECMO initiation
    - Dose: Loading: IV Fluconazole: 12mg/kg/dose followed by maintenance IV Fluconazole 6mg/kg Q24H till decannulation/ off ECMO
    -

- Pain and Sedation
  - Avoid excessive movement which may result in cannulation site bleeding or risk of cannula dislodgement
  - Provide analgesia and sedation as appropriate
  - Minimize use of pharmacological muscle relaxants to assess neurological status and promote spontaneous respiratory effort

- Family Education
  - Assess family's level of education, readiness to learn and provide information as appropriate (ECMO information sheet)
  - Utilize resources such as medical social worker, play therapist and music therapist

- Skin & Immobility
  - Gentle change in position every 3 hours and PRN as tolerated
  - Utilize pressure reducing surfaces (silicone gel pad)
  - Maintain body alignment (avoid neuropathy with femoral cannulation)
  - Monitor lower limb circulation every hour for femoral cannulation

12 WEANING AND DECANNULATION

12.1 Weaning

- The decision to wean is made when the patient's cardiopulmonary function has recovered to an extent that is deemed adequate to be weaned off ECMO. The ECMO support is gradually reduced until the patient is eventually separated from the ECMO circuit
- Optimal atrial filling pressure is achieved before weaning of ECMO flow. Inotropic infusion (dopamine 5-15 mcg/kg/min) and other inotropic support may be required
- In preparation for the patient to be "trialled-off" ECMO, all medications and infusions into the ECMO circuit must be transferred to the patient's own intravenous access
- During weaning, the ECMO pump flow is reduced slowly to allow patient to equilibrate to lower support. In VA ECMO, cardiac contractility is assessed by 2D echocardiography
- When the ECMO flow is reduced to 25% of cardiac index, heparin infusion is increased by 10% to aim for an ACT of 300s
- ECMO decannulation can be initiated if assessments of the cardiac and respiratory function at this support are assessed to be adequate
- Connect IV adrenaline infusion to the patient before initiating ECMO decannulation
- Standby E-cart, albumin 5% and Adrenaline 1:10,000 as appropriate
- Assign a recorder and time-keeper to record duration when pump is off.

NOTE: If the patient's mean arterial pressure is equal to the post-membrane pressure during the weaning procedure, dynamically there is no flow between the patient and the ECMO circuit. Therefore, the potential for clotting the entire circuit is inevitable.

12.2 Decannulation

The decision to decannulate is made after a successful "trial-off" period during weaning or if the cardiopulmonary failure is deemed irreversible. The general rule is that the patient must be able to maintain PaO_2 on a FiO_2 of 50% or less with moderate to low vent settings. In a cardiac patient, the amount of pressor support and ventricular function are also considered.

Preparation

- Valid consent
- Fax OT Chit to OT
- Extend an access line from patient ending with a 3-way tap
- Position patient according to surgeon's recommendation
- Check ABG and ACT

The following medical personnel are present during the decannulation procedure:

- Cardiothoracic surgeon
- Anaesthetist
- Scrub nurse
- ECMO nurse specialist
- Perfusionist
- ICU bedside nurse
- ICU Nurse
- ICU consultant/ registrar

The following equipment should be available during the decannulation process:

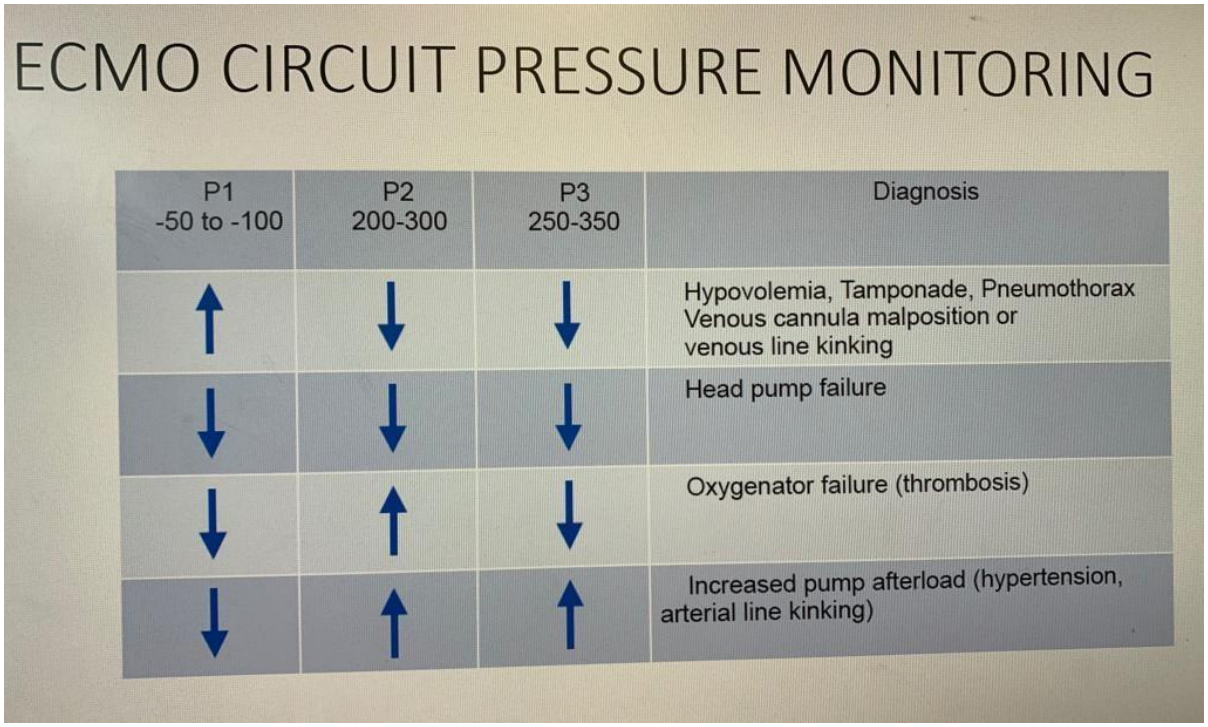
- Emergency trolley
- Back up ECMO machine
- Blood products (as requested by anaesthetists/surgeons)
- Diathermy machine
- ECMO decannulation instruments
- Head lights

