The State of the Art in Extracorporeal Membrane Oxygenation

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Extracorporeal membrane oxygenation has evolved in design, technology, patient selection, insertion techniques, adjunct devices, and management in the past 45 years since it began. Outcomes have improved and indications have expanded. It continues to be an expeditious, cost-effective tool for rapid resuscitation of patients with cardiorespiratory failure, whose outcomes without extracorporeal membrane oxygenation intervention are predominately fatal. However, results are still moderately satisfactory, and the ethical aspects of ongoing care need to be at the forefront of daily family discussions in patients for whom a bridge to transplant or definitive device is not possible.

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INTRODUCTION

Extracorporeal membrane oxygenation (ECMO), often referred to as extracorporeal life support, provides temporary support to critically ill patients who cannot maintain their respiratory or circulatory function or both. A basic circuit is composed of cannula, tubing, a pump, oxygenator, and heat exchanger; there are 2 approaches: veno-venous (VV) ECMO for solely respiratory support and veno-arterial (VA) ECMO for cardiac support, cardiorespiratory support, or undifferentiated etiology support. Since the first use in 1971,[1] ECMO circuits have improved in design and function.[2-4] This review focuses on the current trends in patient selection, improvements in insertion techniques, and contemporary management considerations, which have improved clinical outcomes.

EVOLUTION TO CONTEMPORARY ECMO

Gibbon's development of the heart-lung machine facilitated the first open-heart surgery in 1953.[5] Initial use of heart-lung machine was restricted to the operating room because of damage to blood owing to direct exposure to oxygen. The advent of spiral coil–type membrane oxygenators circumvented this concern and led to the first experiences with maiden ECMO circuits in the early 1970s.[1] Initial experience was for acute respiratory distress syndrome (ARDS), with the early experience of ECMO predominantly reported in pediatric cohorts.[6,7] Growing interest in ECMO led to a National Institute for Health–funded multicenter, randomized controlled trial, the first of its kind comparing ECMO with conventional mechanical ventilation for ARDS. As no survival benefit was discerned, with poor survival in both groups, interest in ECMO waned.[8]

With the development of cardiac surgery and heart-lung machine technology, this improved technology was applied to future iteration ECMO circuits with favorable results. Centrifugal pumps have replaced early rotor pumps in contemporary ECMO circuits,[2] reducing hemolysis and improving flow dynamics. New biocompatible surfaces[9] such as heparin-coated circuits allow reductions in systemic anticoagulation, potentially reducing incidences of bleeding events and systemic inflammatory response syndrome. Innovations leading to the development of solid hollow fiber membranes[3,4] resulted in reduced incidence of air embolism and blood trauma due to oxygen exposure. Smaller and portable configurations facilitated VA ECMO as a tool to initiate management of patients in less intensive

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settings and enable ease of transport[10] to advanced care centers (eg, Cardiohelp device, Maquet). Newer duel-lumen cannulas[11,12] (eg, Avalon, Maquet, and TandemHeart Right Ventricular Assist Device cannula with oxygenator) have made it possible to provide VV ECMO respiratory support with a single cannula, peripherally inserted in the internal jugular vein using the Seldinger technique.

Currently, ECMO is used not only for pulmonary and circulatory failure but also for transport, retrieval of organs, and extracorporeal cardiopulmonary resuscitation (CPR). Recent data from the Extracorporeal Life Support Organization (ELSO)[13] showed that more than 14,000 patients have used short- or medium-term ECMO support, with high overall survival to discharge: ~60% in respiratory and ~45% in cardiac failure.

INDICATIONS

The use of ECMO is often considered in critically ill patients and indicated when the pre-ECMO mortality exceeds 80%.[14] Contraindications include cerebral hemorrhage owing to the need for anticoagulation, severe immunosuppression owing to systemic inflammatory response syndrome, or terminal diagnosis.

Veno-arterial ECMO

VA ECMO is one of the many options available for circulatory support; other options being various ventricular assist devices implanted both surgically and percutaneously. The advantages of VA ECMO compared with these include ease of emergent insertion, potential for biventricular support, and ability to provide respiratory support.[15] It may be used as a bridge to myocardial recovery, heart transplantation, or permanent ventricular assist device.

Potential indications for VA ECMO include spectrum of both isolated cardiac failures and combined cardiorespiratory problems with objective evidence of poor tissue perfusion despite optimal intervention. VA ECMO is most commonly employed in settings of cardiogenic shocks due to a variety of etiologies, such as post−myocardial-infarction, fulminant myocarditis, peripartum cardiomyopathy, septic shock causing cardiac depression, decompensated heart failure, and most commonly, postcardiotomy shock (failure to wean off cardiopulmonary bypass), as examples. Recent novel yet less common applications for VA ECMO support include extracorporeal CPR, resuscitation in cases of severe hypothermia, and extracorporeal interval support for organ retrieval.

Veno-venous ECMO

VV ECMO provides respiratory support in patients with severe hypoxia or hypercapnia due to poor lung function. ELSO guidelines[14] suggest VV ECMO with objective parameters PaO_2/FiO_2 ratio of <150 and Murray Score of 2-3, and strongly indicate it when PaO_2-FiO_2 ratio drops below 80 or for Murray Score of 3-4. Additional applications for VV ECMO[16] include severe hypoxemia (PaO_2/FiO_2 <80) with high positive end-expiratory pressure (typically 15-20 cm of H_2O) and potentially reversible pulmonary function, severe hypercapnia with arterial pH $<$ 7.15 despite optimal mechanical ventilation, or plateau airway pressure of 35-40 cm of H_2O despite optimal mechanical ventilation.

In clinical scenarios, VV ECMO is most widely used in cases of severe ARDS when lung protective ventilation protocols fail. It can also be employed in severe respiratory failure caused by various etiologies such as acute lung injury, chronic obstructive pulmonary disease, severe asthmatic attacks, or severe influenza (eg, H1N1). VV ECMO can also be used to provide recovery time for allograft in cases of primary rejection in lung transplant. It can also be employed as a bridge to lung transplant in acute decompensation cases with temporary support requirement.

The only instance where VV ECMO can be used as support in cardiac failure is in cases of right ventricular failure secondary to pulmonary vasoconstriction, where there is potential to reverse pulmonary vascular resistance by improving oxygenation and CO_2 removal.

TECHNICAL CONSIDERATIONS

Veno-arterial ECMO

VA ECMO support can be initiated via intrathoracic or peripheral cannulation. Intrathoracic cannulation is usually performed after open-heart surgery (postcardiotomy shock) or to solve peripheral ECMO complications. The venous cannula is placed in the right atrium. This siphons blood from the body and inputs it to the ECMO circuit, which subsequently contains the oxygenators and heat exchanger in series. The outflow from the ECMO goes into an arterial cannula, which is placed in the ascending aorta. Both cannulas can be tunneled through the skin to allow a definite chest closure and potential patient extubation.

For peripheral cannulation, the femoral vein is the preferred venous line. The venous cannula is placed in the right atrium through the femoral vein, also using the Seldinger technique.[17] The arterial line can be placed in the femoral artery, axillary artery, or