IDIOSYNCRASIES OF HEMODYNAMIC MONITORING OF SEPTIC PATIENTS UNDER ECMO

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Hemodynamic monitoring in patients with sepsis

- Cardiac output
- Cardiac function
- Volume status and preload responsiveness
- PAP
- SvO2

TOOLS:
- PAC
- Transpulmonary thermodilution
- Echocardiography
- NIRS
ECMO

Veno Arterial

Veno Venous
VenoArterial

Blood drained from venous compartment and injected into artery
Venovenous

Blood drained from venous compartment and reinjected in venous compartment
ECMO

**Veno Arterial**
- Blood drained from venous compartment and injected into artery
- Cardiac and respiratory support

**Veno Venous**
- Blood drained from venous compartment and reinjected in venous compartment
- Respiratory support only (O2 and CO2)
ECMO

Which indications in septic patients?

- Respiratory support for severe ARDS
- Circulatory support for severe myocardial depression
PaO2 depends on ECMO BF/pulmonary BF

ECMO BF 4L/min SO2 100%
Patient SvO2 50%
Lung oxygenation +10%

Total BF 5L/min:
4l x100 + 1l x50 = 5l 90% (PA)
=> SaO2 99%

Total BF 8L/min:
4l x100 + 4l x50 = 8l 75%
=> SaO2 85%
ECMO flow / CO
CESAR trial

Peek G et al
Lancet 374:1351; 2009

180 pts severe ARDS (PF ratio ~75)
## ECMO in H1N1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>All Infections (N = 68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation parameters, median (IQR)</td>
<td>56 (48-63)</td>
</tr>
<tr>
<td>Lowest PaO₂/FIO₂ ratio</td>
<td>1.0 (1.0-1.0)</td>
</tr>
<tr>
<td>Highest FIO₂</td>
<td>1.0 (1.0-1.0)</td>
</tr>
<tr>
<td>Highest PEEP, cm H₂O</td>
<td>18 (15-20)</td>
</tr>
<tr>
<td>Highest peak airway pressure, cm H₂O</td>
<td>36 (33-38)</td>
</tr>
<tr>
<td>Lowest pH</td>
<td>7.2 (7.1-7.3)</td>
</tr>
<tr>
<td>Highest PaCO₂, mm Hg</td>
<td>69 (54-83)</td>
</tr>
<tr>
<td>Highest tidal volume, mL/kg</td>
<td>5.6 (4.6-6.7)</td>
</tr>
<tr>
<td>Quadrants of radiograph infiltrate, No.</td>
<td>4 (4-4)</td>
</tr>
<tr>
<td>Acute lung injury score&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.8 (3.5-4.0)</td>
</tr>
<tr>
<td>Pneumothorax pre-ECMO, No. (%)</td>
<td>10 (15)</td>
</tr>
<tr>
<td>Rescue ARDS therapies used, No. (%)</td>
<td></td>
</tr>
<tr>
<td>Recruitment maneuver</td>
<td>38 (67)</td>
</tr>
<tr>
<td>Prone positioning</td>
<td>12 (20)</td>
</tr>
<tr>
<td>High-frequency oscillation</td>
<td>3 (5)</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>20 (32)</td>
</tr>
<tr>
<td>Prostacyclin</td>
<td>14 (22)</td>
</tr>
</tbody>
</table>

**Survival at ICU discharge** 48 (71)

<table>
<thead>
<tr>
<th>Length of stay, median (IQR), d</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU</td>
</tr>
<tr>
<td>Hospital</td>
</tr>
<tr>
<td>Duration, median (IQR), d</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
</tr>
<tr>
<td>ECMO support</td>
</tr>
<tr>
<td>Still in ICU</td>
</tr>
<tr>
<td>Survival at hospital discharge</td>
</tr>
<tr>
<td>Still in hospital&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ambulant at hospital discharge&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SaO₂ on room air at hospital discharge, median (IQR), %&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Discharge destination</td>
</tr>
<tr>
<td>Died</td>
</tr>
<tr>
<td>Home</td>
</tr>
<tr>
<td>Other hospital</td>
</tr>
<tr>
<td>Rehabilitation facility</td>
</tr>
<tr>
<td>Cause of death&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hemorrhage</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
</tr>
<tr>
<td>Infection</td>
</tr>
<tr>
<td>Intractable respiratory failure</td>
</tr>
</tbody>
</table>
UK H1N1 cohort

Noah et al
JAMA  306:1659;2011

Individual matching

ECMO-referred patients

Non-ECMO-referred patients

Proportion Surviving

No. of Deaths/
Total No. of Patients (%)