13 ECMO TROUBLESHOOTING

Complication	Troubleshooting
Power failure	• Equipment not plugged into wall or power source • Emergency power not functioning • Back up battery not charged
Pre-membrane pressure increasing	• Changes within membrane oxygenator • Clot formation • Inspect membrane with flash light
Pre- and Post-membrane pressures increasing (gradient unchanged)	• Check circuit distal to membrane oxygenator • Patient blood pressure increased (increased afterload) • Tubing kinked – check arterial cannula and cannulation site
Inaccurate flow reading	• Flow probe needs to be zeroed • Check flow probe in proper direction (opposite direction will read negative flow)
Decreasing flow	• Hypovolaemia • Increased resistance in circuit • Malpositioned cannula • High haematocrit • Patient's blood pressure high (high afterload)
Bridge clamp springs open	• Flow drops dramatically • Negative pressure reads less negative • Re-establish clamp
Excessive negative pressure	If occurs quickly, cannula occluded against vessel wall: • Turn down pump flow to release negative pressure, then re-establish flow slowly • Check cannula position (patient may have been moved) If occurs slowly, volume depletion • Check fluid balance • Infuse appropriate fluids/ blood products
Air in Circuit	***Air in pump:*** • Air entry from venous cannula, check position • Air entry from negative venous pressure monitoring site ***Air in membrane:*** • Air from venous side of circuit trapped in membrane • Air introduced during blood product/ drug administration • Membrane rupture – check gas exhaust for blood • High gas to blood flow ratio ***Air distal to membrane oxygenator, this is an EMERGENCY*** • Immediately clamp arterial line • Take patient off ECMO and ventilate, call for help • Establish source – air from membrane, cracked or broken stopcock, loose connector, or air has travelled through entire system from venous site

Oxygenator failure (falling arterial PaO_2)	• Rule out other sources (ie loose gas line, check gas filter in proper direction, check circuits for kinks)
Haemolysis	• Plasma free haemoglobin > 0.1g/dL • Patient has DIC Clot in circuit, check D-dimer level • High RPM to achieve calculated flow • Cannula too small for calculated flow • Excessive negative pressure • Raised free Hb alone, change pump • Raised free Hb and consuming factors (ie low fibrinogen level), change entire circuit
Decreasing patient SvO_2	• Patient toe-core gap widens, poor perfusion • Worsening acidosis with rising lactate • Check ECMO blood flow • Check haematocrit • Demand for oxygen greater than supply • Patient may need sedation or paralysis • Circuit problem (oxygenator failure) • For VV-ECMO: ventilator problems, ETT problem, pneumothorax, atelectasis
Increasing patient $PaCO_2$	• Sweep gas too low • Needs higher minute ventilation from ventilator • Citrate or bicarbonate load • Requirement exceeded capabilities of oxygenator • Wet lung
Oliguria	• Hypovolaemia • Ischaemic renal injury • Low cardiac output and/or pump flow • PDA • Excessive haemolysis leading to AKI
Inconsistent ACTs	• New ACT tubes • ACT machine malfunction • Recent administration of platelets – ACT falls • Increase urine output – ACT falls • Decrease urine output – ACT rises • Low platelets – high ACT • Operator technique variability
Patient bleeding	• ACT too high • Heparin infusion too high • Low platelets • DIC • Infection • Trauma • Post invasive procedure Correct coagulopathy accordingly

Accidental decannulation	• Clamp lines immediately • Notify ICU physician immediately ***Venous cannula dislodged:*** • Apply direct pressure to the neck or site • Take patient off ECMO • Get RT or nurse to ventilate patient • If air entrained, displace it with appropriate volume • If patient requires volume, can infuse via arterial side of manifold ***Arterial cannula dislodged:*** • Patient will need volume • Infuse via venous manifold • Re-establish ECMO ASAP



*Note: P1 (negative venous pressure) monitoring not part of our centre's usual monitoring practice
P2 & P3: Pre and Post membrane pressure respectively

14 INTRA-HOSPITAL TRANSPORT OF PATIENT ON ECMO

Patients on ECMO may be transported for various investigations or procedures that are deemed important for management of the patient. The benefits of such investigations and procedures must be considered against the risks of the transporting a patient on ECMO.

14.1 Indications

- Between NICU and CICU
- ICU and angiography suite
- ICU and radiology department
- ICU and operating theatre

14.2 Personnel

Various medical personnel must be present during the transport:

a. Perfusionist – in charge of the ECMO circuit
b. ECMO Nurse specialist – assists the perfusionist with the ECMO circuit
c. ICU consultant/fellow
d. ICU nurse in charge of the patient
e. Respiratory therapist or a second ICU nurse in charge of the airway and ventilation
f. Security officer to clear the route from ICU to destination and vice versa

14.3 Roles and Responsibilities

14.3.1. ICU Consultant

INSTRUCT ICU MO TO CONTACT THE FOLLOWING PERSONNEL:

- Receiving party re: estimated time of arrival
- Cardiothoracic surgeon to be on standby in hospital during transport
- Security to clear the route and hold the lift

OVERSIGHT THAT ALL EQUIPMENT ARE PREPARED

Respiratory therapist	1 2 3 4	Transport Ventilator Resuscitation bag Oxygen/ Air supply Stethoscope
ECMO Nurse	1 2 3	ECMO Machine M3 Monitor Oxygen/ Air supply
Nurse in charge	1 2	Infusion pumps Resuscitation drugs

