Extracorporeal Life Support

Ventetuolo CE, Muratore CS. Extracorporeal life support in critically ill adults. *Am J Respir Crit Care Med.* 2014;190:497-508.

Combes A, Brodie D, Bartlett R, et al. Position paper for the organization of extracorporeal membrane oxygenation programs for acute respiratory failure in adult patients. *Am J Respir Crit Care Med.* 2014;190:488-496.

Two excellent review papers summarize the current state-of-the-art with respect to extracorporeal life support (ECLS) development and technical applications. In this first group of paragraphs, I have attempted to present the key points from these reports. Later papers describe the best available outcome data with ECLS technology and issues which must be overcome to optimize system performance.

Cardiopulmonary bypass using the first heart-lung machine was introduced at the University of Minnesota by Gibbon in the 1950s. In 1972, Dr. Robert Bartlett reported the successful use of extracorporeal membrane oxygenation (ECMO) outside the operating room. Subsequent decades have seen evaluation and modification of this technology in neonatal and pediatric populations. Since these early days, the ongoing use of ECMO in skilled centers has led to expanded applications in adult populations. More recently, improvements in technology and management of patients receiving ECMO as well as the heightened risk of severe acute respiratory distress syndrome (ARDS) as shown during the 2009 to 2010 influenza A (H1N1) pandemic have resulted in an increasing number of adult patients being supported with various forms of ECLS for cardiopulmonary failure after traditional treatment options including mechanical ventilation have failed. Indications and guidelines for the use of ECMO and other forms of ECLS in the critically ill adult remain unclear.

A basic life support circuit is composed of a blood pump, a membrane lung or oxygenator, a heat exchanger, cannulas to access the circulatory bed, and connecting tubing. Based on patient needs, partial to complete cardiopulmonary support involving both venous and arterial access or partial to complete pulmonary support, which is performed solely with venous access, can be achieved. In a typical circuit, venous blood is drained out of a major vein and passed through a pump, and the membrane lung for gas exchange and oxygenated blood is returned to a major artery (VA-ECMO) or vein (VV-ECMO). An arteriovenous extracorporeal circuit that incorporates a pump or uses the patient's own arterial blood pressure to drive blood across a membrane lung, or a VV configured circuit with a low-flow pump, can partially support the respiratory system by effectively removing carbon dioxide. This process is termed extracorporeal CO_2 removal.

The cannulas used and tubing size limit the flow rate achieved. Typical cannulas in adults range from 23F to 29F for venous drainage and 21F to 23F for blood return. In the current systems, vascular access may be obtained with extrathoracic percutaneous cannulation although central cannulation or a direct cut-down approach is also possible. Femoral vessels usually provide adequate access. Alternative arterial access may be achieved in the subclavian and axillary arteries. In venovenous ECMO systems, a double-lumen cannula with drainage ports in the inferior and superior vena cava and a return port positioned in the right atrium with flow directed across the tricuspid valve is available. This option offers single-site internal jugular access.

When primary support of the heart is intended, the drainage of blood from the patient into the ECLS circuit results in decreased right and left heart filling pressures, a reduction in pulmonary blood flow, cardiac unloading, and an improvement in end-organ perfusion. Targeted flow rates for this form of ECLS are usually 60 to 80 mL/kg/min. In addition to flow through the ECLS (or ECMO) circuit, pulmonary venous oxygen saturation may be monitored from the venous drainage limb, and flow rates are adjusted to maintain oxygen delivery by comparing venous and arterial oxygen saturation levels.

In the venovenous configuration, ventricular filling pressures and hemodynamics are unchanged in the steady state, but oxygen and carbon dioxide are exchanged via the membrane lung. Because both drainage and return cannula are positioned in the venous system, mixing of oxygenated and deoxygenated blood will occur. Recirculation, the term for this phenomenon, can limit oxygen delivery. In the venovenous configuration, the lungs sit in series with the membrane lung situated before the patient's lungs. Supraoxgenated blood is delivered back to the patient venous system or right atrium and then must traverse the native pulmonary circulation. Expected arterial oxygen saturations are lower ($> 85\%$) depending on the patient's innate pulmonary function. Adequate oxygen delivery is maintained as long as cardiac output is adequate. Cardiac output may be augmented by limiting or removing positive pressure ventilation. CO_2 removal is more efficient than oxygenation and requires substantially lower flow rates through the ECLS circuit.

Systemic anticoagulation, usually with unfractionated heparin, is initiated at the time of placement of cannulas to prevent circuit thrombosis and inappropriate clotting in the vascular bed of the patient. The ideal anticoagulation strategy is controversial and is based on institution protocols.

