Methods for the measurement of extravascular lung water (EVLW)

- Radiology
- Indicator dilution techniques
- Imaging techniques
- Gravimetric technique
A 63 yrs old patient with pulmonary edema after TURT

Q#3 What is the EVLW in this patient?
(normal values 3-7 ml/kg; 25 ml/kg is very high)

a. 5 ml/kg
b. 10 ml/kg
c. 15 ml/kg
d. 20 ml/kg
e. 25 ml/kg

Please vote now!
What do you think is the EVLW now?
Chest X-ray changes appear only when EVLW increases by more than 100%.
Bongard FS Surgery 1984

Chest radiograph is insensitive to small changes in EVLW
Helperin BD Chest 1984

There is a significant interobserver variability in applying a radiographic definition for ARDS
Rubenfeld et al, Chest 1999
Findings on the portable chest radiograph correlate with fluid balance in critically ill patients.

Martin GS, Ely EW, Carroll FE, Bernard GR
Chest. 2002 Dec;122(6):2087-95

Objective radiographic measures of intravascular volume may be more appropriate indicators of fluid balance than subjective measures, with vascular pedicle width (VPW) appearing most sensitive.

If systematically quantitated, serial CXRs provide a substantial supplement to other clinically available data for the purpose of fluid management in critically ill patients.

Dr. Martin, how effective is the CXR and how does it compare to the EVLW in assessing lung edema?
The practice parameters for hemodynamic support of sepsis in adult patients in sepsis (Task Force of the ACCCM and the SCCM, CCM 1999;27:639-660) include the following:

“Pulmonary edema may occur as a complication of fluid resuscitation and necessitates monitoring of……”

Q#4 What do you think is the missing word(s)?

a. Arterial oxygenation
b. Chest radiogram
c. Lung compliance
d. All of the above

Please vote now!
Pulmonary edema may occur as a complication of fluid resuscitation and necessitates monitoring of arterial oxygenation.
Oxygenation as a marker of pulmonary edema

Scilia et al. Radiology 1999; 211:161-168

During MV, hypoxemia is a late sign of Pulmonary Edema!!!
Extravascular lung water in patients with severe sepsis: a prospective cohort study
Greg S Martin¹, Stephanie Eaton², Meredith Mealer³ and Marc Moss⁴


Scatter plot showing the relationship between (a) oxygenation (arterial oxygen tension [PaO₂]/inspired fractional oxygen [FiO₂] ratio) and extravascular lung water (EVLW) in all patients ($R^2$ by linear regression $= 0.27$; $P < 0.001$), and (b) between minimum PaO₂/FiO₂ ratio and maximum EVLW in nonsurvivors ($R^2 = 0.60$; $P = 0.005$).
## Detection of incipient pulmonary edema

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Increase in EVLW</th>
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<tbody>
<tr>
<td>Clinical symptoms</td>
<td>100 – 200 %</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>100 – 200 %</td>
</tr>
<tr>
<td>Oxygenation (under MV)</td>
<td>300 %</td>
</tr>
<tr>
<td>EVLW (PiCCO)</td>
<td>10 – 15 %</td>
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The chest X ray, impaired oxygenation and PAOP have been repeatedly shown to correlate poorly with the amount of EVLW.

Bedside measurement of EVLW offers new opportunities in the diagnosis, follow-up and assessment of therapy in critically ill patients.
How is the measurement of EVLW helpful during fluid resuscitation of the critically ill?
Case # 1

- 20 year old man after a motor vehicle accident.
- Neurological injury without improvement over the next 2-3 days.
On the 4th hospital day patient develops severe hypoxemia.

- PEEP is 16
- PCV with IRV
- NO
- Oscillator

- PaO$_2$/FiO$_2$ is still only 80 !!!
Hemodynamic instability appears!!!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Blood pressure</td>
<td>100/55 - 70/40 mmHg</td>
</tr>
<tr>
<td>Heart rate</td>
<td>155 bpm</td>
</tr>
<tr>
<td>CVP</td>
<td>5 cmH$_2$O</td>
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Hypoxemia, hypotension, tachycardia, low CVP
Q#5  What is the reason for this patient’s hypotension?

1. Hypovolemia
2. Heart failure
3. Vasodilation
4. Anaphylaxis

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<tbody>
<tr>
<td><strong>BP</strong></td>
<td>70/40  mmHg</td>
</tr>
<tr>
<td><strong>HR</strong></td>
<td>155 bpm</td>
</tr>
<tr>
<td><strong>CVP</strong></td>
<td>5 cmH₂O</td>
</tr>
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</table>
A PiCCO catheter was inserted

- CO = 12-15 L/min (High !!!)
- SVR = 400-500 (Low !!!)
- ITBVI = 1200 ml/m² (800-1000) (High)
- SVV = 10-12% (up to 10) (Normal)
- EVLW = 19-23 ml/kg (4-7) (High !!!)
Q#4 What should be your therapeutic approach?

1. Fluid loading to improve cardiac output.
2. Aggressive diuresis.
3. Noradrenaline to increase SVR and BP.

Please vote now!