CHECK PATIENT'S STABILITY FOR TRANSFER

Respiratory status	1 2 3 4	Blood gas Ventilatory settings CXR (latest) Clinical examination
Haemodynamic	1 2	HR, BP, SvO_2, lactate ECMO flow
Venous access	1 2	Central line Peripheral line
Arterial line	1 2	Femoral/ UAC Radial/ Dorsalis pedis/ Posterior tibial
Other tubes	1 2 3 4	NG tube Urinary catheter Chest drain (s) Others

BEFORE DEPARTURE

Procedures	1 2 3 4 5	Check patient's parameters Ensure receiving party is ready Security is on site Cardiothoracic surgeon is on standby Perform time out for transport

DURING TRANSPORT

Procedures	1 2 3	Overall coordinator of transport process, including transfer of patient in the radiology department Check patient’s parameters Troubleshoot and give team members directions on interventions

14.3.2. **ECMO Specialist / Perfusionist**

EQUIPMENT

ECMO Machine	1	Delta-stream Pump head Oxygenator Batteries x 2 (fully charged)
	2	OR Rotaflow Console with pump head and oxygenator Handcrank
Monitors	1	M3 Spectrum (fully charged)
Clamps	1	Non sterile clamps x 2
Gas supply	1	2 tanks of oxygen (full pressure)
	2	1 tank oxygen, 1 tank air (for infants < 5kg) for intra-hospital
	3	Gas duplex Y-connector for air & oxygen

PROCEDURE

GETTING READY	1	Check pump flow
	2	Check access and return pressures
	3	Check ECMO cannula site
	4	Check patient's parameters
	5	Check SvO_2 reading
AT DEPARTURE		For delta-stream,
	1	Check pump flow
	2	Connect battery pack to portable pump head
	3	Stop pump flow
	4	Change from console pump head to portable pump head
	5	Dial the flow on the portable pump head to desired flow
	6	Check patient's parameters
	7	Check ECMO cannula
	8	Check and position ECMO tubings
DURING TRANSPORT	1	Ensure security of ECMO cannulae
	2	Ensure integrity of entire ECMO circuit
	3	Check ECMO flow
	4	Check battery life of ECMO machine

14.3.3 **Respiratory Therapist / Code Nurse**

EQUIPMENT

Ventilator	1	Transport ventilator
Gas source	1 2	Oxygen tank (full pressure) x 2 Oxygen tank x 1, Air tank x 1 (for infants < 5kg)
Resuscitation	1 2	Resuscitator ambu bag Mask
Stethoscope	1	Stethoscope

PROCEDURES

GETTING READY	1 2 3 4 5 6 7 8	Check patient's ETT tube position Check patient's parameters Check ventilator settings Set ventilator settings on transport ventilator Connect patient to transport ventilator Check chest rise and auscultate Check patient's parameters Check patient's latest blood gas
AT DEPARTURE	1 2 3 4 5	Check gas tank supply Connect transport ventilator to gas tanks Check patient's ETT position Check chest rise and auscultate Check patient's parameters
DURING TRANSPORT	1 2 3 4 5	Ensure ETT tube is secure Check patient's chest rise Check SpO_2 Check integrity of ventilator circuit Troubleshoot ventilator alarms

14.3.4 **Nurse in charge**

EQUIPMENT

Monitors	1	Transport monitor (fully charged)
Infusions and drugs	1	Infusion pumps (fully charged) Emergency drugs kit

PROCEDURE

GETTING READY	1	Check patient's parameters
	2	Check patient's medication infusions and rates
	3	Ensure infusions are sufficient to last estimated transport duration
	4	Check access - venous
	5	Connect an extension with 3-way stopcock to a good venous access for emergency drugs during transport
	6	Check access - arterial
	7	Check all tubes - NG, urinary catheter, etc
	8	Check transport medications - adrenaline 1:10000 x 2 vials - calcium chloride 10% x 1 vial - Sodium bicarbonate 8.4% x 1 vial - 0.9% NaCl x 1 bottle (500ml) - 5% Albumin x 1 bottle (if available)
AT DEPARTURE	1	Check patient's parameters
	2	Disconnect infusions from wall source
	3	Connect to transport monitor
	4	Perform time out according to checklist (Annex B) to ensure checks by ECMO specialist, respiratory therapist, code nurse
DURING TRANSPORT		Transport infusion pumps with patient Troubleshoot infusion pumps Draw medications en route if instructed by ICU consultant

14.4 **Route**

14.4.1 NICU to CICU

NICU → WICU (outside)→ CSDU →CICU

14.4.2 NICU to Radiology department

NICU → level 2 corridor → level 2 staff lift lobby → staff lift → level 1 staff lift lobby → radiology department

