
CASE REPORT

Venovenous Long Term Extracorporeal CO₂ Removal With Biopump and Hollow Fiber Membrane Oxygenator For the Failing Lung

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Abstract

A 14-year-old male patient developed a severe respiratory insufficiency after a cart racing accident complicated by a bilateral pneumothorax, lung contusion and a rupture of a segmental lobe bronchus, for which two subsequential surgical interventions were needed.

Due to a decreased lung compliance, alveolar ventilation was decreased to a minimum, resulting in the development of hypercapnia.

The patient was placed on partial venovenous bypass utilizing the Biomedicus centrifugal pump and two Sarns hollow fiber membrane oxygenators, in combination with low frequency positive pressure ventilation, for extracorporeal CO₂ removal with limited anticoagulation.

This case report illustrates the safe use and continuous effective performance of the hollow fiber membrane oxygenator and centrifugal pump for more than 60 hours.

Despite all efforts to create an environment for the lungs to heal, the patient succumbed due to irreversible traumatic cerebral damage and the bypass procedure was terminated after 60 hours.

Introduction

Extracorporeal respiratory assist with an artificial lung to support the failing lung, as in Adult Respiratory Distress Syndrome (ARDS), has first been reported by Hill et al in 1972 (1). Their technique was based on extracorporeal membrane oxygenation (ECMO). Since then, many different teams have experimented with this particular therapeutic approach to create time for the severely diseased lung to heal, by avoiding barotrauma and hyperinflation due to long term positive pressure ventilation (2). In 1976, the overall experiences with this technique were reviewed by Gille and Bagniewski (3). They reported an 85% mortality in 233 ECMO cases. In the

same period a multi-center trial supported by the National Heart Lung and Blood Institute (4), revealed no improvement in survival with ECMO. The mortality rate was equal with the conventional continuous positive pressure ventilation (CPPV) technique. In 1979 Gattinoni et al began to use clinical extracorporeal carbon dioxide removal, (ECCO₂R) in combination with a modified mechanical ventilatory technique, the so called low frequency positive pressure ventilation, (LFPPV) (5). The rationale of this technique is to prevent further damage to the severely diseased lungs by reducing the ventilatory settings, to three to five sighs per minute to maintain the functional residual capacity. A condition of "motionless" lungs is achieved. By assessing this method, the process of oxygen uptake and carbon dioxide removal are dissociated; oxygenation is primarily due to apneic oxygenation, while the CO₂ elimination was cleared by leading approximately 35-40% of the cardiac output through an artificial membrane lung in a partial venovenous bypass mode. The overall success rate is 48.8% as reported by Gattinoni et al, at the University of Milan, Italy, and by Lennartz et al, at the Philipps University at Marburg, West Germany (6). Both centers have used a standard roller pump for the ECCO₂R and two spiral coil Sci-Med/Kolobow silicone membrane lungs (7). The latest advancement in membrane oxygenator technology is the introduction of the hollow fiber membrane oxygenator, (HFMO).

These devices are designed in such a way that blood flows either through thousands of cylindrically shaped microporous polypropylene fibers, or the blood flows around these specific fibers. The ventilating gas surrounds the fibers, or the gas flows through the fibers. The hollow fiber membrane oxygenator has already been accepted for use during normal clinical cardiopulmonary bypass procedures. In these procedures the average bypass time seldom takes longer than 6-8 hours; however, there might be isolated procedures necessitating long term use of these oxygenation devices. Until now, these devices have been used up to 14 hours (8); longer use has not been widely

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advocated to date, because there is not yet sufficient clinical evidence reporting the safe and continuous performance of these capillary fiber oxygenators. However, membrane oxygenators constructed of microporous polypropylene as membrane material, have a low resistance to carbon dioxide transfer (9, 10) and therefore a HFMO with microporous polypropylene as membrane material might be ideally suited to perform ECCO₂R during severe acute respiratory failure (ARF).

Our first clinical experience with ECCO₂R is illustrated in this case report. The safe use and continuous effective performance of the Sarns SMO hollow fiber membrane oxygenator (11), in combination with the Biomedicus centrifugal pump (12), is reported for up to 60 hours of extracorporeal respiratory support.

