

Lung Transplantation

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The artificial lung

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Introduction

Over the last 50 years, we have seen remarkable progress in the area of cardiac support as it pertains to artificial organs. Artificial hearts and ventricular assist devices have changed the way we think about end-stage chronic heart failure. Yet the area of the artificial lung has lingered behind many of these accomplishments, not because the need was not recognized but because a full understanding of the engineering problems and the unique material requirements had not reached a level of development to be fully evident. This has changed, and at the centre of this progress has been a close collaboration between the clinician-scientist and the engineer. Here, the underlying concepts that are fundamental to gas exchange in blood have been instrumental in guiding research and in defining the haemodynamic impact on the host as it pertains to both extra- and intracorporeal artificial lung devices [1]. An overview of how this change has occurred and where it appears to be leading us is the subject of this chapter.

Background

Artificial lung technology can be broadly classified into current and next generation (Figure 29.1). What is presently available to clinicians derives from the pioneering work of John Gibbon and his contemporaries who, in the 1950s, developed the early prototypes of the heart-lung machine [2–5]. The goal of these pioneers was to support the heart and the lungs during heart surgery, and the objectives in the design of their oxygenators predicted many of the parameters for artificial lungs under current development. As Galletti and Brecher enumerated, the ‘ideal’ oxygenator must achieve the following [6]:

- 1 Oxygenation of venous by blood safely and efficiently bringing blood into close proximity to the oxygen source. The barrier posed by large diffusion distances must be overcome while providing oxygenation over a wide range of venous inlet conditions.
- 2 Carbon dioxide must be safely and efficiently eliminated to avoid both arterial hyper- and hypocapnia.
- 3 The oxygenator must avoid high shear stress, turbulence, and incompatible surfaces so as to minimize damage to blood cells, platelets and proteins.
- 4 The oxygenator must be able to perform its functions with a small priming volume.
- 5 The oxygenator must be easy and safe to operate, minimizing especially the possibility of air embolism.

These design objectives and early work evolved over the ensuing 40 years to the cardiopulmonary bypass circuits that we use today, with an excessive area of external, synthetic material exposed to the blood through tubes and cannulas, heat exchangers, and several square metres of membrane surface area in the oxygenator – overall a very bioactive environment conducive to the activation of the complement and coagulation cascades along with a host of inflammatory mediators. A goal, therefore, to improving any support systems in the future includes a means of reducing synthetic material interactions by reducing the bulk of material to which the blood is exposed. Next generation technology takes into consideration this fact and attempts to reduce the synthetic material exposed to blood whether in a paracorporeal or intracorporeal configuration.

ECMO

Although support of the lungs was integral to cardiopulmonary bypass during heart surgery, the emphasis was not on the lungs or on any form of targeted lung disease.

Artificial Lung Technology

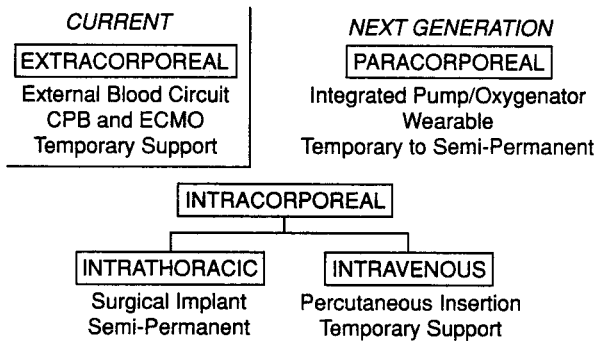


Figure 29.1 Artificial lung technology: current and next generation. CPB, cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation.

ECMO For Respiratory Failure (U. of Michigan Experience)

	Numbers	Mortality
Neonates	586	12%
Children	132	30%
Adults	146	44%

Figure 29.2 Recent results from the University of Michigan experience with extracorporeal membrane oxygenation.

Therefore, as attention turned to the lungs, a natural extension of cardiopulmonary bypass for heart surgery was extracorporeal membrane oxygenation (ECMO), which used the same approach and equipment but concentrated on support of the lungs. In spite of the fact that early trials with ECMO in the 1970s were not encouraging and had mortality rates as high as 80–90% in adult patients with the acute respiratory distress syndrome (ARDS), interest in extracorporeal lung support has continued [7,8]. More recent trials by experienced clinicians such as the Michigan group have lowered this mortality in the adult to 40–50% (Figure 29.2) [9]. This is still a challenge to be further improved upon but clearly a great deal has been learned since the early trials of ECMO that could be applied to the concept of an artificial lung.

Artificial lungs

Artificial lung development can be categorized broadly into devices that are intended as implantable or paracorporeal for prolonged and total support, and intravenous devices

The Artificial Lung

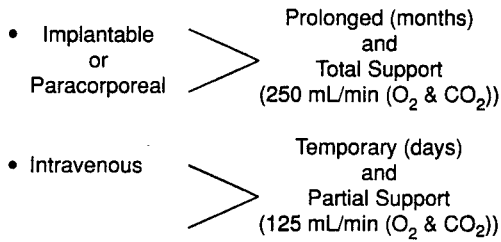


Figure 29.3 Artificial lung development.

The Artificial Lung

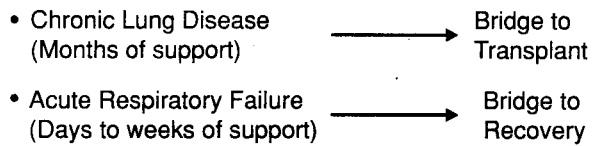


Figure 29.4 The artificial lung as a bridge to transplant or to recovery.

that will provide only temporary and partial support for the lung (Figure 29.3). At present, both implantable and paracorporeal devices would function as a bridge to transplant, whereas intravenous devices that provide only partial support can be used only in the setting where the natural lungs should recover either from a reversible disease or from an acute exacerbation of a chronic lung condition.

Whether one is considering total or partial support, the metabolic requirements for basal gas exchange are different. Total and prolonged support is usually conceptualized in the setting of chronic irreversible lung disease and the invasiveness involved with its implementation makes it less attractive as a temporary support measure (Figure 29.4). Partial support as a bridge to recovery, however, depends on the fact that, even with severe acute respiratory failure, there are areas of the lung that retain relatively normal architecture and compliance [10]. These areas can be accessed for their contribution to gas exchange along with what would in addition be provided by a partial support device. The extent to which partial support assists in gas exchange would enhance the ability to proportionally reduce tidal volumes and peak inspiratory pressures while managing the ventilator in the patient with acute respiratory failure. A 22% reduction in mortality was recently reported in ARDS patients treated with low tidal volume ventilation (6 mL/kg) when compared with the increased death rate with higher tidal volumes (12 mL/kg) [11]. The gas exchange goal of partial support of the lungs is also different from that of total support. Partial support attempts only to

