

# Pumpless extracorporeal lung assist using an arterio-venous shunt

## Applications and limitations

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**We report the use of a pumpless extracorporeal lung assist (PECLA) in 70 patients with severe pulmonary failure of various causes. The device was used under rescue conditions in patients with preserved cardiac function. By establishing a shunt between femoral artery and vein using the arterio-venous pressure gradient as the driving force for the blood flow through the oxygenator, PECLA proved to be extremely effective in terms of oxygenation and carbon dioxide removal.**

**Key words: Respiratory distress syndrome, adult - Pulmonary insufficiency - Extracorporeal membrane oxygenation, methods.**

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Multiple modifications in the treatment of adult respiratory distress syndrome (ARDS) have occurred within the last 25 years. Nevertheless, the mortality has not really been suppressed and remains still above 50 percent.<sup>1-5</sup> The treatment of choice in acute respiratory failure (ARF) is mechanical ventilation, usually with high inspiratory airway pressures, which are necessary to achieve normal values for the partial pressure of arterial carbon dioxide and pH. Mechanical ventilation per se can cause lung damage by several mechanisms such as disruption of pulmonary epitheli-

um, lung inflammation, and alveolar hemorrhage.<sup>6-8</sup> The release of inflammatory mediators could increase lung inflammation and cause injury to other organs.<sup>9, 10</sup> Diverse medical treatments, several schemes of mechanical ventilation, a number of novel supportive techniques, including partial liquid ventilation, inhaled nitric oxide, and surfactant replacement, and attempts to identify subgroups more likely to develop pulmonary failure were unable to improve the situation.<sup>10-12</sup> This has given us the opportunity to question the validity of the practiced mechanical ventilation.

Under the proposition to allow the pulmonary tissue to win time for recovery less aggressive ventilation strategies with lower tidal volumes and decreased airway pressures are advocated. However, this approach may cause severe respiratory acidosis and decrease arterial oxygenation. Extracorporeal gas exchange (extracorporeal lung assist, ECLA) may serve as a temporary tool to overcome acidosis, hypoxia, and hypercapnia in selected patients. Except for unique single center reports the overall results of pump supported ECLA are

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not convincing.<sup>11, 13-15</sup> The most limiting condition is a significant blood trauma during ECLA support leading to hemolysis and coagulation disorders. Moreover, other system-immanent limitations including inflammatory response and specific technical complications made the procedure a high-risk and costly therapy.<sup>14</sup> Monitoring of the system and particularly levelling of the precise anticoagulation did not support great enthusiasm among the personnel in charge for these patients with critical prognosis.

Since few years we have applied an ECLA system which is totally different from the complication provoking pump-driven extracorporeal membrane oxygenation (ECMO), by avoiding pumps and by following a comprehensive, simplified design.<sup>16-17</sup> The following informations are based on our experience on 70 patients supported by this percutaneously applied pumpless extracorporeal lung assist (PECLA).

## Materials and methods

### *Device description, application and management*

The PECLA system (NOVA BREATH™ Lung Assist Device System, JOSTRA, Germany) consists of a completely assembled system for femoral arterial and venous cannulation (15-19 Fr) together with an Introducer Kit, 80 cm PVC tubing, and a low-resistance membrane oxygenator (MO). The system allows continuous flow measurement by an integrated ultrasonic flow probe and has ports for blood sampling and a connector for continuous venovenous hemofiltration. The entire system including the cannulas is heparin coated (BIOLINE COATING™) and has a priming volume of 175 ml. For cannulation the femoral artery of one leg and the femoral vein of the other leg is used. The external diameter of the arterial cannula should be 1.5 mm smaller than the internal diameter of the arterial vessel (determined by ultrasonography) to avoid limb ischemia. The venous cannula

can be of the same size or even wider than the femoral vein. Arterial and venous cannula are inserted by percutaneous puncture (Seldinger's technique). After insertion, the cannulas are connected to the prefilled (isotonic saline) MO and the arteriovenous bypass is established. The oxygenator's gas inflow is connected to an oxygen supply (12 l/min). No additional blood warming device is needed. Anticoagulation by systemic heparinisation can be set at a low level (activated clotting time adjusted at 120 to 150 sec). The system utilizes the arteriovenous pressure gradient as the driving force for the blood passing the oxygenator. Therefore, the mean systemic arterial pressure should be maintained at levels above 70 mmHg. This is apparently necessary to obtain a steady flow through the system of 2-3 l/min. While on the system, the patient remains mobile and can be handled for transportation or nursing as needed. PECLA treatment can be discontinued as soon as the patient presents with stable blood gas exchange (in this series:  $p_aO_2$  of at least 80 mmHg with  $F_iO_2$  of 0.5 or less over 12 hours;  $p_aCO_2$  less than 40 mmHg, respectively) under normalized ventilator settings. The cannulas are taken out by simple retraction followed by manual compression of the insertion site.