Applications of ECLS/ECMO

As a respiratory support modality, ECLS is most appealing for its potential to reduce the injurious effects of positive pressure ventilation. Ventilator-associated lung injury from overdistension of lung units with relatively normal function and cyclical lung expansion and collapse magnifies cellular injury in the lung and the release of inflammatory mediators in already injured lung tissue. High concentrations of inspired oxygen may also be injurious. Low tidal volume strategies for mechanical ventilation have improved outcomes in ARDS; however, some patients develop hypoxemia refractory to these strategies or have very poor lung compliance and severe respiratory acidosis. The optimal triggers for ECLS as salvage therapy in ARDS remain unclear.

Hypercarbic Respiratory Failure

CO_2 clearance is more efficient than oxygenation and largely depends on gas flow through the gas exchange membrane rather than blood flow. Pumpless systems that use the patient's arterial to venous pressure gradient and create a shunt from artery to vein or circuits similar to those used for dialysis that incorporate low-flow pumps and small dual-lumen venous cannulas with avoidance of the arterial circulation have been studied for this purpose. Although these technologies have not been widely studied, it seems logical that primary ventilatory failure may be better treated with these circuits compared with larger ECLS systems or high levels of potentially injurious mechanical ventilation.

Cardiac Support

A number of options exist for mechanical circulatory support in cardiac failure. In acutely decompensated patients, a bridging strategy may best serve patients as the ultimate therapy is determined. There are no trials comparing other short-term interventions (intra-aortic balloon pumps or temporary ventricular assist devices) with a venoarterial ECLS circuit for refractory cardiogenic shock, but this therapy may be used as a salvage option in this setting. Failure to wean from intraoperative cardiopulmonary bypass, acute myocardial infarction, ischemic cardiomyopathy, and postpartum cardiomyopathy are also reasonable indications for venoarterial ECLS. Arterial access and venous access are essential in this application because of the need to support not only pulmonary but also cardiac function.

ECLS may also be considered in patients requiring emergent cardiac catheterization. Small case series describe the successful use of ECLS in patients who suffer cardiac arrest during percutaneous coronary interventions with transcatheter aortic valve implantation or during provision of therapeutic hypothermia.

ECLS/ECMO Programs

During the 2009 pandemic influenza A (H1N1), many centers initiated ECMO programs without significant experience, and many hospitals had patients who could potentially benefit from ECMO but were ill equipped to transport these individuals to a center with this capability. The ECMO community recommends that the administration of this potentially lifesaving but expensive resource should be organized at regional and national levels to provide the best care possible in high-volume dedicated centers because the inappropriate use of ECMO may markedly increase costs and expose individual patients to important risks.

From neonatal and pediatric literature, recent data suggest that ECMO centers caring for more than 20 to 25 cases per year have significantly better outcomes than centers with 10 to 20 cases per year or those institutions with fewer than 10 cases per year. The learning curve to establish competence requires at least 20 cases for optimal results. Not surprisingly, there is controversy related to these criteria.

Centers referring patients with acute respiratory failure but without rapid access to a mobile ECLS or ECMO team may be trained to perform cannulation and the initiation of support in partnership with a referral center until transfer to the regional center can be arranged. Close coordination with the receiving ECLS center is essential to maintain quality control over indications, techniques for cannulation, and maintenance of patients on ECLS. Networks of hospitals at the local, regional, or interregional level may be created around each ECLS center located in tertiary referral hospitals. Such networks have been successfully organized in the United Kingdom, Italy, and Australia.

Mobile ECLS/ECMO Teams

Each ECLS network should ideally create mobile teams to retrieve patients and support patients who have critical cardiopulmonary failure refractory to conventional therapy. Coordination would proceed through the tertiary referral center. A mobile team should be available 24 hours a day, 7 days a week and employ experienced personnel trained in the transport of critically ill patients, the insertion of cannulae, and circuit and patient management. The team should include a mix of physicians, transport specialists, nurses, perfusionists, and other specialists. Imaging requirements at the referring hospital should be considered, and a clinician trained in echocardiography should be considered for team membership in some transfers. Portable ultrasound technology and expertise should also be available. Successful transportation of patients on cardiopulmonary support has been described for short and long distances by ambulance, helicopter, and fixed wing aircraft.

Where a program is maintained or a transport team is based, equipment that should be readily available has been identified. A wet-primed circuit should be available for immediate use around the clock because there is evidence that an assembled circuit can be stored for days to weeks without presenting an additional risk of infection. It should also be possible to change the circuit, if necessary, in considerably