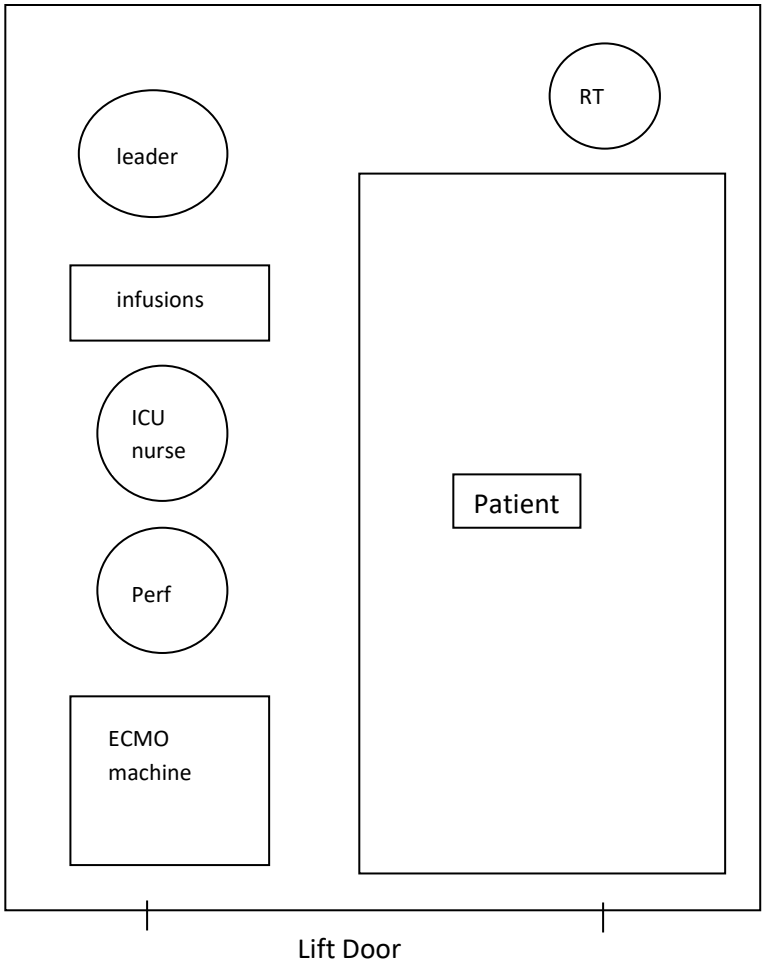
14.4.3 CICU to Angiosuite

CICU → level 2 corridor → level 2 staff lift lobby → angiosuite

14.4.4 CICU to Radiology department

CICU → level 2 corridor → level 2 staff lift lobby → staff lift → level 1 staff lift lobby → radiology department

14.5 **Position within staff lift**



14.6 Troubleshooting during intrahospital transport

Complication	Troubleshooting
Power failure (Deltastream) Power failure (Rotaflow)	• Change battery urgently • Disconnect pump head to hand crank and start handcrank with previously set RPM
Decreasing flow	• Check cannula position • Check for kinks in the circuit • Check if patient's blood pressure is high (high afterload) • Check if patient is hypovolemic with bleeding or increase losses, KIV administer fluids
Air in Circuit	***Air distal to membrane oxygenator, this is an EMERGENCY*** • Immediately clamp arterial line • Take patient off ECMO, start chest compressions and ventilate • Move patient to nearest resuscitation area (level 1 – radiology department, level 2- CICU or NICU, B1 – Children's emergency) • Establish source – air from membrane, cracked or broken stopcock, loose connector, or air has travelled through entire system from venous site • Re-establish ECMO flow when the air has been removed from the circuit
Decreasing patient SvO_2	• Check ECMO blood flow • If haematocrit drops, check for bleeding • Patient may need sedation or paralysis • Circuit problem (oxygenator failure) • For VV-ECMO: ventilator problems, ETT problem, pneumothorax, atelectasis
Accidental decannulation	• Clamp lines immediately ***Venous cannula dislodged:*** • Apply direct pressure to the neck or site • Take patient off ECMO (Clamp arterial cannula followed by venous cannula) • Get RT or nurse to ventilate patient • Get ICU nurse to administer ECM Move patient to the nearest resuscitation area (level 1 – radiology department, level 2- CICU or NICU, B1 – Children's emergency) • Call for ECMO team activation at resuscitation area • Call for ECMO inter-hospital transport bag with cannulae • CTS surgeon to reinsert venous cannula • Establish ECMO ASAP ***Arterial cannula dislodged:*** • Apply direct pressure to the neck or site • Take patient off ECMO (Clamp venous cannula followed by arterial cannula) • Get RT or nurse to ventilate patient • Get ICU nurse to administer ECM Move patient to the nearest resuscitation area (level 1 – radiology department, level 2- CICU or NICU, B1 – Children's emergency)

	• Call for ECMO team activation at resuscitation area • Call for ECMO inter-hospital transport bag with cannulae • CTS surgeon to reinsert arterial cannula • Establish ECMO ASAP

15 INTER-HOSPITAL TRANSPORT

Inter-hospital ECMO transport is activated by the Children's Hospital Emergency Transport Service consultant on call, based on the following indications:

- Diseases that result in cardiopulmonary failure that has a reasonable chance of recovery and cannot be transported on conventional cardiopulmonary support safely to KKH
- As a form of Extracorporeal Cardiopulmonary Resuscitation in patients with a witnessed arrest in a healthcare institution, and had received immediate institution of advanced cardiopulmonary resuscitation. ECPR by the KKH ECMO team must be done with the agreement that patients will thereafter be transported back to KKH for further management

Inter-hospital ECMO transport is initiated in the absence of:

- Recent neurosurgical procedures or intracranial bleeding (within 10 days). Grade II or III intracranial hemorrhage is a general contraindication
- Recent surgery or trauma: increased risk of bleeding. Patients with severe neurologic compromise, genetic abnormalities (not including Trisomy 21)
- End stage hepatic failure, renal failure, or primary pulmonary hypertension

15.1 Personnel

The following medical personnel are activated once decision for ECMO is made by CHETS consultant:

a. Cardiothoracic surgeon on call
b. Perfusionist on call
c. ECMO Nurse specialist on call
d. ICU CHETS nurse
e. Respiratory therapist or a second ICU nurse in charge of the airway and ventilation
f. Cardiologist

Registrar/ resident in ICU will inform:

- Cardiothoracic surgeon on call
- Perfusionist on call
- Cardiologist on call

Information on the medical condition and location of the patient will be given. The CHETS consultant, CTS surgeon, perfusionist and cardiologist will proceed to the location of the patient.

The CHETS nurse will inform

- ECMO nurse specialist on call
- Respiratory therapist/ arrange for another ICU nurse

The ECMO nurse specialist and RT will travel with the CHETS team via ambulance to the location of the patient.

