Cannulation in ECMO

Indira Jayakumar*

*Senior Consultant, PICU & Emergency services, Apollo Childrens Hospital, Chennai

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ABSTRACT:
The approach to cannulation in patients requiring extracorporeal membrane oxygenation should be individualized and based on the specific clinical scenario in which the need arises. Adherence to proper techniques of vessel visualization, exposure, and cannulation along with accurate placement of cannula will optimize flows and minimize complications. In most cases an ECMO(Extracorporeal membrane oxygenation) circuit comprises of two large bore cannulae in a veno-venous(VV) or veno-arterial(VA) configuration (Dual Cannulation). Newer dual lumen VV ECMO cannulas may facilitate extubation and mobilization. Experienced centers apply more advanced strategies by cannulation of three large vessels (triple cannulation or hybrid set ups) resulting in veno-veno-arterial(VVA) or veno-arterio-venous(VAV) cannulation to provide circulatory and respiratory support at the same time.

Key words: ECMO cannula, Pediatrics, Dual cannulation, Venoarterial ECMO, Venovenous ECMO, Extracorporeal membrane oxygenation

Introduction:
The term “cannula” refers to the catheter that goes directly into the vessel for Extracorporeal Life Support (ECLS), to differentiate that device from all other catheters in the body.

By convention, the terms inflow from patient to the pump is synonymous with ‘Drainage’ and outflow from the pump to the patient with ‘Return’. Drainage cannula are always venous.

The modes of vascular access are:
1. Venoarterial (cardiac and respiratory support)
2. Venovenous (preferred for respiratory support with no primary cardiac dysfunction because it avoids using a major artery and potential systemic embolism)
3. AV-arteriovenous (lower blood flow for CO2 removal)

Where to cannulate?
Depending on the patient situation various places can be used for cannulation:
- Operation Theatre
- Intensive Care
- Emergency room
- Cardiac Catheterization Lab
- CPR (during cardiopulmonary resuscitation)

Which site to cannulate??

Central cannulation
It always involves VA ECMO and involves intrathoracic cannulation with drainage of venous blood through a cannula placed in the right atrium and an arterial cannula inserted into the ascending aorta. It is the most appropriate approach for postcardiomyotomy cardiogenic shock and is associated with improved venous drainage, greater cardiac decompression and reduced concern for upper body hypoxemia (Harlequin syndrome) compared to peripheral cannulation. The main disadvantage is that it requires entering the chest for initiation and discontinuation of ECMO with risk of bleeding and mediastinitis. It also precludes extubation and patient mobilization.

Peripheral cannulation
For patients <15 kg – preferred sites are Internal jugular and Carotid artery for VA and Internal Jugular and Femoral vein for VV ECMO. In older children femoral artery and vein are options too. The main advantages of peripheral cannulation are the ease of cannulation, lack of need for surgery. Peripheral VA ECMO cannulation can be done in patients undergoing chest compressions.

How to cannulate?
The proper placement of one or two cannulas is a prerequisite for ECMO therapy and ideally done under ultrasound guidance or fluoroscopy for estimating position and vessel size. The vessel is widened
stepwise with appropriate dilators before advancing the cannula. Various techniques are available as follows:

- Percutaneous - by a vessel puncture, guide wire placement and serial dilation (Seldinger technique),
- Semi Open – percutaneous approach with vessel exposed (Semi Seldinger technique). The advantages of this technique over a pure percutaneous approach are speed, accurate assessment of vessel size, flexibility of approach and safety.
- Open (cut down) – usually necessary in neonates and small children
- Direct cardiac cannulation – in patients who cannot come off cardiopulmonary bypass or during resuscitation through open chest.

Who should cannulate?

Percutaneous- is now being performed by intensivists, cardiologists, interventional radiologists, vascular surgeons.
Central- cardiac surgeons

Cannulas

- It is important to choose a drainage (venous) cannula with largest lumen and shortest length possible. Maximum blood flow is directly proportional to the length and inversely proportional to the fourth power of radius.
- Cannula size is standardly reported according to outer diameter. Arterial cannulas are typically 15–25 Fr and venous cannulas are usually 19–25 Fr. However identically sized cannula vary in inner diameter according to wall thickness of material used. Therefore the internal diameter of the catheter is the most important factor controlling blood flow resistance. High flows, side holes, tapering sections affect resistance.
- For these reasons catheters are tested for their pressure/flow relationship and an ‘M’ number determined that represents a resistive factor that can approximate the expected flow at a specific pressure difference, usually 100cmH2O. There are brand specific charts to determine cannula size based on the flows required.

