Extracorporeal Gas Exchange for Respiratory Failure:

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Disclosures/COI

• No relevant financial relationships with any commercial interests
• Patient consent for use of photos
“I shall shortly further try, whether the suffering the Blood to circulate through a vessel, so as it may be openly exposed to fresh air, will not suffice for the life of an Animal; and make some other Experiments, which, I hope, will thoroughly discover the Genuine use of Respiration; and afterwards consider what benefit this may be to Mankinde.”

PROLONGED EXTRACORPOREAL OXYGENATION FOR ACUTE POST-TRAUMATIC RESPIRATORY FAILURE (SHOCK-LUNG SYNDROME)

Use of the Bramson Membrane Lung


- 24M with subadventitial transection of thoracic aorta and multiple orthopedic injuries due to MVA
- Worsening respiratory failure (“shock lung”) after 4 days, despite maximal CMV
  - Partial venoarterial perfusion via peripheral cannulation using Bramson–membrane heart–lung machine with flow 3.0–3.6 L/min for 75 hours
  - $\text{PaO}_2$ increased from 38 to 75 mmHg
  - $\text{FiO}_2$ decreased from 100% to 60%
  - PIP reduced from 60 to 35 cmH$_2$O
- Patient survived and was discharged to rehab facility 8 weeks after ICU admission

Evidence for ECMO

• Currently no good RCTs comparing ECMO vs. current conventional mechanical ventilation in adults with acute respiratory failure
  – Use of ECMO in neonates with severe respiratory failure has been examined in 4 RCTs
  – Improved patient survival without severe disability
Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure

A Randomized Prospective Study

Warren M. Zapol, MD; Michael T. Snider, MD, PhD; J. Donald Hill, MD; Robert J. Fallat, MD; Robert H. Bartlett, MD; L. Henry Edmunds, MD; Alan H. Morris, MD; E. Converse Peirce II, MD; Arthur N. Thomas, MD; Herbert J. Proctor, MD; Philip A. Drinker, PhD; Philip C. Pratt, MD; Anna Bagniewski, MA; Rupert G. Miller, Jr, PhD

<table>
<thead>
<tr>
<th>Therapy*</th>
<th>Dead—Respiratory Improvement Never Occurred</th>
<th>Dead After Respiratory Improvement</th>
<th>Survived After Respiratory Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO and MV</td>
<td>34</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MV (control)</td>
<td>41</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

*ECMO indicates extracorporeal membrane oxygenation; MV, mechanical ventilation.

Fig 2.—Number of surviving patients treated by either mechanical ventilation alone (control group) or supplemented with partial venoarterial bypass plotted against days after entry into study. From day 2 to day 11, there were greater number of surviving patients in bypass group: ECMO, extracorporeal membrane oxygenation.

ECMO + MV 9.5% (95% CI 3–23%)
MV alone 8.3% (95% CI 3–20%)
Problems with Zapol et al.

• VA rather than VV ECMO used
  – May have contributed to high incidence of pulmonary micro-thrombosis and fibrosis in ECMO patients (due to lower pulmonary blood flow)

• Aggressive anticogulation
  – Severe bleeding and increased transfusion requirements

• Lack of standard ventilatory strategy
  – High rates of barotrauma

• Late initiation of ECMO?
Randomized Clinical Trial of Pressure-controlled Inverse Ratio Ventilation and Extracorporeal CO₂ Removal for Adult Respiratory Distress Syndrome

ALAN H. MORRIS, C. JANE WALLACE, RONALD L. MENLOVE, TERRY P. CLEMMER, JAMES F. ORME, JR., LINDELL K. WEAVER, NATHAN C. DEAN, FRANK THOMAS, THOMAS D. EAST, NATHAN L. PACE, MARY R. SUCHYTA, EDUARDO BECK, MICHELA BOMBINO, DEAN F. SITTIG, STEPHAN BÖHM, BARBARA HOFFMANN, HAYO BECKS, SAMUEL BUTLER, JAMES PEARL, and BRAD RASMUSSON

30-day survival (primary outcome):

New therapy (ECMO) 33%
Conventional MV 42%
(p = 0.8)

Figure 2. Kaplan-Meier survival curves for the 19 control (traditional) therapy (solid line) and the 21 new therapy patients (dotted line). Small vertical bars superimposed on curves indicate censored patients. p = 0.47.
Problems with Morris et al.