<table>
<thead>
<tr>
<th>Matching method</th>
<th>ECMO-Referred</th>
<th>Non-ECMO-Referred</th>
<th>RR (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<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>
<td>.008</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>
<td>.001</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>
<td>.006</td>
</tr>
</tbody>
</table>
# Venoarterial Extracorporeal Membrane Oxygenation Support for Refractory Cardiovascular Dysfunction During Severe Bacterial Septic Shock

Nicolas Bréchot, MD, PhD; Charles-Edouard Luyt, MD, PhD; Matthieu Schmidt, MD; Pascal Leprince, MD, PhD; Jean-Louis Trouillet, MD; Philippe Léger, MD; Alain Pavie, MD; Jean Chastre, MD; Alain Combes, MD, PhD

**CCM 2013**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intropo score, μg/kg/min, median (range)</strong></td>
<td>250 (73–629)</td>
</tr>
<tr>
<td><strong>Catecholamine dose, μg/kg/min, median (range)</strong></td>
<td></td>
</tr>
<tr>
<td>Dobutamine, $n = 4$</td>
<td>17.5 (6–30)</td>
</tr>
<tr>
<td>Norepinephrine, $n = 9$</td>
<td>2.0 (0.5–4.9)</td>
</tr>
<tr>
<td>Epinephrine, $n = 13$</td>
<td>1.25 (0.1–4.2)</td>
</tr>
<tr>
<td><strong>Pre-ECMO mean arterial pressure, mmHg, median (range)</strong></td>
<td>72 (53–105)</td>
</tr>
<tr>
<td><strong>Pre-ECMO central venous pressure, mmHg, median (range)</strong></td>
<td>18 (10–35)</td>
</tr>
<tr>
<td><strong>Pre-ECMO cardiac index, L/min/m², median (range)</strong></td>
<td>1.3 (0.7–2.2)</td>
</tr>
<tr>
<td><strong>Pre-ECMO systemic resistance vascular index, dyne·s/cm²/m², median (range)</strong></td>
<td>3.162 (2.047–7.685)</td>
</tr>
<tr>
<td><strong>Cardiac arrest before ECMO, $n$</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Echocardiographic right ventricular dysfunction, $n$</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Simplified Acute Physiology Score 3, median (range)</strong></td>
<td>84 (75–106)</td>
</tr>
<tr>
<td><strong>Sepsis-Related Organ Failure Assessment score, median (range)</strong></td>
<td>18 (8–21)</td>
</tr>
<tr>
<td><strong>pH, median (range)</strong></td>
<td>7.16 (6.68–7.39)</td>
</tr>
<tr>
<td><strong>Blood lactate, median (range)</strong></td>
<td>9 (2–17)</td>
</tr>
</tbody>
</table>
Brechot N et al
CCM 2013

Refactory septic shock
n = 14

2 Deaths under ECMO
2 Deaths in ICU

10 Long-term survivors

LVEF (%)

ECMO implantation
ECMO explantation
Follow-up

***

***
Harlequin Syndrome
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status and preload responsiveness
- PAP
- SvO2

- PO2
- (PO2 upper/lower body)

TOOLS
- PAC
- Transpulmonary thermodilution
- Echocardiography
- NIRS
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status
- Preload responsiveness
- PAP
- SvO₂
- PO₂
- (PO₂ upper/lower body)
Technical issues with PAC during ECMO

- Loss of indicator (outflow cannula)
DC \sim area^{-1}
DC \sim \text{area}^{-1}\text{ Thermodilution}
Technical issues with PAC during ECMO

- Loss of indicator (outflow cannula)
- Dilution by a large amount of blood at a given temperature (inflow cannula)

=> Cardiac output can be overestimated as well as underestimated
Technical issues with PAC during ECMO

- Loss of indicator (outflow cannula)
- Dilution by a large amount of blood at a given temperature (inflow cannula)

Risks associated with PAC during ECMO

- Difficulties of insertion (aspiration in outflow cannula)
- Thrombosis of PA (VA ECMO only)
Pros and Cons of PAC during ECMO

Pros

- Measurements of PAOP and PAP
- SvO2

Cons

- Cardiac output not reliable
- Difficulties of insertion (aspiration in outflow cannula)
- Thrombosis of PA (VA ECMO only)
RV LV
SvO2
Brain
Skin
Muscle
Kidney
Gut /
Liver
Heart
normal value
around 70 %