Case Report

A 14-year-old male was admitted to our hospital after a race accident. It was necessary to initiate mechanical ventilation during the transportation to the hospital, because he developed severe respiratory insufficiency. The patient was conscious, with no signs of cerebral injuries. On admission, the chest X-ray (Figure 1) showed a left and right sided pneumothorax with no rib fractures. A bronchoscopy, via the endotracheal tube, revealed a bleeding from the right upper lobe and a rupture of the right apical lower lobe bronchus. A lateral thoracotomy was performed for surgical reconstruction of the right stem bronchus, at the level of the superior segment of the lower lobe bronchus, in combination with a resection of the apical segment from the right upper lobe. During the post-operative period the patient remained on a mechanical ventilator (a). The patient developed severe fever. The chest X-ray and a bronchoscopy showed atelectasis of the apical segment of the lower lobe, due to an almost complete obstruction of the segment. A second thoracotomy was necessary and the apex of the right lower lobe

Figure 1: Chest X-ray on Admission



had to be resected. The pulmonary status remained unstable, and the patient developed a respiratory distress syndrome. The condition deteriorated progressively, with mechanical ventilation settings at 10 cm H₂O positive end expiratory pressure (PEEP), FiO₂ of 0.7 tidal minute volume of 16 liters, the peak airway pressure rose to 70 cm H₂O. Arterial blood gases drawn from the left radial artery showed at this stage a PaO₂ of 71 mmHg, PaCO₂ of 70 mmHg, and a pH of 7.33, with a blood pressure of 145/92 mmHg, a pulse rate of 148/min and a rectal temperature of 38.8°C. It was felt that conventional mechanical ventilation was insufficient and inadequate to accomplish CO₂ removal; therefore, it was decided to put the patient on partial venovenous extracorporeal respiratory support, using limited anticoagulation, to perform CO₂ removal. This technique was combined with LFPPV, in conjunction with apneic oxygenation, to optimize lung healing. An emergency femoral vein-femoral vein cannulation was performed in the ICU to start the ECCO₂R procedure.

Method

The ECCO₂R circuit was constructed from a standard perfusion pack. The system consisted of two hollow fiber membrane oxygenators (b). The two HFMO were placed in serie, with a total membrane surface area of 3.6 square meters. A 1000 ml. Sarns venous reservoir was included in the initial setting up of the circuit. A Biomedicus vortex constrained pumphead (c) was used to complete the extracorporeal circuit (Figure 2). Prior to initiation of ECCO₂R, the circuit was flushed for three minutes with 100% carbon dioxide and primed with 400 ml. human albumin 20% and 1600 ml. of Ringers, to which 20,000 units of heparin was added. Shortly before bypass was initiated, 1000 ml. of prime was displaced with two units of packed cells. The replacement took place 90 minutes after the prime solution had been circulating through the extracorporeal circuit. The total prime volume at initiation of bypass was 1500 ml. The two membrane lungs were ventilated with a mixture of room air and oxygen. Oxygen saturation probes were placed in the "arterial" line and venous drainage line for continuous monitoring. Further monitoring included blood pressure drop across the two membrane lungs, outlet blood temperature, extracorporeal blood flow, and pump speed.