CO = 12-15 L/min
SVR = 400-500
ITBVI = 1200 ml/m²
SVV = 10-12%
EVLW = 19-23 ml/kg
Aggressive diuresis was started while blood pressure was maintained with noradrenaline at relatively low doses.

Over the next two days:

- ITBVI decreased to 680 ml/m².
- SVV increased to 18-20%.
- CO decreased to 6-8 l/min.
- EVLW decreased to 16 >12>9>6 ml/kg.
• PaO2/FiO2 increased to 300
• NO weaned
• Ventilatory mode changed to PSV
Conclusions Case # 2

• Hypotension and low CVP do not exclude the presence of high CO and high preload.

• The ability to measure and follow EVLW values is helpful in managing pulmonary edema even in the presence of hemodynamic instability.
Case # 2

- 65 year old man with severe IHD and congestive heart failure per history.

- Patient undergoes angioplasty and stent insertion because of tight carotid lesion, following which he is placed on potent anti-coagulation therapy.
• 2 days later patient becomes confused. CT reveals large frontal intracranial bleed
• Patient develops severe respiratory distress.
  – Saturation 76% on O₂ via face mask.
  – Blood pressure 86/40 mmHg.
  – Heart rate 128 bpm.

• Intubated and ventilated; dopamine started.
  – Blood pressure 100/50 mmHg.
  – Heart rate 110 bpm.
  – Saturation 92%, PEEP 10, FiO₂ 1.0.
  – ECG inconclusive due to LBBB.
- Patient receives morphine (total 10 mg).
- 80 mg furosemide - 800 ml urine / 2hrs.
- Blood pressure decreases again to 86/46 mmHg, heart rate 115 bpm.
- On Echo - CO seems low with poor contractility.
PiCCO parameters include:

- CO = 1.8 - 2.2 L/min
- ITBVi = 600 ml/m²
- SVV = 25 - 30%
- EVLWi = 15 ml/Kg
Q#5 What should be your therapeutic approach?

1. Give more volume
2. Start dobutamine
3. Give diuretics
4. Start noradrenaline

Please vote now!

BP = 86/46
HR = 115
CO = 2 L/min
ITBVi = 600 ml/m²
SVV = 25 - 30%
EVLWi = 15 ml/Kg
Graded fluid boluses of 250 ml crystalloids + 250 ml Hemacel
The following night ……

Patient is agitated, tachycardic, tachypneic, and has another hypoxemic episode…….
From a certain point and on, positive fluid balance was associated with increase in EVLW.
On the 4th day in the ICU following restrictive fluid regime

\[ \text{CO} = 4 - 5\text{ L/min} \]
\[ \text{ITBVi} = 670 - 800\text{ ml/m}^2 \]
\[ \text{EVLWi} = 10\text{ ml/Kg} \]

Patient was extubated and required non-invasive ventilation for a few additional hours.
Conclusions Case # 2

• Patient in pulmonary edema may still be fluid-responsive and respond favorably to fluid administration.

• The ability to measure and follow EVLW values is helpful in preventing pulmonary edema during fluid resuscitation.
The PAC was shown in many reports to be associated with a high positive fluid balance.

Polanczyk CA et al, JAMA 2001;286:309-314
Sandison AJP et al, Eur Soc Vasc Surg, 1999
Connors et al JAMA 1996

Patients managed with a RHC had an excess mortality of 24%.

This may be due to an ‘aggressive style of care’, but may also be due to the fact that the information provided by the PAC cannot alert about or prevent fluid overload with its associated consequences.

Small hemodynamic effect of typical rapid volume infusions in critically ill patients


The mean effects of 159 rapid volume infusions; average 390 ± 160 mL (median 500); crystalloid 2/3, colloid 1/3.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>MBP (mmHg)</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>CI (l/min/m²)</td>
<td>4.3</td>
<td>4.6</td>
</tr>
<tr>
<td>RAP (mmHg)</td>
<td>11.1</td>
<td>12.4</td>
</tr>
<tr>
<td>LVEDA (cm²/m²)</td>
<td>8.6</td>
<td>9.1</td>
</tr>
<tr>
<td>PAOP (mmHg)</td>
<td>12.9</td>
<td>14.7*</td>
</tr>
</tbody>
</table>
High tidal volume and positive fluid balance are associated with worse outcome in ALI


3,147 adult patients admitted to one of the participating ICUs between May 1, 2002, and May 15, 2002.

A multivariable logistic regression analysis with ICU outcome as the dependent factor showed that the independent risks for mortality include higher mean fluid balance.

CONCLUSIONS: In addition to comorbidities and organ dysfunction, high tidal volumes and positive fluid balance are associated with a worse outcome from ALI/ARDS.
Should EVLW be included in the definition of ALI / ARDS?
Both the Lung Injury Score and the PaO$_2$ /FiO$_2$ ratio as criteria of ARDS or ALI are still a source of constant debate, and better criteria should be sought for this purpose.

