Extracorporeal Membrane Oxygenation—What the Nephrologist Needs to Know

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Extracorporeal membrane oxygenation (ECMO) use in adults is rapidly increasing in its use for both cardiac and respiratory failure. ECMO exists in 2 primary configurations: veno-venous ECMO, used in the setting of isolated respiratory failure, and veno-arterial ECMO, which can be used in respiratory failure but is mandatory in the setting of cardiac failure. Acute kidney injury occurs frequently in patients on ECMO, and renal replacement therapy is often required. Continuous forms of renal replacement therapy predominate, but there is a high degree of variation in clinical practice among ECMO centers internationally. No consensus exists regarding the optimal technique, but the use of continuous renal replacement machines has been shown to be safe and effective in patients on ECMO. An understanding of the basic principles and functionality of ECMO is important for both acid-base and fluid management in the intensive care unit.

Key Words: ECMO, Renal replacement therapy, Acute kidney injury, Acid-base, Fluid management

INTRODUCTION

Over the past decade, the use of extracorporeal membrane oxygenation (ECMO) in adult patients in the intensive care unit (ICU) has rapidly increased.[1] ECMO is a technology that emulates the cardiopulmonary bypass machine traditionally used during cardiac surgery. Its purpose is to provide cardiopulmonary support in the setting of cardiac and/or respiratory failure when conventional management strategies have proven inadequate and the patient is felt either likely to recover or to be a candidate for transplant or other definitive therapy. In contrast to a traditional cardiopulmonary bypass machine, ECMO is capable of being used for days and even weeks in the ICU. The first ECMO patient was an adult trauma patient treated in 1971, but the technology has only advanced to the point where its use has become widespread in recent years.[2] Recent case series and clinical trials have shown that in specialized centers, ECMO can be used safely and may be associated with improved mortality in patients with potentially reversible respiratory failure.[3,4] The use of ECMO has increased in previous years due to technological improvements in the devices themselves, the increasing use of ECMO as a bridge to support patients to heart or lung transplant and ventricular assist device implantation, as well as the expanding use of ECMO in the setting of acute respiratory failure. Therefore, it is increasingly likely that nephrologists will encounter patients receiving ECMO support when consulted in the ICU—particularly in specialized cardiovascular ICUs. The purpose of this review was to briefly describe fundamental aspects of ECMO including its clinical use, and the evidence to support it, with particular emphasis on clinical assessment and the incorporation of renal replacement therapy (RRT) in the care of this patient population.

FUNDAMENTALS OF ECMO—UNDERSTANDING THE CIRCUIT

Whereas cardiopulmonary bypass is frequently used for cardiac surgical procedures in the operating room, ECMO can provide similar cardiopulmonary support for a prolonged period of time in the ICU. Although there are many producers of ECMO equipment, there are key components of the ECMO circuit that are universal. An ECMO circuit consists of a pump, a membrane oxygenator, tubing, and vascular access cannulas, which are inserted either percutaneously or via surgical cutdown. The membrane oxygenator is connected to a source of fresh gas flow via a flow-meter—most commonly an air-oxygen blender. The control panel will display pump speed (a parameter that is set by the operator), blood flow (as measured), and occasionally other parameters including pressures measured inside the circuit, blood temperature, and oxygen saturation.

ECMO can be deployed in 2 primary ways. Veno-arterial (V-A) ECMO is most similar to traditional cardiopulmonary bypass in that there are both venous and arterial cannulas inserted into large vessels, and it allows for full cardiopulmonary support. Veno-venous (V-V) ECMO is a modality used only in the setting of isolated respiratory failure as it does not provide any cardiac support. In V-V ECMO, deoxygenated blood is withdrawn from a large venous cannula, passed through the membrane oxygenator, and is then returned to the venous system with all gas exchange occurring before the blood passes through the lungs. V-V ECMO carries a decreased risk of systemic emboli because there is no ECMO blood flow into the arterial system.[5] Despite the use of anticoagulation, there is a small risk for the development of venous thrombi

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(and associated embolic complications) due to the large cannulas present in the venous system.

Modern ECMO circuits have centrifugal pump technology that minimizes shear stress and hemolysis of red blood cells although at high flows or when using small vascular access cannulas, this may still occur. Pump speed is set in revolutions per minute, and flow is then measured in liters per minute by a flow meter. Increased resistance in the circuit (or in the patient's vasculature) will lead to decreased flow. As the pumps are centrifugal, they produce nonpulsatile flow. Commonly, mean arterial pressure is used as a hemodynamic target in addition to measured pump flow.