### *Patients*

This report refers to 70 consecutive patients who entered the application of PECLA under a condition of a last ditch effort to save patients with the severest forms of ARDS. Before initiation of PECLA in each case the referring physician as well as the implanting physician confirmed that the patient otherwise would have died. The mean age of the patients was  $41 \pm 18$  years with a range of 8 (Fig. 1) to 72 years. Male gender was predominant (55 males vs 15 females). The underlying conditions leading to pulmonary failure were pneumonia ( $n=32$ ), lung contusion ( $n=16$ ), and others (pancreatitis  $n=6$ , postperfusion lung  $n=4$ , chemotherapy for acute leukaemia  $n=4$ , bilobectomy  $n=2$ , Wegener's granulomato-

sis  $n=2$ , idiopathic lung fibrosis  $n=2$ , aortic dissection  $n=1$ , suicidal fuel intoxication  $n=1$ ). The mean duration of mechanical ventilation before PECLA was  $16 \pm 12$  days. Ventilator therapy was defined as failing and the patients were considered for PECLA according to the fast or slow entry criteria of the US-ECMO study.<sup>13</sup> To be suitable for PECLA the patients had to fulfill a minimal hemodynamic requirement ( $\text{MAP} > 70$  mmHg,  $\text{CO} > 6$  l/min) which was managed by catecholamines. Patients with cardiac failure were excluded. Patients with severe peripheral circulatory dysregulation (septic shock) were only excluded if the hemodynamic requirements could not be maintained despite of adequate catecholamine therapy. Adjuvant measures prior to PECLA included kinetic therapy in 54 patients (77%), inhaled nitric oxide in 20 patients (29%), and surfactant replacement in 2 patients (3%). Twenty seven patients (39%) suffered from acute renal failure requiring hemodialysis before PECLA institution. The patients were recruited from 5 different intensive care units of the hospital (services of internal medicine, anesthesiology, neurosurgery, general surgery, and cardio-thoracic surgery). In 6 patients PECLA was implanted in the referring institution and the patients were then transported to our service for definitive treatment.

### Results

At the time of PECLA insertion all patients were treated with an aggressive pattern of mechanical ventilation ( $\text{PEEP } 14 \pm 5$  mmHg, maximum airway pressure  $36 \pm 5$  mmHg). They presented with supportatile but stable hemodynamic conditions ( $\text{MAP } 94.1 \pm 10$  mmHg,  $\text{CO } 10.8 \pm 2$  l/min). Thus, a mean extracorporeal flow of  $2.6 \pm 0.6$  l/min could be established. Although this represented an arteriovenous shunt of 24% of the cardiac output, stable circulatory conditions could be maintained without significant increase of the catecholamine dosage. Contrarily, with the amelioration of the blood gases the inotropic support could be dimin-



Fig. 1.—PECLA in a 8 year old girl with ARDS due to aspiration.

ished continuously in most patients. Those patients who did not demonstrate this trend finally had a lethal outcome.

Relevant oxygenation and  $\text{CO}_2$  elimination was achieved in all patients. After a 24 hours course the mean  $\text{p}_a\text{O}_2$  was  $85 \pm 21$  mmHg at  $\text{F}_i\text{O}_2$   $0.8 \pm 0.1$  and the mean  $\text{p}_a\text{CO}_2$  was  $32 \pm 8$  mmHg. This contrasted significantly to the data at PECLA institution ( $\text{p}_a\text{O}_2$   $46 \pm 7$  mmHg at  $\text{F}_i\text{O}_2$  1.0,  $\text{p}_a\text{CO}_2$   $59 \pm 17$  mmHg). The oxygenation index improved from initially 50 to 110 mmHg after 24 hours.

Median PECLA duration was 6 days with a range of 1 to 35 days. Thirty six out of the 70 patients (51%) could be weaned from the device, 34 patients (49%) died during PECLA support. Eleven patients (16%) deceased lateron for unresolvable organ failure. Twenty five patients (36%) survived after an additional period of less aggressive mechanical ventilation (median 16 days, range 1-53 days) and finally could be discharged home. Overall mortality was 64%. Diagnosis of pneumonia was associated with a mortality of 62% (20/32 patients). Conditions classified as "others" produced a 82% mortality (18/22 patients). The lowest mortality was noted among the trauma

patients (44%, 7/16 patients). Irrespective of the cause of lung failure the patients who presented with concomitant renal failure had a poor outcome (mortality 85%, 23/27 patients) compared to those with normal or only moderately impaired renal function (mortality 51%, 22/43 patients).