• Low-flow ECCO$_2$R instead of higher flow ECMO
  – No extracorporeal oxygenation support and reliance on lungs led to increase in airway pressures (no lung rest)
• Lack of ECCO$_2$R expertise
  – Study team had only used new therapy in sheep and 1 human prior to study
  – Bleeding and thrombotic complications
• PCIRV
  – Results have not been replicated in other
What Changed Our Thinking About ECGE?
The number of patients in each category who underwent extracorporeal life support is represented by the respective shaded area as a proportion of the total number of extracorporeal life support cases at each point in time.

Table 1. Survival Outcomes of Extracorporeal Life Support Patients

<table>
<thead>
<tr>
<th>Type of Case</th>
<th>No. of Patients</th>
<th>Survival, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonatal respiratory patients</td>
<td>586</td>
<td>88</td>
</tr>
<tr>
<td>- Meconium aspiration</td>
<td>207</td>
<td>96</td>
</tr>
<tr>
<td>- Infant respiratory distress syndrome</td>
<td>99</td>
<td>89</td>
</tr>
<tr>
<td>Sepsis</td>
<td>92</td>
<td>84</td>
</tr>
<tr>
<td>Diaphragmatic hernia</td>
<td>83</td>
<td>68</td>
</tr>
<tr>
<td>Pure persistent pulmonary hypertension of the newborn</td>
<td>58</td>
<td>93</td>
</tr>
<tr>
<td>Other</td>
<td>47</td>
<td>80</td>
</tr>
<tr>
<td>Pediatric respiratory patients</td>
<td>132</td>
<td>70</td>
</tr>
<tr>
<td>- Pneumonia</td>
<td>73</td>
<td>74</td>
</tr>
<tr>
<td>- Acute respiratory distress syndrome</td>
<td>59</td>
<td>68</td>
</tr>
<tr>
<td>Adult respiratory patients</td>
<td>146</td>
<td>56</td>
</tr>
<tr>
<td>- Pneumonia</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>- Acute respiratory distress syndrome</td>
<td>86</td>
<td>61</td>
</tr>
<tr>
<td>Cardiac/shock patients</td>
<td>136</td>
<td>44</td>
</tr>
<tr>
<td>Adult</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>Pediatric</td>
<td>105</td>
<td>48</td>
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</tbody>
</table>
Extracorporeal Life Support
The University of Michigan Experience

**Figure.** University of Michigan Extracorporeal Life Support Cases

The number of patients in each category who underwent extracorporeal life support is represented by the respective shaded area as a proportion of the total number of extracorporeal life support cases at each point in time.

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<td>33</td>
</tr>
<tr>
<td>Pediatric</td>
<td>105</td>
<td>48</td>
</tr>
</tbody>
</table>
Extracorporeal Membrane Oxygenation for Nonneonatal Acute Respiratory Failure

The Massachusetts General Hospital Experience From 1990 to 2008

Deepika Nehra, MD; Allan M. Goldstein, MD; Daniel P. Doody, MD; Daniel P. Ryan, MD; Yuchiao Chang, PhD; Peter T. Masiakos, MD

Figure 3. Survival by year of extracorporeal membrane oxygenation therapy.

Figure 4. Improvement in survival over time. ECMO indicates extracorporeal membrane oxygenation.
Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome

201 Patients given mechanical ventilation for confirmed or suspected influenza

68 Received ECMO

61 Confirmed 2009 influenza A(H1N1) or influenza A not subtyped

53 Confirmed 2009 influenza A(H1N1)
- 42 Alive
- 4 Still in ICU
- 11 Died

8 Confirmed influenza A not subtyped

7 Had suspected but unconfirmed influenza

6 Alive
- 1 Still in ICU
- 5 Died

133 Confirmed 2009 influenza A(H1N1) or influenza A not subtyped

116 Alive
- 11 Still in ICU
- 17 Died
48 patients (71%) survived to ICU discharge; 32 patients survived to hospital discharge (16 still inpatients)
6-month survival without disability
RR 0.69 (95% CI 0.05–0.97)
Referral to an Extracorporeal Membrane Oxygenation Center and Mortality Among Patients With Severe 2009 Influenza A(H1N1)

### Table 2. Deaths Analyzed by Matching Methods

<table>
<thead>
<tr>
<th>Matching method</th>
<th>No. of Deaths/Total No. of Patients (%)</th>
<th>RR (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECMO-Referred</td>
<td>Non-ECMO-Referred</td>
<td></td>
</tr>
<tr>
<td>Propensity score</td>
<td>18/75 (24.0)</td>
<td>35/75 (46.7)</td>
<td>0.51 (0.31-0.84)</td>
</tr>
<tr>
<td>GenMatch</td>
<td>18/75 (24.0)</td>
<td>38/75 (50.7)</td>
<td>0.47 (0.31-0.72)</td>
</tr>
<tr>
<td>Individual</td>
<td>14/59 (23.7)</td>
<td>31/59 (52.5)</td>
<td>0.45 (0.26-0.79)</td>
</tr>
</tbody>
</table>