- Cannulas are coated with albumin, heparin or both to improve biocompatibility by mimicking human tissue. Venous cannula are large and long with end and side holes to allow flow even if end is occluded. Arterial cannula are shorter and have only end hole to provide less resistance, hemolysis and turbulence to flow. They are also smaller to avoid ischemia. (Fig 1)

**Fig 1- Cannula (Venous and Arterial)**

Cannulation Steps and Issues

- Decide where to cannulate - Except in emergency situations, choose a more controlled environment with adequate space for personnel, monitoring, equipments and ample lighting
- Procedure - obtain consent, order blood products, prepare infusions of inotropes and antihypertensive agents even if hemodynamically stable. After the vessel is exposed or guidewire placed patient is systemically heparinized before cannulae are placed inside.
- Management of the distal vessels - If neck access is used the artery is ligated distally to avoid embolization relying on collateral circulation. In children carotid artery distal ligation is well tolerated. In femoral access venous collateral is adequate but the femoral artery is often significantly occluded. Hence to maintain arterial flow to the leg a distally directed 6–10 Fr catheter is placed in the distal superficial femoral artery by direct cut down, or in the posterior tibial artery for retrograde perfusion to prevent ischemia.
- Role of Ultrasound/ Echocardiogram (ECHO)
Pre Initiation: ECHO helps in diagnosis, selection of mode of ECMO, size of cannula and cardiac condition.

During cannulation: ECHO helps to identify vessels to avoid wrong cannulation especially in pulseless circulatory states, position of J wire to avoid arrhythmias and the desired position of end of cannula. For double lumen cannula it is ideal to use transesophageal echocardiogram.

Post Initiation: ECHO as it difficult to visualize the radiolucent distal end of the ECMO cannula on radiography and to rule out tamponade.

Adding or changing cannulas: If venous drainage is inadequate and is due to the blood flow resistance of the drainage cannula one can add another venous drainage cannula through a different vein as replacing cannulas is difficult. However, if a cannula is damaged or clotted it must be changed.

Types of Cannulation

Dual Cannulation

Veno-Venous for respiratory (VV ECMO)
Veno-Arterial for circulatory support (VA ECMO)

Veno Venous (VV ECMO)⁶ (Fig 2)

- In VV ECMO blood is drained via a cannula from the right atrium (RA) into oxygenator and returned via a second cannula / same cannula by a separate lumen to the right atrium. ECMO circuit functions in parallel to the native heart and lungs.
- The femoral (F) and internal jugular (IJ) veins are usually used with the F for drainage and the IJ for return as recirculation is more if the femoral vein is used for return. Femoral-femoral is less commonly employed as it is associated with greatest incidence of recirculation.
- Sufficient diameters of right-sided femoral and jugular veins usually allow introduction of ECMO cannulas without problems due to the straight route. The correct position of both cannula tips is the border between the right atrium and the superior and inferior caval veins respectively.
- Preoxygenated blood enters the pulmonary circuit and provides systemic oxygenation. Oxygen saturation in the central aorta is the result of a mixture of ECMO oxygenated blood and residual venous blood from the right atrium returning to the pulmonary circulation. Eventually all organs are perfused with approximately the same oxygen saturation, thus a radial or femoral arterial line on either side of the body are sufficient for assessing systemic oxygenation.

Recirculation: malposition causes recirculation, i.e. freshly oxygenated blood being pulled back into the extracorporeal circuit instead of lungs causing desaturation. Rest ventilator settings on ECMO can elevate diaphragm and move cannula inwards increasing recirculation. Traction on the tubings to move it cephalad should sort this problem and reopening is generally not necessary. It is essential to verify optimal cannula position by chest X-ray, ECHO or fluoroscopy and adjust the tip of the supplying cannula.

Heart function: VV ECMO supports gas exchange but does not help hemodynamics unless the cause was right ventricle dysfunction secondary to hypoxia, hypercarbia and high pressures on ventilator. But function of the heart must be closely monitored and heart failure in patients with veno-venous ECMO is an indication for veno-arterio-venous ECMO (triple cannulation).

VV ECMO- Dual Lumen cannulation in a single vein ⁷ ⁸ ⁹ (Figure 3)

- This involves cannulation of only one vein of the upper body by using a single, dual lumen cannula
placed into the right Internal Jugular (IJ) vein.

