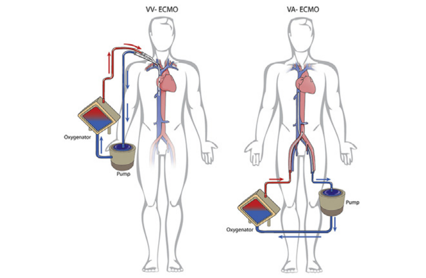
Contemporary extracorporeal membrane oxygenation therapy in adults: Fundamental principles and systematic review of the evidence

John J. Squiers, BSE,[a] Brian Lima, MD,[b] and J. Michael DiMaio, MD[a,b]

ABSTRACT

Extracorporeal membrane oxygenation (ECMO) provides days to weeks of support for patients with respiratory, cardiac, or combined cardiopulmonary failure. Since ECMO was first reported in 1974, nearly 70,000 runs of ECMO have been implemented, and the use of ECMO in adults increased by more than 400% from 2006 to 2011 in the United States. A variety of factors, including the 2009 influenza A epidemic, results from recent clinical trials, and improvements in ECMO technology, have motivated this increased use in adults. Because ECMO is increasingly becoming available to a diverse population of critically ill patients, we provide an overview of its fundamental principles and a systematic review of the evidence basis of this treatment modality for a variety of indications in adults. (J Thorac Cardiovasc Surg 2016;■:1-13)



Commonly implemented venovenous (VV) and venoarterial (VA) extracorporeal membrane oxygenation circuit cannulation schemes.

Central Message

We provide an overview of the fundamental principles of extracorporeal membrane oxygenation and a systematic review of the evidence basis of this treatment modality for a variety of indications in adults.

Perspective

A variety of factors, including the 2009 influenza A epidemic, results from recent trials, and improvements in technology, have motivated increased use of ECMO. We provide a systematic review of the evidence basis for a variety of ECMO indications in adults because ECMO is increasingly becoming available to a diverse population of critically ill patients.

Whereas standard cardiopulmonary bypass is designed to ensure minutes to hours of support for patients undergoing surgery, extracorporeal membrane oxygenation (ECMO) provides support to patients with respiratory, cardiac, or combined failure for days to weeks. For patients with isolated respiratory failure, venovenous (VV) ECMO is typically employed to provide support while the lungs recover. Venoarterial (VA) ECMO is available for cases of cardiac or cardiopulmonary failure. The Extracorporeal Life Support Organization is an international consortium of health care institutions that maintains a registry of ECMO use. As of January 2016, the Extracorporeal Life Support Organization has captured more than 73,000 ECMO implementations, with more than 19,000 in adult patients (Figure 1).[1] The volume of adult ECMO cases increased by 433% from 2006 to 2011 in the United States,[2] with corresponding increases in expenditures and resource use.[3]

The use of ECMO in adults has expanded due to several factors: the global pandemic of the novel influenza A virus led to an a higher incidence of acute respiratory distress syndrome (ARDS) refractory to conventional therapy[4]; improvements in technology allowed more successful applications of ECMO[5]; an infrastructure of specialized

From [a]Baylor Research Institute, Baylor Scott & White Health; and [b]Department of Cardiac and Thoracic Surgery, Baylor University Medical Center, Baylor Healthcare System, Dallas, Tex.
Received for publication Oct 28, 2015; revisions received Jan 30, 2016; accepted for publication Feb 28, 2016.
Address for reprints: J. Michael DiMaio, MD, Baylor Research Institute, 3310 Live Oak, Ste 501, Dallas, TX 75204 (E-mail: jmdimaio@yahoo.com).
0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2016.02.067

Abbreviations and Acronyms

ARDS	= acute respiratory disease syndrome
C-CPR	= conventional cardiopulmonary resuscitation
E-CPR	= extracorporeal cardiopulmonary resuscitation
ECMO	= extracorporeal membrane oxygenation
LVAD	= left ventricular assist device
PGD	= primary graft dysfunction
PCS	= postcardiotomy shock
VA	= venoarterial
VV	= venovenous

centers, capable of transporting patients requiring ECMO from outside facilities to their intensive care units, has been developed[6]; and a prospective randomized controlled trial recently promoted the efficacy of ECMO in adults with ARDS.[7] Because ECMO is increasingly becoming available to a diverse population of critically ill patients, it is appropriate to highlight the fundamental principles of this therapy and systematically review the evidence basis for ECMO across a variety of indications.