15.2 **Roles and Responsibilities**

15.2.1 **ICU Consultant / CHETS consultant**

PREPARATION

- Once ECMO has been activated, ECMO nurse to prepare the equipment according to the checklist (Annex A)
- Request for GXM and packed RBCs for priming of the ECMO circuit at the referring hospital
- Enquire regarding availability of ACT measurement at referring hospital. If not available, instruct the ECMO nurse specialist to bring our ACT machine
- Instruct resident to inform cardiothoracic surgeon, perfusionist and cardiologist

OVERSIGHT THAT ALL EQUIPMENT ARE PREPARED

Respiratory therapist	1 2 3 4	Ventilator Resuscitation bags Oxygen/ Air supply Stethoscope
ECMO Nurse	1 2 3 4 5 6	ECMO Machine M3 Monitor Oxygen/ Air supply ECMO Transport Pelician case ECMO cannulae: - 3 venous (1 size recommended by weight, 1 size above and 1 size below recommended); - 3 arterial (1 size recommended by weight, 1 size above and 1 size below recommended) ECMO circuit (Infant/adult) ACT machine + cartridges (if referring hospital has no ACT machine)
CHETS Nurse	1	CHETS equipment & transport CHETS bag according to the checklist

AT REFERRING HOSPITAL

• Assess the patient and discuss the need of ECMO with cardiothoracic surgeon and cardiologist
• Obtain consent from parents
• Inform referring physician regarding decision to initiate ECMO on site
• Once final decision made for cannulation, inform perfusionist and ECMO nurse specialist to prime the ECMO circuit
• Inform CHETS nurse to get ready medications for cannulation and resuscitation drugs

PATIENT ASSESSMENT PRE-CANNULATION

Respiratory status	1 2 3 4 5	Clinical examination Airway (size and position of ETT) Ventilatory settings CXR (latest) ABG
Haemodynamic	1 2	HR, BP Inotropes or vasopressors
Venous access	1 2	Central line OR Large bore peripheral line
Arterial line	1	Secure arterial line if not already done
Secure other tubes	1 2 3 4	NG tube Urinary catheter Chest drain (s) Others

CANNULATION AND INITIATION OF ECMO

Overall in charge of initiation process
Drug administration – anaesthetic drugs, resuscitation drugs, heparin

BEFORE DEPARTURE

Procedures	1 2	Check patient's parameters Ensure KKH ICU is ready Perform time out according to the checklist (Annex B) to ensure checks by ECMO specialist, respiratory therapist, CHETS nurse have been done

DURING TRANSPORT

Procedures	1 2 3	Overall coordinator of transport process, including transfer of patient onto transport trolley Check patient’s parameters Troubleshoot and give team members directions on interventions

15.2.2. **ECMO Specialist / Perfusionist**

EQUIPMENT FOR CHETS

ECMO Machine	1	Deltastream Pump head Oxygenator Batteries x 3 (fully charged) Portable Battery charger
	2	OR Rotaflow Console with pump head and oxygenator Handcrank
Monitors	1	M3 Spectrum (fully charged)
Clamps	1 2	Sterile clamps x 2 Non sterile clamps x 2
Gas supply	1 2	2 tanks of oxygen (full pressure) 1 tank oxygen, 1 tank air for infants < 5kg)
ACT machine	1 2	If referring hospital has no capability to measure ACT ACT cartridges x 5

PROCEDURE

ECMO INITIATION	1	Perform pre-initiation ACT – report results to ICU consultant
	2	Prime ECMO circuit as per Section 4.6.5
GETTING READY	1 2 3 4 5	Check pump flow Check access and return pressures Check ECMO cannula site Check patient's parameters Check SvO_2 reading
AT DEPARTURE	 1 2 3 4 5	For deltastream, Check pump flow Check battery life Check patient's parameters Check ECMO cannula Check and position ECMO tubings
DURING TRANSPORT	1 2 3 4	Ensure security of ECMO cannulae Ensure integrity of entire ECMO circuit Check ECMO flow Check battery life of ECMO machine

15.2.3 **Respiratory Therapist / Code Nurse**

EQUIPMENT

Ventilator	1	Transport ventilator
Gas source	1 2	Oxygen tank (full pressure) x 2 (Oxygen tank x 1, Air tank x 1 for infants < 5kg)
Resuscitation	1 2	Resuscitator ambu bag Mask
Stethoscope	1	Stethoscope

PROCEDURES

ON ARRIVAL AT REFERRING HOSPITAL	1 2 3 4 5	Check patient's ETT tube position Check patient's parameters Check chest rise and auscultate Check patient's parameters Check patient's latest blood gas
AT DEPARTURE	1 2 3 4 5 6 7 8	Check ventilator settings Set ventilator settings on transport ventilator Connect patient to transport ventilator Check oxygen tank supply Connect transport ventilator to gas tanks Check patient's ETT position and secure ETT Check chest rise and auscultate Check patient's parameters
DURING TRANSPORT	1 2 3 4 5	Ensure ETT tube is secure Check patient’s chest rise Check SpO2 Check integrity of ventilator circuit Troubleshoot ventilator alarms

15.2.4 **CHETS Nurse**

EQUIPMENT

Monitors	1	Transport monitor (fully charged)
Infusions and drugs	1	Infusion pumps (fully charged)
CHETS Bag	1	Contents as per CHETS protocol