Technical problems occurred in 15 patients (21%). Thrombus formation within the arterial cannula (n=5), venous cannula (n=2) and MO (n=1) was the commonest limitation. Abrupt decrease of the extracorporeal flow without alteration of the CO was an early indicator of PECLA thrombosis. By elevation of the ACT level the flow normalized in all but two patients, in whom the cannulas had to be changed. The patient with MO thrombosis later was diagnosed with heparin induced thrombocytopenia (HIT). In 3 patients the arterial cannula had to be removed for limb ischemia. In 5 cases the MO had to be exchanged for reasons of plasma leakage (one patient received 3 MO's). This results in an average number of MO's spent per patient of 1.1 at a cumulative function time of 556 days. The longest PECLA duration was 35 days without technical complications in a patient discharged for home. In a patient the arteriovenous shunt exceeded 4 l/min due to oversizing of the cannulas. As this was hemodynamically intolerable, the shunt was reduced by placing an adjustable clamp.

### Discussion and conclusions

Taking into account that the PECLA therapy has been applied under resuscitation conditions in all patients, the overall survival of 36% in this negatively selected group can be considered promising. This report of clinical experience is not based on random among different means of pulmonary treatment, however such studies are evidently needed. Typical complications of pump-driven long-term extracorporeal devices have not been observed. None of the patients had PECLA induced bleeding, nor significant hemolysis. None of the lethal cases was directly related to PECLA therapy

or technical complications. Compared with conventional ECMO the system is easier to operate and the patient is easier to handle. Since it is compact in design and requires no particular surveillance, nursing, physical therapy (even prone position ventilation) and transportation is facilitated.

The blood gas exchange capabilities of the system were generally found to be sufficient. The key effect of both pump-driven and pumpless ECLA is a nearly 100% oxygen saturation of the blood passing the oxygenator. Thus, the flow through the MO is one of the critical parameters. The unique advantage of the PECLA oxygenator is the low pressure resistance of its blood passage, which is to our knowledge the lowest of all actually available MO's. This allows a patient with preserved cardiac function to tolerate a certain arterio-venous shunt. An important observation was the restitution of the peripheral vascular autoregulation resulting in decreasing doses of catecholamines once PECLA effectively was installed. This led us to rather liberal hemodynamic requirements for initial PECLA implant. Therefore, ARDS on the basis of sepsis evidently is no contraindication as long as cardiac function is sufficient.

With respect to costs, PECLA treatment is cheap as compared to ECMO, because oxygenators may be used for a longer time. No additional pump heads, pumps, and warming devices are needed. Further studies may prove that transfusion needs are substantially lower.

Our observation that the course of the trauma patients was favourable may be due to the fact that this was our youngest population with the lowest comorbidity. In fact, significant comorbidity, like preexisting renal failure should promote hesitant indication.

In conclusion, PECLA is a useful supportive therapy in rescue patients with acute pulmonary failure. PECLA is effective in terms of blood gas exchange and by this means also in reestablishment of hemodynamics. PECLA is easy to apply and offers a durable and reliable oxygenation and CO<sub>2</sub> removal. For its compact design nursing

care and transportation are facilitated. It is therefore preferable to pump driven ECMO in cases with preserved cardiac function. Application in earlier stages of ARDS may promise protection from secondary organ failure and improved outcome. This is to be proved by further collaborative studies.

### Riassunto

*Assistenza respiratoria extracorporea senza pompa (PECLA) mediante shunt arterovenoso: applicazioni e limiti*

Abbiamo utilizzato un circuito di assistenza polmonare extracorporea senza pompa (PECLA) in 70 pazienti con grave insufficienza polmonare da cause diverse. Questo sistema è stato utilizzato in condizioni salvavita in pazienti con funzionalità cardiaca conservata. Stabilendo uno shunt tra l'arteria e la vena femorale, utilizzando il gradiente di pressione artero-venoso come forza che genera il flusso di sangue attraverso l'ossigenatore, PECLA ha dimostrato di essere estremamente efficace in termini di ossigenazione e di rimozione di anidride carbonica.

Parole chiave: Sindrome da distress respiratorio - Insufficienza respiratoria - Ossigenazione extracorporea.

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