An Overview of Extracorporeal Membrane Oxygenation Therapy

Mary Beth Madonna and Robert M. Arensman

Children's Memorial Hospital, Northwestern University Chicago, Illinois, USA

Abstract. A brief overview of extracorporeal membrane oxygenation and its use in infants and children is presented. The history, selection, operative procedure, daily management and complications are discussed. The international results are shown.

Key words: Extracorporeal membrane oxygenation

Despite recent advances in the care of neonates and children with respiratory failure, extracorporeal membrane oxygenation (ECMO) still plays a pivotal role in the care of these children. With current therapy, approximately five per cent of infants with persistent pulmonary hypertension of the neonate (PPHN) fail to respond to other modalities available, including high-frequency ventilation, nitric oxide, surfactant and liquid ventilation. Despite the recent advances, mortality rates for infants and children with respiratory failure remain at 12%-75%. Timmons and colleagues in a retrospective review showed that children with adult respiratory distress syndrome (ARDS) had a mortality of 75%. There is also a high morbidity associated with aggressive ventilator therapy. Even with high-frequency ventilation there is an 11% incidence of chronic lung disease in neonates. Therefore, there is currently a significant role for ECMO in the treatment of neonates and children with respiratory and cardiac failure of various etiologies.

History of Cardiopulmonary Bypass

John Gibbon in 1937 pioneered the use of artificial circulation but it did not come into widespread use for cardiac surgery until the 1950s. Lillehei proposed the use of his biological lung as an oxygenator during extracorporeal circulation because of the problems with protein denaturation in previously used systems. His oxygenator and others such as the bubble oxygenator, now the mainstay for cardiac surgery, can cause damage to cells by direct exposure of blood to oxygen if used for more than a few hours. This led to research into the development of a membrane oxygenator. In 1957, Kammenmeyer reported the excellent gas exchange properties of a polymer of dimethylsiloxane, now known as silicone. Once these membrane lungs and the circuit become coated with a protein monolayer, blood is no longer in direct contact with the thrombogenic foreign surface so that there is not excessive
damage to blood cells. This research led to the first human trials of prolonged extracorporeal support and forms the basis for the systems in use today.\(^9\)

**Physiology of Extracorporeal Circulation**

The membrane lungs that are currently available for use in ECMO patients have two compartments divided by a gas permeable membrane of silicone. The ventilating gas (gas phase) is on one side and the (blood phase) is on the other side so that the gas and blood phases never come into contact with each other in an intact circuit. The oxygen and carbon dioxide are then free to diffuse across the membrane at a molecular level. The gradient for oxygen diffusion across the membrane is the difference between the oxygen content in the ventilating gas, generally FiO\(_2\) is 1.0, and that in the venous blood of the patient. The inherent potential for O\(_2\) transfer across a silicone membrane is 1210 ml O\(_2\)/ml/mil thickness at a diffusion gradient of 760 mm Hg. In addition, the actual oxygen delivery potential of the blood phase is limited by the oxygen carrying capacity of the blood with each gram of hemoglobin having the capacity to bind 1.39 ml O\(_2\).\(^{10,11}\)

Red blood cells that are nearest to the membrane wall become saturated with oxygen first and then the PO\(_2\) locally rises. Subsequently, dissolved oxygen diffuses deeper into the blood phase, saturating more blood cells. If complete saturation of the blood phase with oxygen is to occur, then it must remain in contact with the membrane lung long enough for oxygen diffusion to the centre of the film. Oxygen transfer, therefore, increases in proportion to the flow rate until a limitation in O\(_2\) transfer is imposed by the thickness of the blood. When venous blood enters the membrane lung with a saturation of 75%, the flow rate needed to achieve saturation of 95% in blood leaving the membrane is termed as the rated flow and allows standardization between various oxygenators.\(^2\) In most cases the amount of oxygen that can be delivered is dependent on blood flow available and not the capacity of the membrane to transfer oxygen to the blood.

Carbon dioxide is much more diffusible through plasma than oxygen. Thus, CO\(_2\) transfer is limited by its diffusion rate across the membrane. The CO\(_2\) transfer potential across the membrane lung is about four times that for oxygen. Often, carbon dioxide transfer across the membrane is so efficient that it must be added to the gas phase to decrease the diffusion gradient. Because CO\(_2\) transfer is dependent on surface area of the membrane and not blood flow, a rising PCO\(_2\) can be an early indicator of loss of oxygenator function, due to clot formation or water in the gas phase.

Blood flow to the membrane is limited by total circulating blood volume and the diameter of the venous catheter as well as resistance to blood return through the arterial catheter or return port in venovenous ECMO. The system must be able to flow at least at 120ml/kg/min (near total support of cardiorespiratory function). The ECMO circuit is designed to permit these flows and incorporates an oxygenator that is rated for flows above this level.

**Patient Selection**

Two factors are critical in determining the application of ECMO: determining the