PROCEDURE

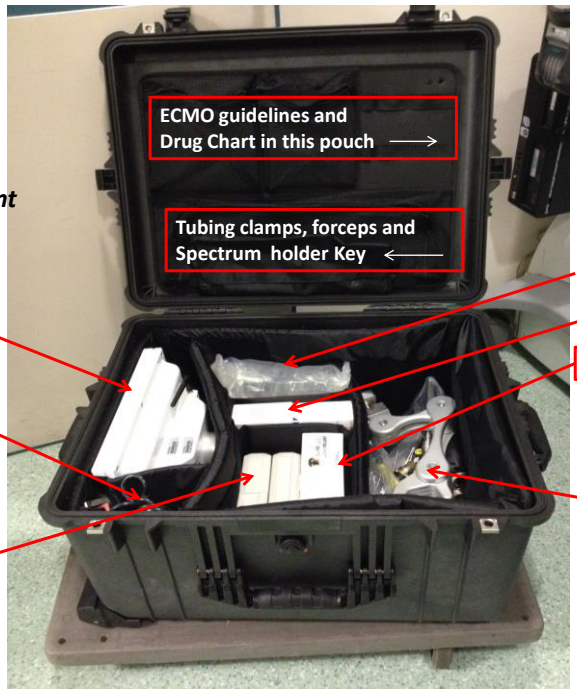
ON ARRIVAL AT REFERRING HOSPITAL	1	Check and record patient's parameters
	2	Check patient's medication infusions and rates
	3	Check access - venous
	4	Connect an extension with 3-way stopcock to a good venous access for emergency drugs during cannulation
	5	Check access - arterial
	6	Check all tubes - NG, urinary catheter, etc
	7	Prepare medications as per instruction by CHETS consultant
AT DEPARTURE	1	Check patient's parameters
	2	Ensure infusions are sufficient to last estimated transport duration
	3	Check infusion pumps battery
	4	Disconnect infusions from wall source
	5	Connect to transport monitor
DURING TRANSPORT	1	Transport infusion pumps with patient
	2	Troubleshoot infusion pumps
	3	Draw medications en route if instructed by CHETS consultant

15.3 ECMO Transport Bag

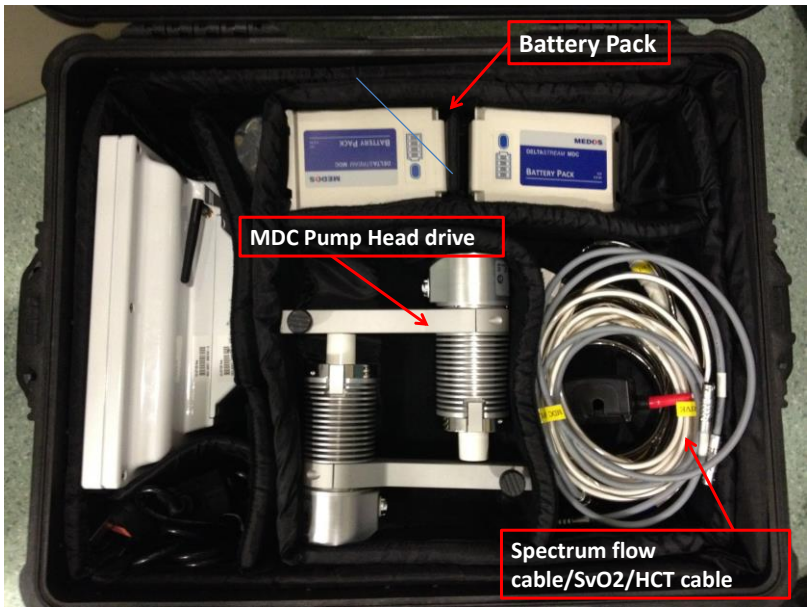
Internal Compartment

ECMO Transport Trolley Case

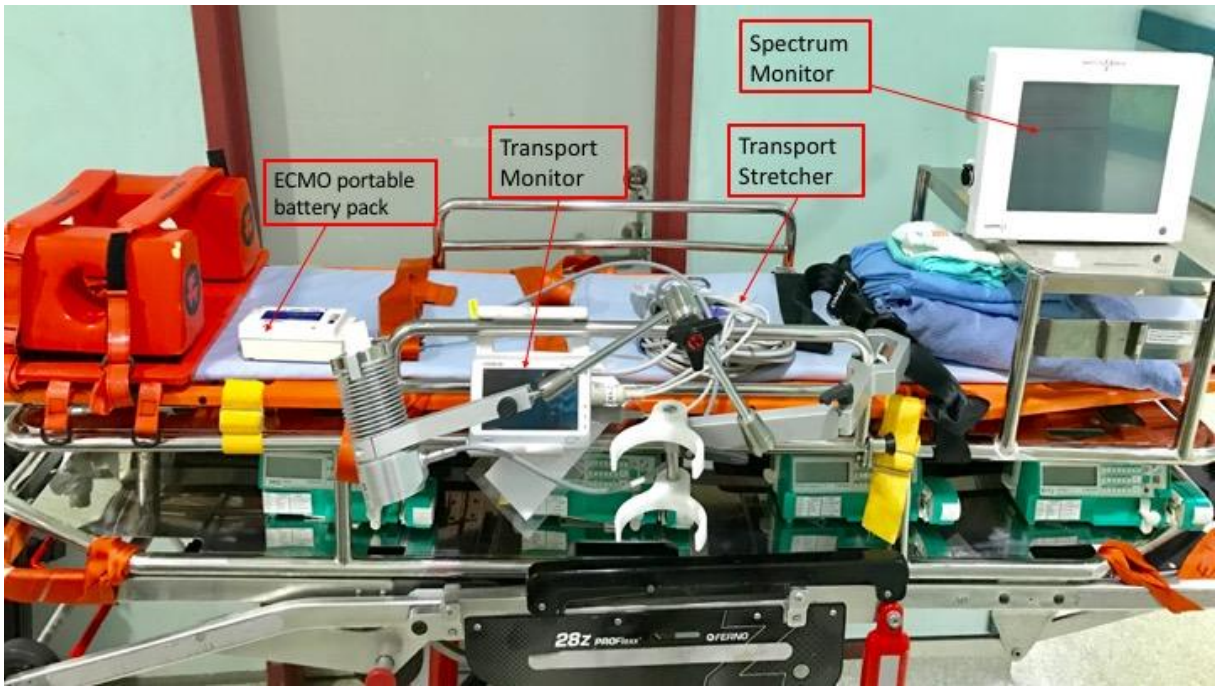
Internal Compartment



Top Layer: **Medos MDC Pump drive, Battery pack and Spectrum Flow/HCT/SvO2 Cables**



