Estimating extravascular lung water

Thousands have lived without love, not one without water
W.H. Auden

John Granton MD FRCPC
Objectives…

So What?
Alveolar Fluid Clearance Is Impaired in the Majority of Patients with Acute Lung Injury and the Acute Respiratory Distress Syndrome

LORRAINE B. WARE and MICHAEL A. MATTHAY

Cardiovascular Research Institute and Departments of Medicine and Anesthesia, University of California, San Francisco, San Francisco, California

Am J Respir Crit Care Med, 2001;163:376
Resolution of Pulmonary Edema
Thirty Years of Progress

Michael A. Matthay
Departments of Medicine and Anesthesia and Cardiovascular Research Institute, University of California, San Francisco, San Francisco, California

Am J Respir Crit Care Med, 2014;189(11):1301
A Prospective Study of Lung Water Measurements during Patient Management in an Intensive Care Unit

Paul R. Eisenberg, J. R. Hansbrough, Dixie Anderson, and Daniel P. Schuster

Am Rev Resp Dis, 1987;136:662

Improved Outcome Based on Fluid Management in Critically Ill Patients Requiring Pulmonary Artery Catheterization

John P. Mitchell, Dan Schuller, Frank S. Calandrino, and Daniel P. Schuster

Am Rev Resp Dis, 1992;145:990
Comparison of Two Fluid-Management Strategies in Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*

N Engl J Med 2006;354
Randomized, Placebo-controlled Clinical Trial of an Aerosolized β2-Agonist for Treatment of Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network

Effect of intravenous β-2 agonist treatment on clinical outcomes in acute respiratory distress syndrome (BALTI-2): a multicentre, randomised controlled trial

Fang Gao Smith, Gavin D Perkins, Simon Gates, Duncan Young, Daniel F McAuley, William Tunnicliffe, Zahid Khan, Sarah E Lamb, for the BALTI-2 study investigators

Am J Respir Crit Care Med, 2011;184:561

Lancet, 2012;379:229
Fluid resuscitation in septic shock: A positive fluid balance and elevated central venous pressure are associated with increased mortality*

John H. Boyd, MD, FRCP(C); Jason Forbes, MD; Taka-aki Nakada, MD, PhD; Keith R. Walley, MD, FRCP(C); James A. Russell, MD, FRCP(C)
Fluid Related AcUte Organ Dysfunction
Objective 2

Wonderful toys...
Physical examination, central venous pressure, and chest radiography for the prediction of transpulmonary thermodilution–derived hemodynamic parameters in critically ill patients: A prospective trial

Bernd Saugel MD, Stephan Ringmaier MD, Konstantin Holzapfel MD, Tibor Schuster PhD, Veit Phillip MD, Roland M Schmid MD, Wolfgang Huber MD

Journal of Critical Care, 2011;26:402
Double Indicator

Fig. 3  Measurement of extravascular lung water by thermo-dye dilution (MTt mean transit time)

Extravascular lung water measurements and hemodynamic monitoring in the critically ill: bedside alternatives to the pulmonary artery catheter

Warren Isakow and Daniel P. Schuster
Department of Internal Medicine, Washington University School of Medicine, St. Louis, Missouri

Am J Physiol Lung Cell Mol Physiol, 2006; 291: L1118

Comparison Between Intrathoracic Blood Volume and Cardiac Filling Pressures in the Early Phase of Hemodynamic Instability of Patients With Sepsis or Septic Shock

Samir G. Sakka, Donald L. Bredle, Konrad Reinhart, and Andreas Meier-Hellmann

Journal of Critical Care, 1999;14(2):78
Transpulmonary Thermodilution Enables to Detect Small Short-Term Changes in Extravascular Lung Water Induced by a Bronchoalveolar Lavage