Abbreviations: ECMO, extracorporeal membrane oxygenation; RR, relative risk.
Improving Survival with

- Lubnow 2010
- Roch 2010
- Hei 2010
- Freed 2010
- Peris 2010
- Norfolk 2010
- Bartlett 2000
- CESAR 2009
- ANZIC 2009
- Zapol 1979
- Gattinoni 1986
- Morris 1994
Where Do We Go From
## Summary of the Evidence

### 3.1.1 Randomized Trials

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ECMO Events Total</th>
<th>Control Events Total</th>
<th>Weight</th>
<th>Odds Ratio M-H, Random, 95% CI</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zapol 1979</td>
<td>38 42</td>
<td>44 48</td>
<td>10.7%</td>
<td>0.86 [0.20, 3.69]</td>
<td>1979</td>
</tr>
<tr>
<td>Morris 1994</td>
<td>14 21</td>
<td>11 19</td>
<td>11.8%</td>
<td>1.45 [0.40, 5.26]</td>
<td>1994</td>
</tr>
<tr>
<td>CESAR 2009</td>
<td>33 90</td>
<td>45 90</td>
<td>16.3%</td>
<td>0.58 [0.32, 1.05]</td>
<td>2009</td>
</tr>
<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td><strong>153 157</strong></td>
<td></td>
<td><strong>38.8%</strong></td>
<td><strong>0.70 [0.42, 1.16]</strong></td>
<td></td>
</tr>
</tbody>
</table>

Total events 85 100
Heterogeneity: Tau² = 0.00; Chi² = 1.71, df = 2 (P = 0.42); I² = 0%
Test for overall effect: Z = 1.37 (P = 0.17)

### 3.1.2 Non-Randomized Trials

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ECMO Events Total</th>
<th>Control Events Total</th>
<th>Weight</th>
<th>Odds Ratio M-H, Random, 95% CI</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mols 2000</td>
<td>28 62</td>
<td>71 183</td>
<td>16.3%</td>
<td>1.30 [0.73, 2.32]</td>
<td>2000</td>
</tr>
<tr>
<td>Beiderlinden 2006</td>
<td>15 32</td>
<td>34 118</td>
<td>15.0%</td>
<td>2.18 [0.98, 4.85]</td>
<td>2006</td>
</tr>
<tr>
<td>Noah 2011</td>
<td>18 75</td>
<td>38 75</td>
<td>15.7%</td>
<td>0.31 [0.15, 0.62]</td>
<td>2011</td>
</tr>
<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td><strong>218 449</strong></td>
<td></td>
<td><strong>61.2%</strong></td>
<td><strong>1.51 [0.47, 4.82]</strong></td>
<td></td>
</tr>
</tbody>
</table>

Total events 83 151
Heterogeneity: Tau² = 1.26; Chi² = 29.90, df = 3 (P < 0.00001); I² = 90%
Test for overall effect: Z = 0.69 (P = 0.49)

**Total (95% CI)**

<table>
<thead>
<tr>
<th>ECMO Events Total</th>
<th>Control Events Total</th>
<th>Weight</th>
<th>Odds Ratio M-H, Random, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>371 606</td>
<td></td>
<td>100.0%</td>
<td>1.20 [0.57, 2.53]</td>
</tr>
</tbody>
</table>

Total events 168 251
Heterogeneity: Tau² = 0.80; Chi² = 35.00, df = 6 (P < 0.00001); I² = 83%
Test for overall effect: Z = 0.48 (P = 0.63)
Test for subgroup differences: Chi² = 1.40, df = 1 (P = 0.24), I² = 28.6%
Will CESAR answer the adult ECMO debate?

VS.

We do not need mechanical ventilation any more

Lorenzo Del Sorbo, MD; V. Marco Ranieri, MD
Ventilatory support versus ECMO for severe adult respiratory failure

Correspondence

• Expertise – patients transported to center of excellence – center effect??