ECMO CIRCUITS AND EQUIPMENT

ECMO Circuits

The basic ECMO circuit consists of a blood pump, the membrane oxygenator, conduit tubing, a heat exchanger, and drainage and return cannulae. The circuit drains blood from the venous system and pumps it through a membrane oxygenator before returning newly oxygenated blood to the patient. By facilitating oxygen and carbon dioxide exchange, ECMO allows for reduction of ventilator settings to diminish the potential for lung injury. The major difference between VA and VV ECMO circuits is the types of cannulae and location of their insertion.

Modes of Vascular Access

VA ECMO is designed to provide cardiac support in addition to respiratory support. Deoxygenated blood is drained from the venous system, and oxygenated blood is returned into the arterial circulation, in a similar fashion to standard cardiopulmonary bypass. The pulmonary circulation is bypassed by placing the artificial lung in parallel with the native lungs.[8] Cannulation can be obtained centrally (blood drained directly from the right atrium and returned to the proximal ascending aorta) or peripherally (blood drained from the proximal femoral or jugular vein and returned to the carotid, axillary, or femoral artery), typically using the Seldinger technique via an open or percutaneous approach.[9] In cases of femoral arterial cannulation, a high risk of distal limb ischemia has motivated many centers to place an ipsilateral perfusion catheter proactively.[10,11]

During ECMO support in the setting of severe myocardial dysfunction, the left atrial and left ventricular end-diastolic pressures can increase to extremely high levels. To prevent left heart distention, a transseptal drainage cannula can be placed to decompress the left atrium[12] or an Impella 2.5 (Abiomed, Danvers, Mass) left ventricular assist device (LVAD) can be placed to unload the left ventricle.[13,14] The successful management of a case of acute cardiopulmonary failure with a hybrid configuration of VV ECMO and an Impella 5.0 (Abiomed) was recently described, as well.[15] Although this hybrid configuration offered the advantage of uncoupling heart and lung recovery, more evidence is required before its use should become routine. VA ECMO remains the best option for acute cardiopulmonary arrest due to the rapidity with which it can be deployed.[16] After initiation of VA ECMO, clinicians can confirm successful decompression of the left heart using echocardiography.

Another important consideration for peripherally cannulated VA ECMO is monitoring of cerebral oxygenation. In patients with both poor heart and lung function, oxygenated blood returning from the ECMO circuit will initially provide antegrade flow beyond the site of arterial cannulation and retrograde flow to the coronary and cerebral circulations. As heart function improves, competitive flow between native cardiac output and the arterial cannulation may cause a distal shift in the location of blood mixing. Even when ECMO flow is adequate and the oxygenator is functioning properly, this shift can result in deoxygenated blood circulating through the coronary and cerebral circulations if lung function remains poor or ventilator settings are inadequate. Peripheral blood gas monitoring through the right radial artery (except in cases of right common carotid or right axillary artery cannulation) can be employed to detect coronary and/or cerebral hypoxemia and to guide ventilator and ECMO circuit management.[17]

VV ECMO is designed to provide partial or complete respiratory support without any cardiac support, so VV ECMO is indicated only when native cardiac output is sufficient. VV ECMO places the native lungs in series with the artificial lung.[8] In adults, several cannulation options currently exist. Traditionally, deoxygenated blood is drained from a femoral vein and returned to the right internal jugular vein.[18] More recently, a bicaval dual-lumen catheter has been developed to provide both drainage and return directly into the right atrium via the internal jugular vein.[5] Potential benefits of the single cannulation technique include reduced recirculation (the phenomenon of oxygenated blood returning from the ECMO unit being drained immediately by the outflow cannula, creating a closed extracorporeal circulatory loop that decreases systemic oxygenation), liberation of the femoral vein to allow patient mobility, and reductions in cannulation site infection risk. For patients in whom internal jugular vein access is not available, bifemoral vein