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Review Article

Echocardiographic Guidance and Troubleshooting for Venovenous Extracorporeal Membrane Oxygenation Using the Dual-Lumen Bicaval Cannula

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ACUTE RESPIRATORY DISTRESS syndrome is a devastating condition found in 5% of mechanically ventilated hospitalized patients, with a mortality reaching 40-to-50% in severe cases.[1] The standard of care for decreasing mortality emphasizes minimizing barotrauma while maintaining alveolar recruitment with positive end-expiratory pressure.[2] Patients with severe acute respiratory distress syndrome still may not have adequate oxygenation with this technique, however, leading to the need for salvage strategies. These include neuromuscular paralysis, prone positioning, the use of inverse-ratio ventilation, and extracorporeal membrane oxygenation (ECMO).

ECMO involves cannulation of central blood vessels to establish a bypass circuit comprising a pump and a membrane oxygenator. The membrane oxygenator oxygenates the blood and removes carbon dioxide. In patients with isolated respiratory failure, venovenous (VV) ECMO is sufficient, whereas patients with concurrent respiratory and cardiac failure require venoarterial ECMO. Whereas traditional VV ECMO cannulation involves 2 cannulae (a femoral venous drainage cannula and an internal jugular [IJ], subclavian, or second femoral venous cannula to return blood in or near the right atrium [RA]), the newer dual-lumen cannula can be placed in the IJ position alone. The IJ insertion site facilitates mobilization of the patient's lower extremities compared with femoral cannulation.

Due to the large size of the cannula and the need to place the cannula across the RA and into the inferior vena cava (IVC), some centers use fluoroscopic guidance. The authors' practice is dual-lumen VV ECMO cannula placement with transesophageal echocardiography (TEE) guidance in the intensive care unit (ICU). Advantages of echocardiography include avoiding radiation and the ability to evaluate cardiac structure and function. In addition, placing the cannula in the ICU with TEE guidance eliminates the time and risk of transport. However, TEE guidance for placement of the dual-lumen cannula requires experience in echocardiography and has been reported to be more technically complex compared with traditional cannulation.[3] A step-by-step description of the technique and a review of the methods presented in the literature for solving common problems encountered during placement may aid in overcoming this barrier.

A detailed review of VV ECMO, including information on equipment, physiology, and patient management, has been published in this *Journal*.[4] The purpose of this article is to

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illustrate and describe the role of echocardiography both to guide initial placement of the dual-lumen catheter and to evaluate the cause of persistent hypoxemia during VV ECMO support. Supplementary chest x-ray, computed tomography (CT), and transthoracic echocardiographic (TTE) images are included to illustrate proper and problematic orientation of the cannula.

Patient Selection

Indications

VV ECMO is used to treat patients with life-threatening respiratory failure. The Extracorporeal Life Support Organization definition of refractory hypoxemia is an arterial partial pressure of oxygen <100 mmHg with an inspired oxygen fraction (F_IO_2) of >0.9, which corresponds to an estimated mortality risk of 80%.[5]

Ideal candidates for ECMO have acute, reversible, refractory, isolated respiratory failure. Patients with pneumonia or asthma-induced hypoxemia without cardiogenic shock or neurologic injury have improved rates of survival compared with patients with multisystem organ failure.[6] In addition, VV ECMO as a bridge to lung transplantation is well described.[7]

Less common indications for VV ECMO may include massive pulmonary embolism, life-threatening airway obstruction, severe air leak syndromes, and primary graft dysfunction after lung transplantation.[5] Clinical considerations for and against dual-lumen VV ECMO support are presented in Table 1.

Contraindications

Nonreversible respiratory failure, such as advanced interstitial lung disease, in patients who are not transplant candidates, is a contraindication to VV ECMO. Patients who are not expected to survive hospitalization due to brain injury, multisystem organ failure, or advanced malignancy also should not be considered for VV ECMO.[5] Patients with concurrent cardiogenic shock and respiratory failure may be candidates for venoarterial ECMO, but not VV ECMO. Patients who have an absolute contraindication to systemic anticoagulation (eg, intracranial hemorrhage or refractory thrombocytopenia) are not candidates because the filter and cannula are thrombogenic surfaces.

Risks of placement of an ECMO cannula, along with safety precautions to avoid complications, are presented in Table 2 and are discussed in detail in the text.

Table 1
Clinical Considerations

	Indications	Contraindications
Patient population	Adults or children with refractory respiratory failure	Concurrent cardiac failure, moribund condition, limited code status*
Prognosis	Reversible etiology	Irreversible (and not transplant candidate)
Anatomy	IJ or SC site available	Only femoral vessels available
Coagulation status	Candidate for anticoagulation	Prohibitive risk of anticoagulation or ongoing coagulopathy†

Abbreviations: ECMO, extracorporeal membrane oxygenation; IJ, internal jugular; SC, subclavian vein; VV, venovenous.

*Neonates and other patients with small vessels may be at higher risk of perforation of great vessels or heart.

†Relative contraindication; running VV ECMO without anticoagulation is a possibility.

Table 2
Complications and Safety Considerations

Complication	Safety Tip
Injury of carotid or pleura	Ultrasound guidance of venous access
Perforation of RA, RV, IVC	Use multiplane TEE or fluoroscopy to exclude loop of wire in cardiac chamber before dilation and catheter advancement
Subacute tamponade and arrest	Surveillance echocardiography after initiation of ECMO
IVC difficult to cannulate, leading to prolonged attempts	• Decrease positive end-expiratory pressure or disconnect circuit • Fluid challenge • Leave cannula tip in RA and determine whether recirculation is prohibitive • Consider using only return lumen and place separate venous drainage cannula • Consider stiffer wire • Consider additional imaging modality

Abbreviations: ECMO, extracorporeal membrane oxygenation; IVC, inferior vena cava; RA, right atrium; RV, right ventricle; TEE, transesophageal echocardiography.

Description of the Dual-Lumen Cannula

An example of a dual-lumen cannula designed for right IJ insertion is shown in Figure 1; dimensions are summarized in Figure 2. Cannulae are available in diameters ranging from 13-to-31F to accommodate a wide range of patient sizes, although in adults the most commonly used sizes are 20-to-31F. For those sizes, the distances between superior vena cava (SVC) drainage, return flow, and IVC drainage are identical. The venous drainage lumen has distal openings for drainage from the IVC, both at the tip and 1 cm from the tip. The beveled side spout for return flow to the RA is located 7.5 cm above the side holes for IVC drainage and 9.4 cm from the distal tip; the SVC drainage openings are 5.3 cm above the return flow orifice.

The beveling of the return flow orifice results in the return flow jet being directed about 45 degrees away from the axis of the cannula, which is well-suited for aiming the flow into the right ventricle (RV) when the return orifice is slightly below the SVC/RA junction (Fig 3). Note that the foramen ovale is an important positioning landmark, just behind the return flow spout in Figure 1.

The proper surface orientation of the cannula is for the return flow lumen to be positioned anterior to the venous

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