- The cannula is placed percutaneously into the right IJ vein such that the most distal portion of the cannula rests in the inferior vena cava (IVC) in the lower third of right Atrium. One lumen drains deoxygenated venous blood from the SVC and IVC through proximal and distal ports, respectively, while the return lumen directs oxygenated blood toward the tricuspid valve.
- Avalon (Maquet, Germany) is the brand name of a popular dual lumen ECMO cannula. Origen is another brand. In the Protek Duo (Cardiac Assist, USA) the distal tip of this cannula is placed into the main pulmonary artery to decompress the right ventricle as well. At present, this cannula is new and in frequently used.
- Advantage - requires only one large access vein, minimizes recirculation by directed blood towards the tricuspid valve, facilitates awake ECMO, early extubation and mobilization, proning is easier.
- Disadvantage – flow is lower as it has 2 lumens for drainage and return, requires fluoroscopy or echocardiography guided placement, a lot of expertise, risk of right atrial or ventricular perforation, hemolysis with higher flow rates, expensive, not ideal for emergency settings. migration as well as rotation of the return port away from the tricuspid valve.

Blood is drained from the right atrium, into the ECMO device and returned via femoral or carotid artery.

- A femoral / internal jugular vein (drainage) and the ipsilateral carotid / femoral artery (return) are used for vascular access. The correct position of the neck venous cannula tip is the mid-right atrium to enable homogenous drainage of venous blood from both caval veins. If placed in the femoral artery, the arterial cannula should be fully introduced with the tip positioned in the common iliac artery or higher in IVC/ RA for better flows.
- Return cannula in the carotid artery is preferred over femoral artery if lungs are also damaged to avoid deoxygenated blood perfusing ascending aorta (coronary, brain) causing the North South/Harlequin Syndrome. It is mandatory to establish an arterial line in the right radial artery for monitoring upper body (brain) oxygenation. The addition of a second draining cannula, resulting in triple cannulation (two for drainage and one for supply) can help resolve this problem.
- Left ventricular distension and pulmonary congestion may occur in cases of extremely low left ventricular output. Retrograde aortic ECMO flow increases afterload and prevents forward emptying while some blood still arrives in the left heart returning from Bronchial and Thebesian veins causing left atrial distension. In such cases a second venous draining cannula for enhanced preload reduction can be helpful (veno-veno-arterial cannulation).
Triple cannulation is a novel and special form of ECMO support, which is usually employed as an “upgrade” of an existing VV or VA ECMO.

Addition of a Venous Cannula- When venous drainage from a single cannulae is inadequate, hemolysis occurs due to high flows, Harlequin syndrome or left atrial distension with pulmonary congestion, VA ECMO complicated by lung failure an additional cannula is inserted in the venous side. The draining flows from the two venous cannulas are merged outside the body using a Y-connector.

Addition of an Arterial Cannula- when cardiovascular support is required ie- VV ECMO is complicated by heart failure an arterial cannula must be added to provide circulatory support.

The nomenclature just depends on the starting set up- VV turns into VVA and VA turns into VAV. However circulatory support during veno-arteriovenous ECMO is lower (nearly half the support) compared to veno-arterial and veno-veno-arterial cannulation, since not the whole arterial flow is directed towards the aorta.

In addition to the VA circuit, the additional venous cannula (VAV ECMO) adds pre-oxygenated blood to the lungs and thereby establishes a ‘VV component.’ This ensures sufficient oxygen content of blood ejected by the heart and allows for lung protective ventilation. However VAV ECMO requires sufficient RV function, otherwise it may be necessary to relocate the venous supplying cannula into the pulmonary artery, veno-arterio-pulmonary artery cannulation (VAPa).

A number of venous cannulae have a radiolucent distal segment, and the tip may therefore lie more distally than suspected on radiographic imaging. Some types have a radiopaque tip beyond the radiolucent segment.

VV- The drainage cannula tip should lie approximately at the level of the eighth–ninth ribs posteriorly, the expected level of the right atrium. The femoral cannula distal tip should rest in IVC at T10-11 vertebra. Beyond the hepatic vein it can obstruct and lead to hepatic congestion.

Dual Lumen in neck – In infants the junction of IVC and RA is approximately 0.5 cm above the diaphragm thus the catheter tip must be visible 1 cm above the diaphragm.

VA - the return cannula tip should therefore lie at the level of the second–third ribs posteriorly because this position correlates with the origin of the common carotid artery.

Complications

Percutaneous cannulation and technical improvements of all parts of the ECMO unit have enabled a very quick setup of the system. Nevertheless, ECMO is an invasive life support system with substantial risk of adverse events like bleeding, vascular complications, thromboembolic events, infection, ischemia of the corresponding extremity, blood loss, relocation of cannulas. Cannulation failure warrants increase in vasoactive agents and central cannulation if all fails. As lack of experience is the trigger of many complications adequate training of cannulation techniques is essential to minimize adverse events. Careful insertion technique, close surveillance and monitoring are mandatory. There are many different options for vascular cannulation in the patient requiring ECMO support. The appropriate choice of type and location of cannula should be individualized to patient factors and the urgency of the clinical setting.

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