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>-1</th>
<th>-2</th>
<th>-3</th>
<th>-4</th>
<th>-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative risk</td>
<td>0.69</td>
<td>0.71</td>
<td>0.72</td>
<td>0.74</td>
<td>0.76</td>
<td>0.78</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.50–0.97</td>
<td>0.51–0.99</td>
<td>0.52–1.02</td>
<td>0.53–1.04</td>
<td>0.54–1.07</td>
<td>0.55–1.10</td>
</tr>
<tr>
<td>p value</td>
<td>0.03</td>
<td>0.05</td>
<td>0.07</td>
<td>0.10</td>
<td>0.13</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Analysis based on the 177 patients with complete data on which the primary CESAR outcome reported with Fisher’s exact test.

Table: Sensitivity analysis showing hypothetical effects of decreased occurrence of death or disability (expressed in column headings as number of fewer patients) in control group, assuming no changes in ECMO group

• Availability and cost–effectiveness?
• Optimal patient population and timing of initiation?
**Therapies for Refractory Hypoxemia in Acute Respiratory Distress Syndrome**

**Table. Therapeutic Strategy for Severe Acute Respiratory Distress Syndrome (ARDS) With Refractory Hypoxemia**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Special Considerations</th>
<th>Supporting Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy sedation and neuromuscular blockade</td>
<td>Consider for patient-ventilator asynchrony. Low cost and widely available. Risk of delirium from heavy sedation. Risk of prolonged weakness from neuromuscular blockade.</td>
<td>Improved Oxygenation: 8, 13 Mortality Risk (95% CI): Adjusted HR, 0.68 (0.48-0.98)(^a,b)</td>
</tr>
<tr>
<td>Higher positive end-expiratory pressure or recruitment maneuvers</td>
<td>Easily done with conventional mechanical ventilators. Low cost and widely available. Risk of barotrauma and hypotension.</td>
<td>Improved Oxygenation: 14-17 Mortality Risk (95% CI): Adjusted RR, 0.90 (0.81-1.00)(^16,c)</td>
</tr>
<tr>
<td>Prone positioning</td>
<td>No special equipment required. Low cost and widely available. Risk of local complications (eg, pressure sores, facial edema). Difficulty performing routine nursing care while patient is prone.</td>
<td>Improved Oxygenation: 11, 18-20 Mortality Risk (95% CI): RR, 0.84 (0.74-0.96)(^20,d)</td>
</tr>
<tr>
<td>High-frequency oscillatory ventilation</td>
<td>Consider early application if oxygenation improves with higher positive end-expiratory pressure or recruitment maneuvers. Requires special ventilator and expertise.</td>
<td>Improved Oxygenation: 21-23 Mortality Risk (95% CI): RR, 0.77 (0.61-0.98)(^23,e)</td>
</tr>
<tr>
<td>Inhaled nitric oxide</td>
<td>Consider if associated pulmonary hypertension. Change in dose-response curve over time. May not be widely available. Expensive.</td>
<td>Improved Oxygenation: 24-27 Mortality Risk (95% CI): None</td>
</tr>
<tr>
<td>Extracorporeal membrane oxygenation</td>
<td>Ability to use lower tidal volumes and airway pressures for lung recovery. Requires systemic anticoagulation. Expensive. Highly invasive. Requires expertise.</td>
<td>Improved Oxygenation: 10, 28, 29 Mortality Risk (95% CI): RR, 0.69 (0.05-0.97)(^10,f)</td>
</tr>
</tbody>
</table>
If clinically appropriate, consider transfer to a regional referral center specializing in ARDS management, in which advanced therapies (e.g., HFOV, ECMO) are available.
Tidal Volume Reduction in Patients with Acute Lung Injury When Plateau Pressures Are Not High

David N. Hager, Jerry A. Krishnan, Douglas L. Hayden, and Roy G. Brower for the ARDS Clinical Trials Network

Department of Medicine, Johns Hopkins University, Baltimore, Maryland; and Biostatistics Center, Massachusetts General Hospital, Boston, Massachusetts
Tidal Volume Reduction in Patients with Acute Lung Injury When Plateau Pressures Are Not High

David N. Hager, Jerry A. Krishnan, Douglas L. Hayden, and Roy G. Brower for the ARDS Clinical Trials Network

Department of Medicine, Johns Hopkins University, Baltimore, Maryland; and Biostatistics Center, Massachusetts General Hospital, Boston, Massachusetts
Low Stretch (Intervention)
- $V_T$: 6.2 mL/kg
- $P_{PLAT}$: 25 cmH$_2$O
- RR: 29
- $V_{MIN}$: 13 L/min
- PEEP: 9 cmH$_2$O

