ECCO$_2$ Removal
The Perfusionists’ Perspective

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Definition

ECCO₂ Removal:

- Process by which an extracorporeal circuit is used for removing CO₂ from the body
Arterial blood content

- 500mL/L of CO$_2$:
  - 5% dissolved
  - 20% bound
  - 75% as bicarbonates

- CO$_2$ Production at rest:
  - 200mL/min
Removal factor

- During CPB
  - Gas diffusion gradient
  - Sweep gas
  - Membrane area
  - NOT blood flow
  - NOT thickness of membrane

- During ECCO$_2$R
  - Minimal blood flow
  - CO$_2$ level before membrane
Gas exchange efficiency

- Veno-venous device: from 300 to 1500ml/min
  - \( \text{PaCO}_2 \) 40mmHg
    - 500ml/min remove all \( \text{CO}_2 \)
  - \( \text{PaCO}_2 \) 90mmHg
    - 1000ml/min remove all \( \text{CO}_2 \)

- 500 to 1000ml/min
  - 5min needed to decrease from 75/100mmHg to 45mmHg, gas flow 8 to 16L/min
  - Ok for ARDS
  - Caution for COPD
Devices

- 4 modern devices
  - Not all CE marked and none FDA approved
  - PALP (Maquet)
  - iLA Active (Novalung)
  - Hemolung (ALung)
  - Decap system
Cannula
- Double lumen catheters
- Seldinger technique
- Jugular vein
- From 13 to 19 Fr

Pump
- Centrifugal or diagonal
- Electromagnetic field

Membrane
- Polymethylpentene (non-microporous)
- Not polypropylene (use for CPB)
- Heparine coated
- From 0.67 to 3 m²
Anticoagulation

- 250ml/min or less
  - Regional anticoagulation Citrate/Calcium
  - Flow control?

- More than 250ml/min
  - Systemic heparinisation
  - Same as for VV ECMO
Experimental study – CHU Liège

- 10 pigs
- PALP
  - No heat exchanger
  - Polymethylpentene (PMP)
  - Bioline or Softline
  - Blood flow: 0.2 – 2.8 L/min
  - Gas flow: 0 – 10 L/min
  - Ratio 10/1

Hemodynamics probes:
- Baseline
- ARDS created
- ARDSnet ventilation
- PALP On
- PALP Off

<table>
<thead>
<tr>
<th></th>
<th>$\text{SaO}_2$ (%)</th>
<th>$\text{PaO}_2$ (mm Hg)</th>
<th>$\text{PaCO}_2$ (mm Hg)</th>
<th>$\text{pH}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>$99.8 \pm 0.3^#$</td>
<td>$178.8 \pm 15.1^#$</td>
<td>$41.7 \pm 1.3^#$</td>
<td>$7.44 \pm 0.02^#$</td>
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<tr>
<td><strong>ARDS</strong></td>
<td>$68.1 \pm 5.9^*$</td>
<td>$54.7 \pm 4.4^*$</td>
<td>$78.6 \pm 2.9^*$</td>
<td>$7.13 \pm 0.02^*$</td>
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<tr>
<td><strong>ECCO2RT</strong></td>
<td>$85.5 \pm 3.9$</td>
<td>$72.2 \pm 7.5^*$</td>
<td>$39.8 \pm 2.0^#$</td>
<td>$7.36 \pm 0.02^#$</td>
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<tr>
<td><strong>OFF</strong></td>
<td>$72.5 \pm 6.2^*$</td>
<td>$61.1 \pm 5.4^*$</td>
<td>$70.5 \pm 4.0^*$</td>
<td>$7.15 \pm 0.03^*$</td>
</tr>
</tbody>
</table>

* Significant difference vs. baseline at $p < 0.05$; $^\#$ Significant difference vs. ARDS at $p < 0.05$. All data are means ± SEM.
Results

- Normocapnia while low tidal volumes
- PAP normalization
- Right ventricular function improvement
- Complementary therapy

Experimental study – Upssala University, Sweden

- Animal study – 6 pigs
- Feasible
  - If blood flow from 750 to 1000ml/min, 19fr cannula
    - CO₂R: 146.1 ± 22.6 mL/minute max
    - pH: increase from 7,13 to 7,41
    - Sweep: 16L/min
  - Sweep decreasing at 8L/min
    - CO₂R: 138,0 ± 16,9ml/min max
  - 14,5Fr cannula:
    - CO₂R: 77,9 ml/min
    - pH not normalized

2 Clinical Cases

AF Rousseau – T Amand, JN Koch
Pediatric oxygenator integrated into CRRT circuit for CO₂ Removal