15.4 Equipment positioning on Transport Trolley



15.5 Ambulance Transfer to KKH

15.5.1 Personnel

KKH ambulance allows 6 persons in the ambulance:
Driver
Patient
CHETS consultant
Perfusionist
Cardiothoracic surgeon
CHETS nurse/ ECMO nurse specialist (if also CHETS trained)

The rest of the personnel shall travel by taxi back to KKH

15.5.2 Troubleshooting

Complication	**Troubleshooting**
Power failure (Deltastream) Power failure (Rotaflow)	• Change battery urgently • Disconnect pump head to hand crank and start handcrank with previously set RPM
Decreasing flow	• Check cannula position • Check for kinks in the circuit • Check if patient's blood pressure is high (high afterload) • Check if patient is hypovolemic with bleeding or increase losses, KIV administer fluids
Air in Circuit	***Air distal to membrane oxygenator, this is an EMERGENCY*** • Perfusionist immediately clamp arterial line • Perfusionist take patient off ECMO • CHETS nurse to administer ECM • CHETS consultant to adjust ventilator settings – FiO_2 100%, ventilator pressures to adequate chest rise and assume role as code leader • Perfusionist to take over ECM • CHETS nurse to draw and administer resuscitation drugs • Ambulance to drive to the nearest emergency department • Establish source – air from membrane, cracked or broken stopcock, loose connector, or air has travelled through entire system from venous site • Re-establish ECMO flow when the air has been removed from the circuit
Decreasing patient SvO_2	• Check ECMO blood flow • If haematocrit drops, check for bleeding • Patient may need sedation or paralysis • Circuit problem (oxygenator failure) • For VV-ECMO: ventilator problems, ETT problem, pneumothorax, atelectasis

Accidental decannulation	• Clamp lines immediately ***Venous cannula dislodged:*** • CTS surgeon applies direct pressure to the neck or site • Perfusionist take patient off ECMO (Clamp arterial cannula followed by venous cannula) • CHETS nurse to administer ECM • CHETS consultant to adjust ventilator settings – FiO_2 100%, ventilator pressures to adequate chest rise and assume role as code leader • Perfusionist to take over ECM • CHETS nurse to draw and administer resuscitation drugs • Ambulance to drive to the nearest emergency department • CTS surgeon to reinsert venous cannula at the nearest ED • Establish ECMO ASAP ***Arterial cannula dislodged:*** • Apply direct pressure to the neck or site • Perfusionist take patient off ECMO (Clamp venous cannula followed by arterial cannula) • CHETS nurse administer ECM • CHETS consultant to adjust ventilator settings – FiO2 100%, ventilator pressures to adequate chest rise and assume role as code leader • Perfusionist to take over ECM • CHETS nurse to draw and administer resuscitation drugs • Ambulance to drive to the nearest emergency department • CTS surgeon to reinsert arterial cannula at the nearest ED • Establish ECMO ASAP

ANNEX A: ECMO CHETS EQUIPMENT CHECKLIST

KK Women's and Children's Hospital
SingHealth

KKH ECMO SERVICE
ECMO CHETS EQUIPMENT CHECKLIST
To use stretcher with transport deck for all age group

ECMO Resource Nurse Name/Sign_____ Date_____

NO	EQUIPMENTS	QTY	Y / N	Remark
A. USING MEDOS DELTASTREAM				
1	**The following items should obtain from Medos ConsoleTrolley and Black box toput inside pelican trolley bag**			
1.1	MDC Pump Drive with Cable (Take from Console trolley/Sensor Box)	2		
1.2	Battery Pack (Additional)	1		
1.3	Integrated Oxygenator/ Pump Holder Infant or Adult	1		
1.4	Spectrum SO2/HCT Sensor Cable Size: 1/4" or 3/8"	1		
1.5	Spectrum V & A Flow Cables Size: 1/4" or 3/8"	2		
2	Circuit and Cannulas to choose according to the patient's weight and to bring additional cannulas- one size small and big			
2.1	Medos Infant Circuit if patient < 20kg Medos or EOS Adult Circuit if pateint > 20kg	1		
2.2	Choose & circle for VEN (10F 12F 14F 15F 16F 17F 18F 19F)	2		
2.3	Choose and Circle for ART (8F 10F 12F 14F 15F 17F)	2		
2.4	Additonal cannulas both and V & A - one size big and small	2each		
	Radifocus Distal Reperfusion cath 4fr, 5Fr, 6Fr (Femoral cannulation)	1 each		
2.5	Guide wire 100 cm (For Maquet A15. A17F, Avalon 16F, 19F)	1		
2.6	Guide wire 150 cm (For Maquet V19 and Avalon 27F)	1		
3	a. ACT Machine	1		
	b. ACT Cartridge	5 pair		
4	Oxygen Tank (additional) To inform CHETS Nurse to bring	1		
B. USING MAQUET ROTAFLOW				
1	Rotaflow Console with AC Cable	1		
2	Rotaflow Pump Drive with Cable	1		
3	Rotaflow Hand Crank	1		
4	Rotaflow Adult Oxygenator Holder for EOS Circuit	1		
5	Maquet Centrifugal Pump Head	1		
6	Rotaflow Ultrasonic Cream	1		
C. OTHERS				

Legend: V- VEN, A- ART, Y-Yes, N-No, NA-Not Applicable

Note: ECMO NURSE SPECIALIST is to confirm with Perfusionist and CTS surgeon on;
i) SIZE of the ECMO circuit ii) TYPES of cannulas and guide wire is required

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ANNEX B: CHECKLIST FOR ECMO TRANSPORT TIMEOUT

Check List for ECMO Transport Timeout

Date of Transfer: _____

Time of Transfer: _____

Patient's Label

1. Intra-Hospital Transport of Patient on ECMO

☐ NICU to CICU ☐ CICU to Angiography Suite ☐ CICU & Radiology Dept ☐ CICU to Operating Theatre