Cannulation

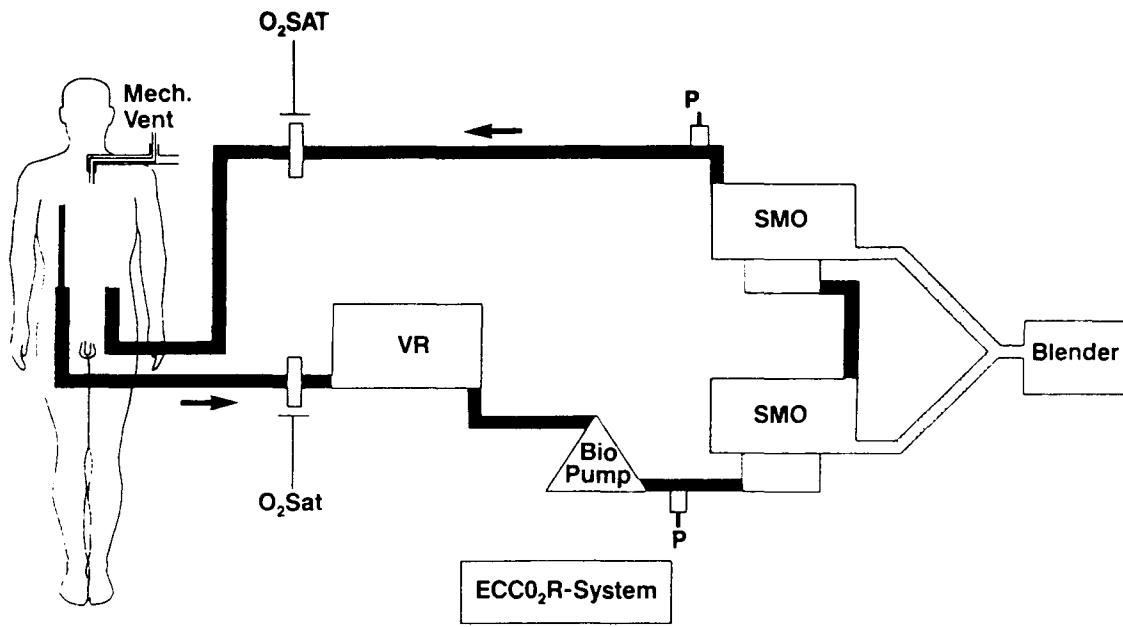
ECCO₂R was performed using venovenous bypass, necessitating the cannulation of the right and left femoral veins. A 80 cm., 28 French venous cannula (d), was introduced via the right femoral vein into the right atrium for gravity drainage to the venous reservoir via 12.7 mm. ID PVC tubing. The same cannula was placed in the vena cava inferior via the left femoral vein for the "arterial" return to the patient. Both cannulae were left in the femoral veins with a purse string suture, and the

a. Servo 900 B

b. Sarns SMO, Sarns/3M, Ann Arbor USA

c. Biomedicus Inc., Minneapolis, USA

d. Dideco, Mirandola, Italy



Mech. Vent. = Mechanical Ventilator with "apneic catheter", P= pressure transducer, VR= venous reservoir, S.M.O.= Sarns hollow fiber oxygenator.

Figure 2: Schematic representation of the Extracorporeal System

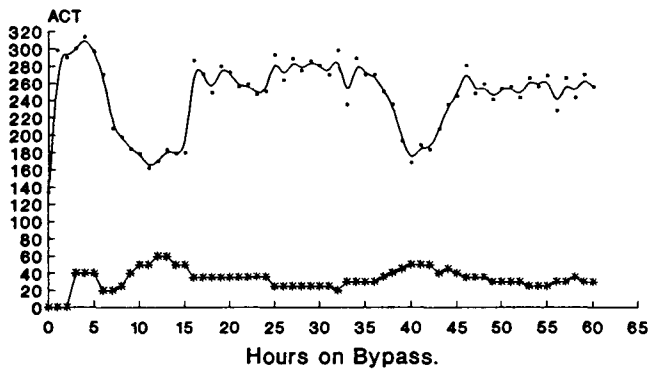


Figure 3: Heparin dose and ACT values

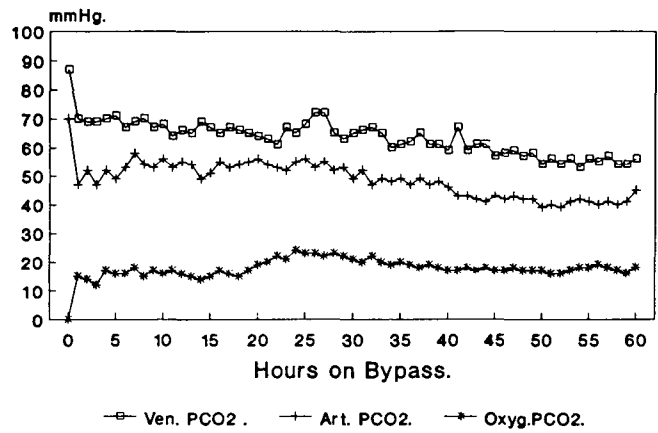


Figure 4: Carbon dioxide removal capacity, demonstrated by the oxygenator outlet pCO₂, versus the patient arterial and venous pCO₂

