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Extracorporeal Membrane Oxygenation in Cardiopulmonary Disease in Adults

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The use of extracorporeal membrane oxygenation (ECMO) for both respiratory and cardiac failure in adults is evolving rapidly. Advances in technology and accumulating data are spurring greater interest and explosive growth in ECMO worldwide. Expanding indications and novel strategies are being used. Yet the use of ECMO outpaces the data. The promise of a major paradigm shift for the treatment of respiratory and cardiac failure is tempered by a need for evidence to support many current and potential future uses. The authors review cannulation strategies, indications, and evidence for ECMO in respiratory and cardiac failure in adults as well as potential applications and the impact they may have on current treatment paradigms. (J Am Coll Cardiol 2014;63:2769–78) © 2014 by the American College of Cardiology Foundation

Although extracorporeal membrane oxygenation (ECMO) has been in existence since the 1970s as a means of supporting respiratory or cardiac function, early application of this technology was plagued by high complication rates, with no proven survival advantage over conventional management (1,2). Major recent advances in extracorporeal technology have favorably altered its risk-benefit profile (3–6), and an expanding body of evidence and more extensive experience have generated renewed interest as well as a considerable rise in the use of ECMO for cardiopulmonary disease (7,8). In this review, we discuss the cannulation strategies, indications, and evidence for the initiation of ECMO in cardiopulmonary disease, along with potential future applications that could shift the paradigm in approaches to both respiratory and cardiac failure.

Configurations and Cannulation Strategies

ECMO involves an extracorporeal circuit that directly oxygenates and removes carbon dioxide from the blood using an oxygenator, a gas exchange device that uses a semipermeable membrane to separate a blood compartment from a gas compartment. Deoxygenated blood is withdrawn through a drainage cannula by an external pump, passes through the oxygenator, and is returned to the patient through a reinfusion cannula. When blood is drained from a central vein and returned to a central vein, a process known as venovenous ECMO, the device is providing gas exchange only. When blood is drained from the venous system and pumped into an artery, a process known as venoarterial ECMO, the circuit provides both respiratory and circulatory support. The amount of blood flow through the circuit, the fraction of oxygen delivered through the oxygenator, and the contribution of the native lungs are the main determinants of blood oxygenation for a given device, whereas the rate of gas flow through the oxygenator, known as the sweep gas flow rate, and the blood flow rate are the major determinants of carbon dioxide removal (9). Extracorporeal circuits are very efficient at removing carbon dioxide and can do so at blood flow rates much lower than what is needed to achieve adequate oxygenation (10,11). Therefore, when the goal is extracorporeal carbon dioxide removal ($ECCO_2R$), smaller cannulae can be used, which may be easier and safer to insert (12). $ECCO_2R$ may be used to address hypercapnic respiratory failure or to eliminate carbon dioxide in primarily hypoxemic respiratory failure to permit reduced ventilation strategies. An alternative configuration used primarily for carbon dioxide removal is arteriovenous $ECCO_2R$, in which the patient's native cardiac output generates blood flow through the circuit, without the need for an external pump (13).

Traditional venovenous ECMO configurations involve cannulation at 2 distinct venous access points for drainage and reinfusion of blood (9) (Fig. 1). This configuration,

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Abbreviations and Acronyms

ARDS = acute respiratory distress syndrome

CPR = cardiopulmonary resuscitation

$ECCO_2R$ = extracorporeal carbon dioxide removal

ECMO = extracorporeal membrane oxygenation

ECPR = extracorporeal cardiopulmonary resuscitation

LVAD = left ventricular assist device

PCI = percutaneous coronary intervention

PGF = primary graft failure

VAD = ventricular assist device

with the drainage and infusion ports in close approximation, may lend itself to drawing reinfused, oxygenated blood back into the circuit, a phenomenon known as recirculation. Recirculated blood does not contribute to systemic oxygenation. Additionally, 2-site venovenous ECMO requires femoral access. With the advent of bicaval dual-lumen cannulae, the internal jugular vein can be used as the lone venous access site to provide venovenous extracorporeal support, avoiding femoral cannulation altogether (5,6) (Fig. 2). This approach requires the proper positioning of the cannula, with the reinfusion port oriented such that flow is directed across the tricuspid valve, minimizing the amount of recirculation (6). Placement is typically accomplished under fluoroscopic or transesophageal echocardiographic guidance (14). For patients in whom mobilization is anticipated, particularly those awaiting transplantation whose candidacy depends in part on their physical conditioning, a configuration that avoids femoral cannulation is preferred. Cannula size is based on the physiologic needs of the patient, and particular consideration should be given to the patient's estimated cardiac output. For a given extracorporeal blood flow, changes in cardiac output will alter the percent of the patient's blood volume passing through the oxygenator, which will affect systemic oxygenation.