ECMO
3-4 L/min
SO2 100 %
Interpretation of SvO2 in VV ECMO

SvO2 = adequacy of flow

SvO2 = efficiency of ECMO (after mixing)

SvO2 = efficacy of SO2

SvcO2 = adequacy of flow

SVC cannula

SVC

PA

IVC cannula

SvcO2 = adequacy of flow

Not reliable
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output ???
- Cardiac function ????
- Volume status
- Preload responsiveness
- PAP
- SvO2
- PO2
- (PO2 upper/lower body)
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status
- Preload responsiveness
- ScvO2

- PO2
- (PO2 upper/lower body)

TPD + pulse contour
Technical issues with transpulmonary thermodilution and pulse contour during ECMO

- Loss of indicator (outflow cannula)
- Dilution by large amount of blood at a given temperature (inflow cannula)

=> Cardiac output can be overestimated as well as underestimated

=> GEDV and EVLW are not reliable anymore!
Pros and Cons of transpulmonary thermodilution and pulse contour during ECMO

Pros

Cons

- ??
- Cardiac output not reliable
- Derived measurements not reliable (GEDV, EVLW, ...)
- Pulse contour not feasible in VA ECMO
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status
- Preload responsiveness
- ScvO2
- PO2
- (PO2 upper/lower body)

TPD + pulse contour
Hemodynamic monitoring in patients with sepsis under ECMO

ECHOCARDIOGRAPHY
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status
- Preload responsiveness
- PAP
- SvO2
- PO2
- (PO2 upper/lower body)
Veno-venous ECMO

- Check correctable factors before ECMO
- Position of cannulas
- Evaluation of RV function
- Cardiac output measurements
Echo in veno-venous ECMO

- Check for reversible factors prior to ECMO
  - PFO
  - Large pleural effusion
Large pleural effusion (Right)
Position of cannulas in VV ECMO

- Two types of cannulations

Dual cannulation

Double lumen cannula
Dual cannulation

• The position of the IVC cannula should be carefully checked (good drainage / no recirculation)

• The SVC cannula is usually not visualized
Dual cannulation

Brodie D et al
NEJM 365:1905;2011
Dual cannulation

SVC cannula

IVC cannula
IVC cannula repositioned
IVC cannula slightly too much withdrawn
The best position
Wang-Zwische Double Lumen Cannula—Toward a Percutaneous and Ambulatory Paracorporeal Artificial Lung

Dongfang Wang,* Xiaoqin Zhou,* Xiaojun Liu,† Bill Sidor,‡ James Lynch,† and Joseph B. Zwischenberger*
Double lumen cannula

Brodie D et al
NEJM 365:1905;2011

Cross-section of bicaval dual-lumen cannula
Quantification of recirculation as an adjuvant to transthoracic echocardiography for optimization of dual-lumen extracorporeal life support
Right ventricular rupture and tamponade caused by malposition of the Avalon cannula for venovenous extracorporeal membrane oxygenation.
Echo in veno-venous ECMO

- Check for reversible factor prior to ECMO
- Position of cannulas
- Evaluation of RV function (before / during run / during weaning)
- Cardiac output measurements
- Filling pressures / PAP
- Fluid responsiveness
- Check for thrombi around cannulas
Passive leg raising can predict fluid responsiveness in patients placed on venovenous extracorporeal membrane oxygenation.
### Table