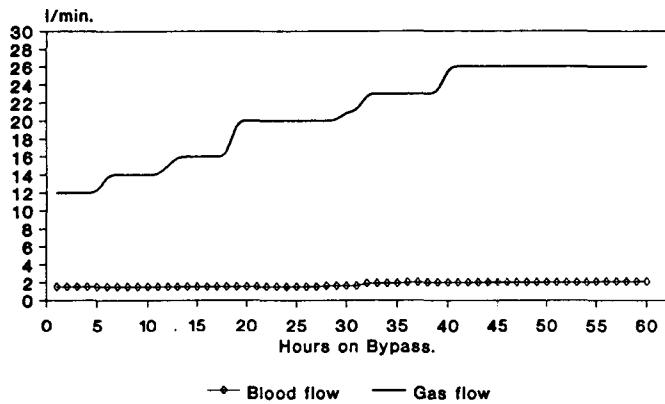


Figure 5: Oxygenator blood and gas flow

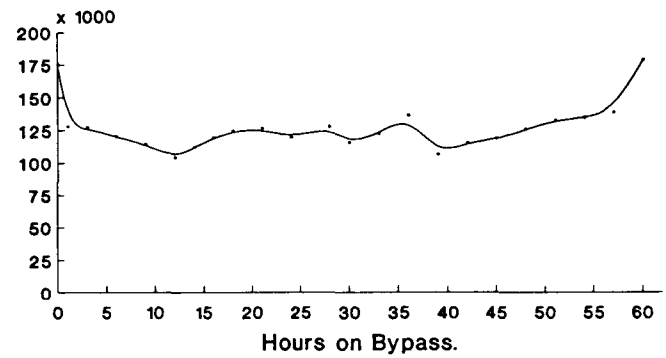


Figure 6: Platelet count during the entire perfusion period

femoral veins were not occluded to prevent venous congestion of the legs.

Heparinization

After the displacement with two units of packed cells, no additional heparin was added to the circulating prime volume. Prior to the initiation of bypass, baseline celite ACT was determined at 134 seconds. One hundred U/kg of heparin was administered to the patient to ensure an ACT of 1.5-2.0 times the baseline value. After three hours on bypass, a continuous heparin infusion was started. The average infusion rate ranged from 25-65 U/kg body weight per hour (Figure 3). Before bypass was instituted, baseline data were obtained. ECCO₂R was begun slowly (250-350 ml/min.) and over a period of 15 minutes, the pump flow was increased to 1.5 l/min. The flow rate was kept constant for a period of 30 hours. Thereafter, the pump flow was readjusted to 2.0 l/min. to increase the gas to blood ratio to optimize the extracorporeal CO₂ elimination. The following hematological and biochemical analytic protocols were followed throughout the whole procedure:

1. Patient and oxygenator blood pH and blood gases
2. Hematocrit, electrolytes, platelet and leucocyte count
3. Plasma Hb., total protein, urea and creatinine
4. Celite ACT, FDP, fibrinogen.

Low Frequency Positive-Pressure Ventilation

Mechanical ventilation was continued along with bypass, but the ventilator was slowly readjusted to decrease the FiO₂ to 0.4 PEEP to 5 cm H₂O, tidal volume to 450 ml. and the respiratory rate to five breaths per minute. With these settings, the peak airway pressure dropped from 70 to 40 cm H₂O. During the long end expiratory pause we directed a continuous flow of 100% humidified oxygen, 0.7-1.5 l/min., via a small teflon catheter through the endotracheal tube into the trachea just above the carina. In combination with oxygenator FiO₂ settings, the arterial PO₂ could be kept above 95 mmHg.

By adjusting both the gas and blood flow through the HFMO, the average oxygenator inlet venous pCO₂, which was approximately 71 mmHg, could be reduced to an oxygenator outlet pCO₂ ranging from 14-21 mmHg. This resulted in an average patient arterial pCO₂ of approximately 50 mmHg, as shown in Figure 4. The maximum gas flow through both oxygenators necessary to achieve this CO₂ elimination was 26 l/min. (Figure 5). Due to the apneic oxygenation technique, as described elsewhere in this paper, the oxygenator FiO₂ never exceeded 0.5 to sustain an arterial pO₂ greater than 95 mmHg. After 50 hours of bypass, the fluid condensation at the gas outlet port of the oxygenator, due to the temperature difference between ventilating gas and blood, contained small amounts of protein. However, this had no effect on either oxygenation or carbon dioxide removal of the device for the remaining bypass time. The initial effect of ECCO₂R showed a fall in baseline CVP, from 15 to 8 mmHg and a decrease in pulse rate, 151 to 127/min. The mean arterial pressure was maintained between 65-75 mmHg during the entire procedure. Immediately after the

onset of bypass, the patient remained haemodynamically stable with neurolept (Fentanyl). Sedation and paralysis (pancuronium bromide) were used to lower the body oxygen consumption and to prevent spontaneous respirations. There was minimal oozing from both cannulation sites, and the patient received a total of two units of packed cells to keep the haematocrit above 30%. It was not necessary to give platelet transfusions throughout the whole bypass period. We noted a maximum depletion of 40% in platelet count after 12 hours of extracorporeal circulation; thereafter, the number rose and at termination of bypass this was 101% of the pre-bypass value (Figure 6).