A PAOP$>18$ should not exclude ARDS

Ferguson ND et al, Intensive care Med 2002
EVLW in patients fulfilling the ALI / ARDS criteria defined by the American-European Consensus Conference

Measurement of pulmonary edema in patients with acute respiratory distress syndrome
Patroniti N, Bellani G, Maggioni E, Manfio A, Marcora B, Pesenti A
Crit Care Med 2005; 33:2547–2554

Measurements of lung edema by thermal indocyanine green-dye double-dilution method show good correlation with those by quantitative computed tomography and good reproducibility in patients with acute respiratory distress syndrome.

EVLWI values were found to be similar to the ones reported by other investigators in patients with ARDS. Some of our patients, although satisfying all the criteria for ARDS, had EVLWI values only slightly increased above normal.

For such patients, the suggested EVLWI threshold of 10 mL/kg for the diagnosis of ARDS appears too selective.
25% of ARDS patients had normal EVLW!!!

57% of non-ARDS patients had high EVLW!!!

Lower EVLW was associated with better survival.

EVLW may improve both risk stratification and management of patients with severe sepsis.
New criteria for ARDS

- Diffuse alveolar edema *(EVLW > 7 ml/kg)*
- Increased lung vascular permeability
- Diffuse Alveolar Damage pathologically

Effects of sustained post-traumatic shock and initial fluid resuscitation on EVLW in a porcine model of shock


Pulmonary vascular injury may occur within the first hour after the onset of shock.

These changes may not be accompanied by overt changes in oxygenation, compliance, or EVLWi.
Extravascular Lung Water in Early ARDS

EVLW was markedly elevated (13.5 ml/kg) in patients with early ARDS, was significantly higher in non-survivors and correlated with Vd/Vt.

Conclusions: Increased EVLW is a feature of early ARDS and correlates with Vd/Vt. A new index, the lung water-dead space product, appears to predict mortality better than either index alone.
Keep the lung dry--sense or nonsense?

Fluid management in ARDS: “Keep them dry” or does it matter?
Negative fluid balance, if tolerated hemodynamically, is associated with improved end-points, such as reduced EVLW, less ventilator days and possibly better outcome.

The β-Agonist Lung Injury Trial (BALTI)  
A Randomized Placebo-controlled Clinical Trial

Gavin D. Perkins, Daniel F. McAuley, David R. Thickett, and Fang Gao

Department of Intensive Care Medicine, Birmingham Heartlands Hospital; Division of Medical Sciences, University of Birmingham, Birmingham; and Department of Intensive Care Medicine, Queen’s University of Belfast, Belfast, United Kingdom


**Methods:** This was a single-center, double-blind, randomized controlled trial. Patients with ALI/ARDS were randomized to treatment with intravenous salbutamol (15 μg kg⁻¹ h⁻¹) or placebo for 7 d. The primary endpoint was extravascular lung water measured by thermodilution (PICCO) at Day 7.

**Conclusion:** Although further research is required to confirm the efficacy and safety of intravenous salbutamol in ALI/ARDS, this trial provides the first proof of principle that, in humans with ALI/ARDS, sustained treatment with intravenous β-agonists reduces extravascular lung water.
Quantifying pulmonary microvascular permeability impairment
EVLWI / ITBVI = “permeability” index

EVLWI / PBV = Pulmonary Vascular Permeability Index

[Graph showing EVLWI (ml/kg) vs. ITBVI (ml/m²) with normal range and increased permeability markers.]
Increased pulmonary capillary permeability and extravascular lung water after major vascular surgery: effect on radiography and ventilatory variables.


The EVLW was elevated in 5 of 16 patients, while the pulmonary leak index (PLI, radioactive technique) was elevated in 11 patients.

A supranormal EVLW was associated with a high PLI and higher EVLW / ITBV or EVLW / PBV.

<table>
<thead>
<tr>
<th>EVLW ≤ 7 mL kg⁻¹ (n = 11)</th>
<th>EVLW &gt; 7 mL kg⁻¹ (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVLW (mL kg⁻¹)</td>
<td>5.7 (2.5–6.5)</td>
</tr>
<tr>
<td>EVLW/ITBV (mL mL⁻¹)</td>
<td>0.22 (0.09–0.28)</td>
</tr>
<tr>
<td>EVLW/PBV (mL mL⁻¹)</td>
<td>1.1 (0.4–1.6)</td>
</tr>
<tr>
<td>PLI (10⁻³ min⁻¹)</td>
<td>14 (11–32)</td>
</tr>
</tbody>
</table>
P352 – Investigation of the pulmonary vascular permeability index and EVLW in patients with SIRS and ARDS under the PiCCO system.

T Tagami et al, (abstract ISICEM 2006).

In 41 patients PVPI was significantly higher in the SIRS than the NON SIRS group and higher in SIRS with ARDS than SIRS without ARDS.

Conclusion: PVPI may increase due to systemic inflammation and may represent subclinical lung injury which is undetectable by other bedside monitors or clinical examination.
Q#7 Following this session how do you rate the importance of bedside measurement of EVLW?

1. Very important
2. Moderately important
3. Unimportant

Please vote now!
Conclusions

- Easy and reliable bedside measurement of EVLW is now a practical reality.

- EVLW is an important element in the fluid management of the critically ill.

- EVLW may contribute to a better understanding, diagnosis and treatment of ARDS.

Thank you for your attention!

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