2. Inter-Hospital Transport of Patient on ECMO via CHETS

☐ Local Hospital to KKH (NICU/CICU)

3. Transport Team Personnel

Personnel	Roles
ICU Consultant/Fellow	Team Leader
Perfusionist	In charge of ECMO Circuit
ECMO Nurse Specialist	Assist the perfusionist with the ECMO Circuit
ICU Nurse	In-charge of the patient
Respiratory Therapist/Code Nurse or Second Nurse in Charge	In-charge of the Airway and Ventilation
Security Officer	To clear the route from ICU to destination and vice versa

ICU CONSULTANT TO INSTRUCT ICU MO TO CONTACT THE FOLLOWING PERSONNEL:

- Receiving party re: estimated time of arrival
- Cardiothoracic surgeon to be on standby in hospital during transport
- Security to clear the route and hold the lift

OVERSIGHT THAT ALL EQUIPMENT ARE PREPARED

Respiratory therapist	Yes	No	ECMO Specialist Nurse	Yes	No
Transport Ventilator			ECMO Machine		
Resuscitation Bag			Spectrum M3 Monitor		
Oxygen/Air supply			Oxygen/Air Supply for ECMO Machine		
Stethoscope			Duplex- Y connector for Oxygen		
Nurse in charge			Duplex -Y connector for Air		
Infusion pumps					
Resuscitation drugs					

CHECK PATIENT'S STABILITY FOR TRANSFER

Respiratory status	Tick if ok	Haemodynamic	Tick if ok
Blood gas		HR, BP, SvO_2, lactate	
Ventilatory settings		ECMO flow	
CXR (latest)		**Arterial Line**	
Clinical examination		Femoral/ UAC/ Radial/ Doralis pedis/ Posterior tibial	
Venous access			
Central line		**Other Tubes**	
Peripheral line		NG tube/ Urinary catheter/ Chest drain (s)	
		Others	

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BEFORE DEPARTURE Procedures	Tick	**DURING TRANSPORT** Procedures	Tick
Check patient's parameters	☐	Overall coordinator of transport process, including transfer of patient in the radiology department	☐
Ensure receiving party is ready	☐	Check patient's parameters	☐
Security is on site	☐	Troubleshoot and give team members directions on interventions	☐
Cardiothoracic surgeon is on standby	☐		

ECMO Specialist/ Perfusionist

EQUIPMENT					
ECMO Machine	☐	**Delta-stream**	☐	**Rotaflow**	☐
		Pump head	☐	Console with pump head and oxygenator	☐
		Oxygenator	☐		
		Batteries x2 (fully charged)	☐	Rotaflow Handcrank	☐
Monitors	☐	M3 Spectrum (fully charged)	☐	Data Master for Rotaflow	☐
Clamps	☐	Non-sterile clamps x2	☐		
		2 tank of oxygen (full pressure)	☐		
		1 tank oxygen, 1 tank air in console	☐		
Gas Supply	☐	(for infants <5kg)	☐		

PROCEDURE					
GETTING READY		**AT DEPARTURE**		**DURING TRANSPORT**	
Check pump flow	☐	For delta-stream	☐	Ensure security of ECMO cannulae	☐
Check access and return pressures	☐	Check pump flow	☐	Ensure integrity of entire ECMO circuit	☐
Check ECMO cannula site	☐	Connect battery pack to portable pump head	☐	Check ECMO flow	☐
Check patient's parameters	☐	Stop pump flow	☐	Check battery life of ECMO machine	☐
Check SvO_2 reading	☐	Change from console pump head to portable pump head	☐		
		Dial the flow on the portable pump head to desired flow	☐		
		Check patient's parameters	☐		
		Check ECMO cannula	☐		
		Check and position ECMO tubings	☐		

Respiratory Therapist/ Code Nurse

EQUIPMENT		**AT DEPARTURE**	
Transport ventilator	☐	Check gas tank supply	☐
Oxygen tank (full pressure) x 1 each for ECMO & Vent	☐	Connect transport ventilator to gas tanks	☐
Oxygen tank x 1, Air tank x 1 for infants < 5kg	☐	Check patient's ETT position	☐
Resuscitation bag and Mask	☐	Check chest rise and auscultate	☐
Stethoscope	☐	Check patient's parameters	☐
PROCEDURES : GETTING READY		**DURING TRANSPORT**	
Check patient's ETT tube position	☐	Ensure ETT tube is secure	☐
Check patient's parameters	☐	Check patient's chest rise	☐
Check ventilator settings	☐	Check SpO_2	☐
Set ventilator settings on transport ventilator	☐	Check integrity of ventilator circuit	☐
Connect patient to transport ventilator	☐	Troubleshoot ventilator alarms	☐
Check chest rise and auscultate	☐		
Check patient's parameters	☐		
Check patient's latest blood gas	☐		

Nurse in charge		
EQUIPMENT ☐ Monitors Infusions and drugs Transport monitor (fully charged) Infusion pumps (fully charged) Emergency drugs kit	**PROCEDURES : GETTING READY** ☐ Check patient's parameters Check patient's medication infusions and rates Ensure infusions are sufficient to last estimated transport duration Check access - venous Connect an extension with 3-way stopcock to a good venous access for emergency drugs during transport Check access - arterial Check all tubes - NG, urinary catheter, etc Check transport medications - adrenaline 1: 10000 x 2 vials - calcium chloride 10% x 1 vial - Sodium bicarbonate 8.4% x 1 vial - 0.9% NaCl x 1 bottle (500ml) - 5% Albumin x 1 bottle (if available)	**AT DEPARTURE** ☐ Check patient's parameters Disconnect infusions from wall source Connect to transport monitor **DURING TRANSPORT** ☐ Transport infusion pumps with patient Troubleshoot infusion pumps Draw medications en route if instructed by ICU consultant

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