**Patient 1:**
- 48 year-old man
- Deep flame burns (+/- 65% total body area)
- Septic shock
- Mechanical Ventilation (>24d)
- Continuous Renal Replacement therapy (dialysis catheter subclavian vein 13Fr, 15 cm)
- Neuromuscular block, NO, prone position
- Day 29: hypercapnia

VV ECMO
Pediatric oxygenator integarted into CRRT circuit for CO$_2$ Removal

- **Patient 2:**

  - 34 years-old man,
  - Hematologic disease (Lymphoïd leukemia); coagulopathy ++
  - ARDS and hypercapnia
  - Continuous Renal Replacement therapy (dialysis catheter subclavian vein (13Fr, 15 cm))
  - Mechanical Ventilation, NO (20 ppm)
Circuit

- **CVVH Pump**
- **UF**
- **Substitution fluid**
- **Quadrox iD pédiatrique® / Lilliput 2 ®**
- **PvCO₂ = 84.8 mmHg**
- **PCO₂ = 78.3 mmHg**
- **PCO₂ = 21.9 mmHg**

**Systemic unfractional Heparin**

- **CaCl₂**
- **Citrate**

**Blood Gas Values**
- **PCO₂ = 78.2 mmHg**

**Additional Values**
- **PvCO₂ = 84.8 mmHg**
- **PaCO₂ = 21.9 mmHg**
Blood flow: 170mL/min. to 350 mL/min.
Sweep Gas: 5.5 L/min.
Change of the circuit

IN

Citrate

NaCl 9%

OUT

Calcium
Change of the circuit
Change of the circuit

IN

Citrate

OUT

Calcium

Calcium
Clinical improvement

- Controlled hypercapnia
- pHa raised to 7.28
- Blood pressure increased
  => Reduce/stop noradrenaline doses
- Ventilation setting unchanged during 24h, than decreased
Blood gas analysis
Pat n°2 one hour after beginning

<table>
<thead>
<tr>
<th>Pre membrane</th>
<th>Post membrane</th>
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<tbody>
<tr>
<td>7,20</td>
<td>7,72</td>
</tr>
<tr>
<td>67,8 mmHg</td>
<td>13,9 mmHg</td>
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<tr>
<td>26,0 mmol/L</td>
<td>17,5 mmol/L</td>
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- Sweep gas: 5L/min
- Blood Flow: 0,3L/min
- RESULTS: 67,9 ml/min CO₂ extracted
Anticoagulation:

- **Citrate/Calcium:** as a routine C.V.V.H.
  - Ionised calcium patient: 1.12 - 1.20 mmol/l
  - Ionised calcium post-filtre: 0.25 - 0.34 mmol/l
- **Heparin:**
  - TCA ratio: 1.5 - 2

Outcome:

- Patient 1: Died 33th day (M.O.F.)
- Patient 2: Died (cerebral ischemia + hemorrhage)
Limit of the technique

CO₂ extraction rate may fluctuate according to:

- Blood flow
- Pre-oxygenator CO₂ content level
- Oxygenator position in the C.V.V.H. circuit
- Ultrafiltration rate
- Bicarbonate content in substitution fluid
Perfusion perspectives?

- CO\textsubscript{2} extraction = “Respiratory dialysis”

- Hope:
  - Simple technique
  - Less invasive
  - More efficient
  - Cheaper

- Ultra protective ventilation

- Avoid mechanical ventilation for COPD
Super Nova Study
European Multicentric Study
Moderate ARDS

Classic ventilation

barotrauma => alveolar injury

Protective ventilation

↑ CO₂ and respiratory acidosis

↑ pulmonary resistances
down cardiac contractility

Solution (?): Protective ventilation + CO₂ Removal
Super Nova Study

- Feasibility
- Belgium: 20 Patients (10 CHU Lg, 10 Erasme)
- Moderate ARDS
- HLS® + Novaport® cannula 18Fr.
- Mechanical Ventilation:
  - >24 hours
  - pCO₂ > 60mmHg
- Reduce tidal volume
  - 6ml/kg
  - 5ml/kg
  - 4.5ml/kg
  - 4ml/kg
Conclusions:

- Clinical cases needed
- Experience needed
- Cannula design?
- Ideal blood flow?
- Ideal sweep gas flow?
- Perfusionist management
  - Continuous training for ICU nurses
  - Circuit manipulation
- ECCO$_2$R on CVVH with pediatric membrane
  - Partial extraction
  - Easier, less invasive, less expensive
Conclusions:

We would not recommend this kind of therapy in a center where there is no involvement by the perfusionist.