In patients with significantly impaired cardiac function, with or without impaired gas exchange, a venoarterial configuration is necessary to provide circulatory support. The traditional configuration for venoarterial ECMO involves femoral venous drainage and femoral arterial reinfusion. With this configuration, the reinfusion jet flows retrograde up the aorta and may meet resistance from antegrade flow generated by the left ventricle (Fig. 3). Depending on the amount of native cardiac function, the location of the interface between antegrade and retrograde flow will vary, and in circumstances in which there is impaired native gas exchange with a significant amount of poorly oxygenated blood ejected from the left ventricle, the oxygenated, reinfused blood may not reach the aortic arch from below, thereby rendering oxygen delivery to the cerebral and coronary vascular beds suboptimal. In such patients, an additional reinfusion cannula may be added to the configuration with a "Y" connection off of the femoral arterial reinfusion cannula, with insertion into an internal jugular vein. This configuration of venous drainage combined with both arterial and venous return (venoarterial-venous ECMO) may facilitate oxygenation of the cerebral and coronary circulation by returning oxygenated blood into the native cardiac circulation while providing circulatory support. In cases of severe left ventricular dysfunction, venoarterial ECMO may result in overdistention of the left ventricle and worsening pulmonary edema (15). Several approaches have been described to facilitate left ventricular decompression (16,17).

ECMO cannulation has traditionally been performed in the operating room by cardiothoracic surgeons, because they are best suited to perform cut-down procedures for cannulation and manage complications requiring surgical intervention (5,18). However, with a general trend toward percutaneous approaches, cannulation is being performed

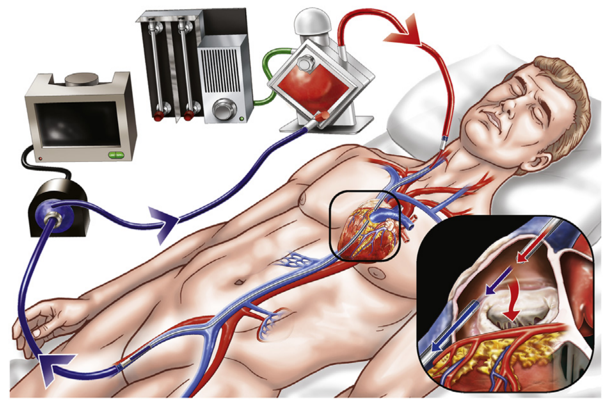

Figure 1 **Two-Site Venovenous Extracorporeal Membrane Oxygenation**

Venous blood is withdrawn from a central vein, pumped through an oxygenator, and reinfused into a central vein. **(Inset)** Drainage and reinfusion ports in close proximity may lead to oxygenated blood being drawn back into the circuit without having entered the systemic circulation, known as recirculation **(purple arrow)**.

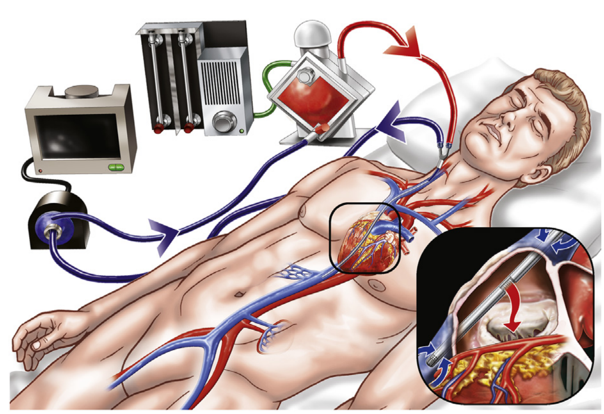

Figure 2 **Single-Site Venovenous Extracorporeal Membrane Oxygenation**

A dual-lumen cannula in the internal jugular vein permits both venous drainage and reinfusion without the need for femoral cannulation. **(Inset)** Deoxygenated blood is withdrawn through ports in the superior and inferior vena cavae. The reinfusion port is oriented such that oxygenated blood is directed toward the tricuspid valve.