Blood tubing and cannulas are frequently pretreated by the manufacturer with an anticoagulant coating that allows for lower levels of anticoagulation compared with traditional cardiopulmonary bypass. However, almost all patients will require anticoagulation—most commonly with unfractionated heparin. Anticoagulation protocols will vary among centers and may be altered based on the clinical status of an individual patient (eg, in the setting of surgical bleeding).[6,7] Non-heparin anticoagulants such as argatroban or bivalirudin may be used in isolated circumstances, such as the development of heparin-induced thrombocytopenia, but this is uncommon, and individual institutions will differ in their approach.

The membrane oxygenator is where gas exchange occurs—oxygenating venous blood and removing carbon dioxide. The newest generation of oxygenators uses nonmicroporous hollow fibers. Gas flow through the oxygenator is administered with an air-oxygen mix (FiO_2), and the flow (called "sweep") is titrated from ~1 to 6 L per minute. The FiO_2 is titrated to maintain a pO_2 based on institutional protocol, and the sweep is adjusted to maintain pCO_2. As sweep is increased, CO_2 clearance will increase in a directly proportional manner due to the effect of increased countercurrent flow inside the oxygenator and diffusion of carbon dioxide by its concentration gradient.[5] It is useful to think of sweep gas flow as analogous to minute ventilation in that increases in sweep flow will result in decreased pCO_2.

An important difference between traditional cardiopulmonary bypass and the ECMO circuit is that there is often not a venous reservoir between the venous cannula/tubing and the pump as a result of the need to minimize circuit volume and decrease the potential for stasis within it. This results in an increased risk that air or other emboli entering the venous arm of the circuit may pass through to the arterial outflow. Particular care must be taken when placing large venous lines such as hemodialysis catheters so as not to entrain air into the circuit.

CLINICAL SUMMARY

- Extracorporeal membrane oxygenation (ECMO) use is rapidly increasing.
- Acute kidney injury is common in this patient population.
- Renal replacement therapy is frequently required and has been shown to be safe.
- Understanding the principles of ECMO is critical to managing acid-base and fluid status.

ECMO FOR CARDIAC FAILURE

ECMO is commonly used in the patient with cardiac failure as a "bridge to recovery" from an acute insult. It is also used to "bridge" patients to either heart transplantation or, more recently, to the implantation of an implantable left ventricular assist device.

In the setting of cardiac failure or shock, V-A ECMO is the modality of choice as it provides systemic blood flow via an arterial cannula. A long venous cannula is commonly placed via the femoral vein into the inferior vena cava (IVC) adjacent to the right atrium and an arterial cannula inserted into the femoral artery (see Fig 1; V-A ECMO). This is often referred to as "peripheral" cannulation in contrast to "central" cannulation where the venous cannula is inserted directly into the right atrium and the arterial cannula into the ascending aorta or subclavian artery. Whereas "peripheral" cannulation can often be performed at the bedside (and occasionally in the awake patient), "central" cannulation must be performed in an operating room. "Central" cannulation is a much more invasive procedure and carries an increased risk of bleeding due to the need to perform a sternotomy (or leave the chest open in patient who has undergone sternotomy) in a patient who will continue to require anticoagulation. It is most commonly used in patients who are unable to wean from cardiopulmonary bypass in the setting of cardiac surgery.

In the patient who has cannulas placed in the femoral vessels, arterial flow from the ECMO circuit flows in a retrograde fashion through the aorta. As the patient's cardiac function improves and there is increased flow through their heart, an increase in "pulsatility"—as evidenced by an increase in pulse pressure—may be seen on the patient's arterial pressure tracing (in contrast to the nonpulsatile flow produced by the ECMO circuit). In patients with concurrent respiratory failure and poor lung function, the blood being ejected from the left ventricle may be poorly oxygenated leading to a gradient of less oxygenated blood more proximally and highly oxygenated blood more distally (as this blood is coming from the ECMO circuit). Most patients will have some degree of "pulsatility", and a complete lack of any pulsatile flow should be interpreted as a sign of very poor intrinsic cardiac function. As cardiac recovery occurs, it is common to use serial echocardiography to assess ventricular function in anticipation of weaning ECMO support.

ECMO FOR RESPIRATORY FAILURE

The use of ECMO in providing support for patients with respiratory failure has increased dramatically after the publication of the CESAR trial and a case series of patients with acute respiratory distress syndrome (ARDS) due to influenza A (H1N1) infection from Australia and New Zealand in 2009.[3,4] In the setting of respiratory failure, ECMO is primarily used as a "bridge to recovery" although it is also being used increasingly as a "bridge to transplant" for patients awaiting lung transplantation.[8]