High Stretch (Control)
- $V_T$: 11.8
- $P_{PLAT}$: 32–34 cmH$_2$O
- RR: 18
- $V_{MIN}$: 13
- PEEP: 8

P = 0.005

Tidal Hyperinflation during Low Tidal Volume Ventilation in Acute Respiratory Distress Syndrome

Pier Paolo Terragni, Giulio Rosboch, Andrea Tealdi, Eleonora Corno, Eleonora Menaldo, Ottavio Davini, Giovanni Gandini, Peter Herrmann, Luciana Mascia, Michel Quintel, Arthur S. Slutsky, Luciano Gattinoni, and V. Marco Ranieri
• Reductions in ECCO$_2$R group
  • $V_T$ from 6.3 to 4.2 mL/kg PBW
  • $P_{plat}$ from 29.1 to 25.0 cmH$_2$O
• ECCO$_2$R normalized PaCO$_2$ (50.4 mmHg) and pH (7.32) despite lower $V_T$
• After 72 hrs of ventilation and ECCO$_2$R
  • Significant improvement in morphological markers of lung protection and pulmonary cytokines
• No patient–related complications observed
Ventilation During ECMO

- Ventilator settings reduced to allow “lung rest”
  - PIP 20 cm H$_2$O
  - RR 10 breaths/min
  - FiO$_2$ 30%
  - Spontaneous breathing

- The “ultimate” lung protective ventilatory strategy?
Extrapulmonary Intervenotional Ventilatory Support in Severe Acute Respiratory Distress Syndrome (ARDS) (Xtravent)

This study has been completed.

First Received: October 2, 2007   Last Updated: March 1, 2011   History of Changes

<table>
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<th>University of Regensburg</th>
</tr>
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<tbody>
<tr>
<td>Collaborator</td>
<td>Charite University, Berlin, Germany</td>
</tr>
<tr>
<td>Information provided by</td>
<td>University of Regensburg</td>
</tr>
<tr>
<td>ClinicalTrials.gov Identifier</td>
<td>NCT00538928</td>
</tr>
</tbody>
</table>

Purpose

A prospective, randomized study will be performed investigating the effects of a pumpless extracorporeal intervenotional lung assist (ILV) on the implementation of a lung-protective ventilatory strategy in patients with acute respiratory distress syndrome (ARDS) with a PaO2/FiO2 ratio < 200. The duration of ventilation, intensive care and hospital stay and in-hospital mortality will be investigated.

Primary Outcome Measures:

- Ventilator free days within 28 days after enrollment [ Time Frame: 28 days ] [ Designated as safety issue: Yes ]

Secondary Outcome Measures:

- hospital mortality, organ-failure free days, pulmonary gas exchange [ Time Frame: 28 days - 60 days ] [ Designated as safety issue: Yes ]

Estimated Enrollment: 120
Study Start Date: September 2007
Study Completion Date: January 2011
Primary Completion Date: January 2011 (Final data collection date for primary outcome measure)
EOLIA

ECMO to rescue Lung Injury in severe ARDS
Randomization

Experimental Treatment Arm
- Venovenous ECMO will be started as rapidly as possible
- Mechanical ventilation settings: volume-assist control mode, FiO₂ 30–60%, PEEP ≥10 cm H₂O, V̇₉ lowered to obtain a plateau pressure ≤20 cm H₂O, RR 10–30/minute or APRV mode with high pressure level ≤20 cm H₂O and low pressure level ≥10 cm H₂O
- ECMO weaning according to protocol

Control Conventional Treatment Arm
- Conventional management of ARDS
- Ventilatory settings: volume-assist control mode, V̇₉ 6 ml/kg of ideal body weight and PEEP adapted so as not to exceed plateau pressure of 28–30 cm H₂O
- In the case of refractory hypoxemia, the usual adjunctive therapeutics can be used: NO, prone position, HFO ventilation, almitrine infusion
- Cross-over option to ECMO possible if refractory hypoxemia defined as SaO₂ <80% for >6 hours, despite mandatory use of recruitment maneuvers, and inhaled NO/prostacyclin and if technically possible a test of prone position.
Final Thoughts…1979

“The membrane oxygenator has now proved to be as limited as other temporary mechanical assistance devices…Like the others, it maintains the body in proper balance but cannot heal the organ it assists. At present, we have no therapy to speed healing of the severely injury lung…When such therapies are developed, clinicians may once again turn to the artificial lung to buy time necessary for these therapies to take effect and increase survival rates. In the meanwhile, study of the effect of bypass route on the injured lung and research to
Questions?

efan@mtsinai.on.ca