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Responders (n = 13)</th>
<th>Nonresponders (n = 12)</th>
<th>(P) values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAP (mmHg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>77 (65 to 84)</td>
<td>75 (62 to 83)</td>
<td>0.62</td>
</tr>
<tr>
<td>PLR</td>
<td>77 (61 to 84)</td>
<td>72 (58 to 84)</td>
<td>0.64</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>83 (71 to 90)&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;</td>
<td>71 (67 to 87)</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>CVP (mmHg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>7 (5 to 13)</td>
<td>11 (8 to 15)</td>
<td>0.08</td>
</tr>
<tr>
<td>PLR</td>
<td>12 (8 to 14)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12 (10 to 13)</td>
<td>0.68</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>12 (10 to 15)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13 (10 to 17)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>(\Delta{\text{RespPP}}) (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>6 (4 to 8)</td>
<td>7 (4 to 10)</td>
<td>0.59</td>
</tr>
<tr>
<td>PLR</td>
<td>6 (4 to 7)</td>
<td>9 (5 to 11)</td>
<td>0.14</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>5 (4 to 8)</td>
<td>7 (5 to 10)</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>VTI (cm/second)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>20 (15.2 to 25)</td>
<td>16.1 (13.7 to 21.6)</td>
<td>0.3</td>
</tr>
<tr>
<td>PLR</td>
<td>24.7 (17.7 to 28.3)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.8 (12.9 to 22.3)</td>
<td>0.03</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>25.4 (19.1 to 30)&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;</td>
<td>16 (14 to 21.4)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>SV (mL)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>72 (50 to 88)</td>
<td>55 (49 to 84)</td>
<td>0.7</td>
</tr>
<tr>
<td>PLR</td>
<td>85 (59 to 99)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>58 (48 to 85)</td>
<td>0.1</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>89 (66 to 109)&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;</td>
<td>60 (48 to 82)</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>CO (L/minute)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>5.8 (4 to 8.3)</td>
<td>5.6 (4.3 to 7.8)</td>
<td>0.96</td>
</tr>
<tr>
<td>PLR</td>
<td>5.9 (4.7 to 9.6)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.8 (4 to 6.6)</td>
<td>0.27</td>
</tr>
<tr>
<td>Volume expansion</td>
<td>7.5 (5.2 to 10.1)&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.2 (4.4 to 7.7)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**N=25**
Thrombi around IVC cannula
Echocardiography in veno-arterial ECMO

• Before ECMO:
  • Evaluation of indication and exclusion of correctable causes of cardiogenic shock
  • Evaluation of aorta and aortic valve
Echocardiography in veno-arterial ECMO

- Before ECMO:
- During ECMO insertion:
- Position of guidewires and cannulas
VA ECMO

Top of venous cannula in RA

- No risk of recirculation
- Avoid risk of IVC collapse
IVC cannula positioned
Kinked cannula (high lateral velocities/no tip velocity)

ECLS flow: 1.4 L/min

Pump: 8500 RPM
Cannula withdrawn

Calderon et al
Hemodynamic monitoring using echocardiography in the critically ill
Eds: De Backer et al
Springer 2011
Echocardiography in veno-arterial ECMO

- Before ECMO:
- During ECMO insertion:
- During ECMO run:
  - Evaluation of RV / LV function
  - Aortic regurgitation ?
  - LV ballooning / pulmonary edema
  - Cardiac output measurements
  - Detection of thrombus
  - Weaning
Increased LV afterload

Descending aorta blood flow

Calderon et al
Hemodynamic monitoring using echocardiography in the critically ill
Eds: De Backer et al
Springer 2011
Large A wave on pulmonary vein flow => elevated PAOP

Calderon et al
Hemodynamic monitoring using echocardiography in the critically ill
Eds: De Backer et al
Springer 2011
Abnormal mitral flow waves (backflow!)

Mitral regurgitation

E  A (biphasic with diastolic backflow)
Risk for clotting
Echo for weaning of ECMO

- **VV ECMO**: Check RV
- **VA ECMO**: Check RV/LV/VTI/filling pressures
Female 46 YO  AMI

• Admitted for AMI

• Hemodynamically stable

• Immediate coronary arteries angiography

• During revascularization attempt, the patient developed cardiac arrest (VF => EMD)

• Implantation of ECMO for eCPR

• Revascularization effective
Measurements of Ao VTI for ECMO weaning

FR 50Hz
15cm

2D
59%
C 50
P Low
HPen

ECMO 3L

LVOT VTI
Vmax 84.6 cm/s
Vmean 62.4 cm/s
Max PG 3 mmHg
Mean PG 2 mmHg
VTI 13.6 cm
Measurements of Ao VTI for ECMO weaning
Measurements of Ao VTI for ECMO weaning
Echo for weaning of ECMO

Aissaoui N et al
ICM 37:1738;2011

ECMO n=33
Weaned ▲
Failed ●
Echo for weaning of ECMO

Aissaoui N et al
ICM 37:1738;2011

ECMO n=33
Weaned ▲
Failed ●

VTI > 10-12 cm
TDSa > 6 cm/s
LVEF > 20-25%
Hemodynamic monitoring in patients with sepsis under ECMO

- Cardiac output
- Cardiac function
- Volume status
- Preload responsiveness
- PAP
- $\text{SvO2}$
- $\text{PO2}$
- (PO2 upper/lower body)
A place for regional O2 saturations monitoring in VA ECMO

Wong JS et al
ASAIO 36:659;2012

Left cerebral
Right cerebral
Left leg
Right leg
Which hemodynamic monitoring in patients with sepsis under ECMO?

- Echocardiography
- PAC in some patients
- NIRS (or equivalent) in VA ECMO
Thank you