Extracorporeal CO$_2$ removal
New Techniques

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Conflicts of interest

• Consulting and received research and travel grants from Maquet
• Consulting for Novalung
• Consulting and received research grant from Drager
**Table III. Comparative technical difficulty of haemodialysis, extracorporeal removal of carbon dioxide and extracorporeal oxygenation**

<table>
<thead>
<tr>
<th>Extracorporeal Blood Flow (ml min⁻¹)</th>
<th>Renal Haemodialysis</th>
<th>Extracorporeal Removal of Carbon Dioxide</th>
<th>Extracorporeal Oxygenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optional</td>
<td>200–300</td>
<td>500–1000</td>
<td>2000–4000</td>
</tr>
<tr>
<td>Blood Pumping</td>
<td>small</td>
<td>optional</td>
<td>required</td>
</tr>
<tr>
<td>Haemodynamic Changes</td>
<td>A–V Shunt</td>
<td>A–V Shunt</td>
<td>major</td>
</tr>
<tr>
<td>Vascular Access</td>
<td>or</td>
<td>or A–V Fistula</td>
<td>V–A</td>
</tr>
<tr>
<td></td>
<td>A–V Fistula</td>
<td>or</td>
<td>or V–V</td>
</tr>
<tr>
<td></td>
<td>or V–V pumping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical Complexity</td>
<td>simple</td>
<td>simple</td>
<td>complex</td>
</tr>
<tr>
<td>Complexity of Equipment</td>
<td>moderate</td>
<td>simple</td>
<td>advanced</td>
</tr>
<tr>
<td>Requirement for Heparin</td>
<td>small</td>
<td>small</td>
<td>large</td>
</tr>
</tbody>
</table>
The technique seems to prevent the pulmonary barotrauma and extrapulmonary derangements caused by conventional mechanical ventilation.

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Summary  Terminal respiratory failure was reversed in three patients with a combination of extracorporeal CO₂ removal through a membrane lung and oxygen diffusion into the diseased lungs between mechanical breaths induced at a frequency of 2–3/min. The technique seems to prevent the pulmonary barotrauma and extrapulmonary derangements caused by conventional mechanical ventilation.
Ventilatory Impact of Partial Extracorporeal CO\textsubscript{2} Removal (PECOR) in ARF Patients

EXTRACORPOREAL CO\textsubscript{2} REMOVAL IN ARF

Table 3. Baseline VS. PECOR (33\% \textdagger \textasciitilde CO\textsubscript{2})

<table>
<thead>
<tr>
<th></th>
<th>(\dot{V}E) (l/min)</th>
<th>TV (ml)</th>
<th>RR</th>
<th>(PaCO_2) (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>14 ± 5</td>
<td>459 ± 140</td>
<td>32 ± 9</td>
<td>45 ± 9</td>
</tr>
<tr>
<td>PECOR</td>
<td>10 ± 5*</td>
<td>382 ± 128*</td>
<td>27 ± 9*</td>
<td>41 ± 9*</td>
</tr>
</tbody>
</table>

\* \(P < 0.05\).
Marcolin R et al:
Trans Am Soc Artif Intern Organs  1986

We investigated the possibility of avoiding mechanical ventilation and its side effects in ARF patients by coupling partial extracorporeal removal of the CO₂ production (PE-COR) to spontaneous breathing.

In these moderate ARF patients on removing 33% of total CO₂ production, we could show a normalization of PaCO₂ and a significant VE reduction. Such a small amount of CO₂ may be removed by a very simple, low blood flow extracorporeal apparatus.
Percutaneous Extracorporeal CO$_2$ Removal in a Patient with Bullous Emphysema with Recurrent Bilateral Pneumothoraces and Respiratory Failure

ANTONIO PESENTI, M.D.,* GIAN PIERA ROSSI, M.D.,† PAOLO PELOSI, M.D.,‡
LUCA BRAZZI,§ LUCIANO GATTINONI, M.D.¶
Extracorporeal CO2 removal

- Reducing ventilation anywhere down to 0 according to the proportion of VCO2 removed

- No ventilation, no VILI
TIME TO HEAL

Arteriovenous extracorporeal respiratory support
Vv ILA with a pump
The A Lung
PALP System
DECAPsmart è l'apparecchiatura che permette di effettuare una decap semplice.
Research

Efficacy and safety of a low-flow veno-venous carbon dioxide removal device: results of an experimental study in adult sheep

Sergio Livigni¹, Mariella Maio¹, Enrica Ferretti¹, Annalisa Longobardo¹, Raffaele Potenza¹, Luca Rivalta¹, Paola Selvaggi¹, Marco Vergano¹ and Guido Bertolini²

Critical Care 2006, 10:R151
End Inspiratory
Tidal Volume Lower than 6 ml/kg Enhances Lung Protection

Role of Extracorporeal Carbon Dioxide Removal

Pier Paolo Terragni, M.D.,* Lorenzo Del Sorbo, M.D.,* Luciana Mascia, M.D., Ph.D.,* Rosario Urbino, M.D.,*

Anesthesiology 2009; 111:826–35
PaCO$_2$ (mmHg)  
baseline  $T_0$  $T_{24}$  $T_{48}$  $T_{72}$

Arterial pH
baseline  $T_0$  $T_{24}$  $T_{48}$  $T_{72}$

*
Avoiding invasive mechanical ventilation by extracorporeal carbon dioxide removal in patients failing noninvasive ventilation