Plasma hemoglobin levels were lower than 10 umol/l for the entire perfusion period.

Despite all efforts to create a condition in which the severely diseased lungs could heal, the patient succumbed due to intracerebral hemorrhage. For this reason, the ECCO₂R procedure was terminated after 60 hours of bypass.

Discussion

Acute respiratory failure is a complex sequelae of shock, systemic sepsis, highway trauma, viral respiratory infections and many other insults (13). This disorder is particular tragic, because it often afflicts young and previously healthy patients. The mortality associated with acute respiratory distress is high, despite current supportive therapy. Two major therapeutic approaches have been evaluated, using extracorporeal gas exchange, (ECMO and ECCO₂R) in combination with LFPPV. The survival rate by using ECCO₂R has been greater than with ECMO (14). This improvement in survival may lie in the fact that the two techniques are different in both the bypass mode and respiratory support mode. During ECCO₂R, a venovenous bypass is used instead of veno-arterial bypass with the ECMO technique. This may play an important role in pulmonary hemodynamics, because during veno-arterial bypass a relative pulmonary hypoperfusion can occur. This may lead to pulmonary thrombosis in patients suffering from acute respiratory failure (15). Furthermore, Kolobow, et al. reported the development of pulmonary infarction due to the ventilation of nonperfused alveoli, in an experimental model (16). Since this was our first experience with severe ARF requiring extracorporeal support, we choose to use the ECCO₂R technique, because of the results reported in recent medical literature (14). Although our patient did not survive the procedure, we experienced that two hollow fiber membrane lungs, in conjunction with a centrifugal pump, effectively decreased a dramatic rise in arterial pCO₂ during a 60 hour period. These devices are not (yet) generally clinically accepted for long term artificial gas exchange, although several evaluations of a polypropylene-type hollow fiber membrane oxygenator have indicated satisfactory performance of oxygen transfer during prolonged extracorporeal oxygenation in experimental studies (17-19).

During the ECCO₂R procedure, we found that some of the claimed benefits of a non-occlusive pump were demonstrated with the use of the Biomedicus centrifugal vortex constrained pump. There was no evidence of blood trauma of mechanical

origin, reflected by the plasma hemoglobin value during the entire perfusion period. Furthermore, thrombocytopenia, which often occurs during standard clinical cardiopulmonary bypass, did not stringently appear in this case; the platelet number never fell below 100,000 per cubic millimeter. The Sarns hollow fiber membrane oxygenator proved to be very efficient. We noted no decrease in gas exchange performance for the whole bypass time. It is our opinion that the composition of the pre-bypass circulating prime volume ringers in combination with human albumin and 20,000 units of heparin, had a favorable effect on the hemocompatibility and contributed to a limited anticoagulation. We also observed no rise in pressure gradient across the total blood path of the two oxygenators, comparing the initial pressure gradient and the gradient at termination of bypass. Despite low systemic heparinization, we did not visualize any evidence of thrombus formation within the HFMO leading to an impaired gas transfer or pumphead. The post-mortem examination revealed intra-cerebral lacerations with cerebral bleeding due to mechanical trauma. No systemic thrombotic events could be discovered. The patient did not appear to suffer from any complications that might be caused due to the usage of either the Sarns SMO hollow fiber membrane oxygenator or the Biomedicus centrifugal pump. We would recommend further clinical studies to investigate the efficiency and hemocompatibility of HFMO to perform during respiratory support in ARF; in particular, the use of a low prime HFMO with a minimal amount of membrane surface area to accomplish sufficient gas exchange. Moreover, the entire extra-corporeal system should be made of antithrombogenic surfaces. This might obviate the need for continuous heparin infusions and therefore reduce the risks involved with full systemic heparinization and perhaps improving patient survival.

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