Extracorporeal Gas Exchange

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KEYWORDS

- Critical care • Respiratory failure • Acute respiratory distress syndrome
- Mechanical ventilation • Extracorporeal gas exchange
- Extracorporeal membrane oxygenation (ECMO) • Extracorporeal CO_2 removal

KEY POINTS

- The transfer of O_2 and CO_2 via a selective membrane that separates gas and blood is a basic tenet of life.
- ECMO integrates an additional, "external" option for gas exchange into the circulation, the artificial lung mimics the principle of the native lungs.
- Extracorporeal gas exchange is a powerful tool. However, deeper understanding of the interactions between native and artificial lung, monitoring with better technologies, physiologic and observational studies and, patience are needed to avoid multicenter studies leading to results that carry a high risk to impede a successful further development.

INTRODUCTION

The transfer of O_2 and CO_2 via a selective membrane that separates gas and blood is a basic tenet of life. The lungs represent the first and last membrane to pass between the external environment and human body, allowing oxygen uptake and carbon dioxide delivery to happen. Any serious change in the integrity and functionality of the lungs potentially threatens life. Acute respiratory failure is characterized by hypoxemia, mostly caused by a marked increase of pulmonary shunt and impaired CO_2 removal caused by the inability of the respiratory muscles to move enough gas into heavy, edematous lungs to ensure a minute volume adequate to remove the CO_2 dissolved in plasma at an appropriate rate. These 2 impairments exist in parallel, but their degree of influence

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Crit Care Clin 34 (2018) 413–422
https://doi.org/10.1016/j.ccc.2018.03.011 criticalcare.theclinics.com

might vary. In severe forms of acute respiratory failure like acute respiratory distress syndrome (ARDS), oxygenation and CO_2 removal represent equivalent treatment challenges, although only hypoxemia might cause an acutely life-threatening state. The classical and established treatment option is mechanical ventilation. However, mechanical ventilation has its own adverse effects, described as ventilator-induced lung injury (VILI), caused by the mechanical power transmitted to the lungs during ventilation and high fractions of inspired oxygen, leading either to direct destruction of the pulmonary matrix (barotrauma) or to the initiation or perpetuation of an inflammatory reaction of the lungs.[1] Another article in this issue deals with the causation of VILI and suggests an approach to its avoidance by conventional means.

Increasing knowledge about the negative adverse effects of mechanical ventilation and the technical development of artificial lungs mimicking the aveolo-capillary membrane while using silicone as membrane stimulated the conceptual idea to supportively use extracorporeal gas exchange during mechanical ventilation.[2] In the beginning, the objective to reduce the FiO_2 was the main driver for its use. Later on, the possibility to reduce the invasiveness of mechanical ventilation gained more importance when deciding about the use of extracorporeal gas exchange. In 1972, Hill and colleagues[3] reported the first successful treatment of an ARDS patient using a Bramson membrane lung for a period of 72 hours. In 1976, Bartlett[4] successfully treated the first newborn. Influenced by the oxygenator, the technique was reported as extracorporeal membrane oxygenation (ECMO). At that time, the ECMO technique, also used for respiratory support, was applied in the veno-arterial VA-mode.

In brief, an ECMO unit consists of a driving force, today mostly realized by a centrifugal pump, a gas exchanging unit, and mostly implemented as a hollow fiber membrane oxygenator, connecting tubing, and 2 single-stage or 1 double-stage cannula(s) for vascular drainage and return. The double stage cannula is by definition linked to veno-venous (VV)-ECMO, while single-stage cannulas are suitable for both the VA and VV modes. For respiratory support, the VV approach has become standard of care; in extreme cases, a hybrid solution combining VV with partial arterial return might be used.

In the ECMO unit, the oxygenator surface and blood flow are key determinants of oxygen transfer, whereas oxygenator surface and gas flow through the membrane lung (sweep gas) are key determinants of CO_2 removal. Consequently, if oxygenation is an issue, high blood flow rates are required; conversely, if decarboxylation is the goal, relatively low blood flow rates are needed to remove reasonable amounts of CO_2. The intended goals of extracorporeal support therefore largely influence the unit to choose (oxygenator size, cannula, and tubing size). Beside the artificial surface per se, the mechanical power created by the pump stresses corpuscular blood components in dependency from the pressures generated, and determines the biocompatibility of the procedure. A well-chosen set up respects the balance between invasiveness and need. According to the treatment goals, it might be appropriate to roughly categorize high-flow ECMO (full-blown) systems with blood flows of 4 L that offer more oxygenation and extensive CO_2 removal, mid-range flow systems with up to 2 L of blood flow (less oxygenation and good CO_2 removal), and low-flow systems up to 1 L of blood flow (no oxygenation benefit but significant CO_2 removal). Set-ups in these flow categories have been and are extensively used for numerous indications (**Tables 1** and **2**). In summary, for the classical rescue indication aimed primarily at assuring oxygenation, full-blown ECMO is indicated; for lung protection and reduced risk of mechanical ventilation, mid- and low blood flow devices are suitable.

In the following discussion, the authors describe the indications for which extracorporeal gas exchange is actually applied and critically reflect upon the current evidence justifying its use for each of these indications.