In this study the use of extracorporeal carbon dioxide removal allowed avoiding intubation and invasive mechanical ventilation in the majority of patients with acute on chronic respiratory failure not responding to NIV.
Fig. 2 Sequential changes in arterial partial pressure of carbon dioxide (PaCO₂), pH, and respiratory rate over time from ICU admission until 24 h after PECLA implantation. Boxplots display medians, 10th, 25th, 75th and 90th percentiles. *p < 0.001 BL vs. 21–24 h
Table 2 Comparison of outcomes between the PECLA group and mechanical ventilator (MV) group

<table>
<thead>
<tr>
<th>Outcome</th>
<th>PECLA group (n = 21)</th>
<th>MV group (n = 21)</th>
<th>p value</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intubation, n (%)</td>
<td>2 (10)</td>
<td>21 (100)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>28-day mortality, n (%)</td>
<td>5 (24)</td>
<td>4 (19)</td>
<td>1</td>
<td>0.845</td>
</tr>
<tr>
<td>6-month mortality, n (%)</td>
<td>7 (33)</td>
<td>7 (33)</td>
<td>1</td>
<td>0.897</td>
</tr>
<tr>
<td>Time on PECLA/MV (days)</td>
<td>9 (1–116)</td>
<td>21 (1–47)</td>
<td>0.944</td>
<td>0.944</td>
</tr>
<tr>
<td>Length of ICU stay (days)</td>
<td>15 (4–137)</td>
<td>30 (4–66)</td>
<td>0.577</td>
<td>0.263</td>
</tr>
<tr>
<td>Length of hospital stay (days)</td>
<td>23 (4–137)</td>
<td>42 (4–248)</td>
<td>0.342</td>
<td>0.056</td>
</tr>
<tr>
<td>Tracheostomy, n (%)</td>
<td>2 (10)</td>
<td>14 (67)</td>
<td>0.004</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Values given as median (range) or no (%). PECLA pumpeless real lung assist, mechanical ventilator. * Adjusted for baseline characteristics of patients (Table 1)
Extracorporeal CO2 Removal

Physiological Side Effects

• Extracorporeal Carbon Dioxide Removal is an experimental technique
• Extracorporeal Carbon Dioxide Removal effects on outcome are not known
• Extracorporeal Carbon Dioxide Removal Physiology and Pathophysiology is only partially understood
Figure 7. Alveolar ventilation as a fraction of control alveolar ventilation, as a function of extracorporeal CO$_2$ removal in anesthetized, and spontaneously breathing lambs.
Venovenous Carbon Dioxide Removal in Chronic Obstructive Pulmonary Disease

Cardenas et al ASAIO J 2009
Venovenous Carbon Dioxide Removal in Chronic Obstructive Pulmonary Disease

Cardenas et al ASAIO J 2009
$\text{PAO}_2 = \text{FiO}_2 \times 713 - \left( \frac{\text{PaCO}_2}{\text{R}} \right)$
Low-Frequency Positive Pressure Ventilation with Extracorporeal Carbon Dioxide Removal (LFPPV-ECCO$_2$R): An Experimental Study

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Anesth Analg 57: 470: 1978
Extracorporeal CO2 Removal
Physiological Side Effects

• Decreased $P_A O_2$: (Due to decreased QR)
• Decreased TV - Decrecruitment
  – Higher PEEP Maintain Paw
• Ineffective Coughing (?)
Maximizing CO2 removal by low flow (250-500 ml/min) vv bypass

• Target:
  – Achieve Natural Lung Rest by blood flows comparable to dialysis
  – Avoid intubation
  – Avoid mechanical ventilation
1. CO2 moves across the ML membrane driven by partial pressure difference

2. This difference in best conditions is small, usually 40 to 50 mmHg

3. Can we increase this driving pressure?
pH = 7.39
PCO2 = 40 mmHg
HCO3- = 24 mMol/l
BE = 0
pH = 6.57
PCO₂ = 208 mmHg
HCO₃⁻ = 18.7 mMol/l
BE = -10
Blood acidification enhances carbon dioxide removal of membrane lung: an experimental study
How much acidification?

L-lactic acid
0.5 N

6 pigs
37±2 Kg

Blood Flow
500 ml/min

Gas Flow
FiO₂ 100%
10 l/min

Quadrox D

1 mEq/min
2 mEq/min
5 mEq/min
CO₂ removal

+ 16%  + 30%  + 64%

Adult CO₂ production

Blood flow = 500 ml/min
Acidification and CO2 removal

Arterial [Lactate]

- **No Acid**
- **Acid**

0h, 24h, 48h

Pig  Bf  50 ml/min  Lactic  2.5 mEq/min  ML Maquet pediatric
Perhaps in the near future, management of ARDS will include a minimally invasive ECCO2R circuit, and noninvasive CPAP.

This would embody the modern philosophy of mechanical ventilation: to avoid tracheal tubes, minimize sedation, and prevent ventilator-induced acute lung injury and nosocomial infections.
Gas Stores of the Body and the Unsteady State

L. E. FARHI² and H. RAHN. From the Dept. of Medicine, Rochester School of Medicine and Dentistry, Rochester, Minn.

Whenever the oxygen uptake and carbon dioxide output measured in the expired air is equal to the metabolic gas exchange of the tissue we have by classical definition a ‘steady state’. This state is ordinarily recognized by the attainment of a gas exchange ratio, \( R \), which is equal to the ratio one would predict for the combustion of a mixture of certain foodstuffs. Under these conditions one is unaware of a body gas store which in man (excluding the lung gases) consists of about 1 liter of \( N_2 \), 1 liter of \( O_2 \), 17 liters of \( CO_2 \) (soft tissues) and about 100 liters \( CO_2 \) (bone). These gases are either physically dissolved or chemically bound.
Figure 10.10 A hydrostatic analogy of the elimination of carbon dioxide. See text.