Martin Dres, MD1,2; Jean-Louis Teboul, MD, PhD1,2; Laurent Guerin, MD1,2; Nadia Anguel, MD1,2; Virginie Amilien, MD1,2; Marie-Philippine Clair, MD1,2; Aurélie Grüner, MD1,2; Christian Richard, MD1,2; Xavier Monnet, MD, PhD1,2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before BAL</th>
<th>Post-BAL</th>
<th>1 Hour After BAL</th>
<th>2 Hour After BAL</th>
<th>4 Hour After BAL</th>
<th>6 Hour After BAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>89±20</td>
<td>88±19</td>
<td>89±22</td>
<td>88±18</td>
<td>89±19</td>
<td>90±21</td>
</tr>
<tr>
<td>Systolic arterial pressure (mm Hg)</td>
<td>126±21</td>
<td>126±15</td>
<td>135±22</td>
<td>133±16</td>
<td>134±19</td>
<td>130±27</td>
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<tr>
<td>Diastolic arterial pressure (mm Hg)</td>
<td>57±11</td>
<td>56±10</td>
<td>60±10</td>
<td>59±10</td>
<td>60±10</td>
<td>58±8</td>
</tr>
<tr>
<td>Pulse oximetry saturation (%)</td>
<td>97±2</td>
<td>96±3a</td>
<td>97±2</td>
<td>97±3</td>
<td>97±3</td>
<td>97±2</td>
</tr>
<tr>
<td>Tidal volume (mL/kg of ideal body weight)</td>
<td>6.7±1.3</td>
<td>6.7±1.4</td>
<td>6.4±1.9</td>
<td>5.9±2.4</td>
<td>6.1±2.1</td>
<td>6.1±2.1</td>
</tr>
<tr>
<td>Positive end-expiratory pressure (cm H2O)</td>
<td>9±3</td>
<td>9±4</td>
<td>9±4</td>
<td>9±4</td>
<td>9±4</td>
<td>9±4</td>
</tr>
<tr>
<td>Respiratory rate (rate/min)</td>
<td>23±8</td>
<td>23±8</td>
<td>24±7</td>
<td>25±8</td>
<td>25±8</td>
<td>25±8</td>
</tr>
<tr>
<td>Cardiac index (L/min/m²)</td>
<td>3.9±1.2</td>
<td>4.0±1.1</td>
<td>3.9±1.0</td>
<td>3.9±1.1</td>
<td>4.0±1.2</td>
<td>4.0±1.1</td>
</tr>
<tr>
<td>Global end-diastolic volume (mL/m²)</td>
<td>805±137</td>
<td>818±162</td>
<td>833±131</td>
<td>830±150</td>
<td>836±161</td>
<td>857±182</td>
</tr>
<tr>
<td>Indexed extravascular lung water (mL/Kg of ideal body weight)</td>
<td>12.4</td>
<td>15.1a</td>
<td>14.6a</td>
<td>14.5a</td>
<td>14.5a</td>
<td>13.4a</td>
</tr>
</tbody>
</table>

Crit Care Med 2014; 42:1869
Validation of extravascular lung water measurement by single transpulmonary thermodilution: human autopsy study

Takashi Tagami*, Shigeki Kushimoto#, Yasuhiro Yamamoto§, Takahiro Atsumi¶, Ryoichi Tosa¶, Kiyoshi Matsuda†, Renpei Oyama§, Takanori Kawaguchi§, Tomohiko Masuno§, Hisao Hirama¶, Hiroyuki Yokota‡

Critical Care 2010, 14:R162
Potential pitfalls

Requires mathematic assumptions for 1 indicator model

Areas of hyoperfusion (PE, high PEEP)

Loss of lung
  
  Lung resection
  
  ? Heterogeneity

Temperature sinks
  
  Inflammatory cells
  
  Pleural Effusions
Point-of-care Ultrasonography for the Diagnosis of Acute Cardiogenic Pulmonary Edema in Patients Presenting With Acute Dyspnea: A Systematic Review and Meta-analysis

Mohammad Al Deeb, MD, FRCP, Skye Barbic, PhD, Robin Featherstone, MLIS, Jerrald Dankoff, MD, and David Barbic, MD, MSc, FRCP

Acad Emerg Med, 2014;21:844
Ultrasound of extravascular lung water: a new standard for pulmonary congestion

Eugenio Picano¹* and Patricia A. Pellikka²

EHJ, 2016; 37, 2097
Simplified lung ultrasound protocol shows excellent prediction of extravascular lung water in ventilated intensive care patients

Philipp Enghard, Sibylle Rademacher, Jens Nee, Dietrich Hasper, Ulrike Engert, Achim Jörres and Jan M Kruse

Critical Care (2015) 19:36
Ultrasound Assessment for Extravascular Lung Water in Patients Undergoing Hemodialysis*

Time Course for Resolution

Vicki E. Noble, MD, RDMS; Alice F. Murray, MBChB; Roberta Capp, MD; Mary H. Sylvia-Reardon, RN; David J. R. Steele, MD; and Andrew Liteplo, MD, RDMS
Lung Ultrasound-Implemented Diagnosis of Acute Decompensated Heart Failure in the ED
A SIMEU Multicenter Study

Emanuele Rivetta, MD; Alberto Goffi, MD; Enrico Lupia, MD, PhD; Maria Tizzani, MD; Giulio Porrino, MD; Enrico Ferreri, MD; Giovanni Volpicelli, MD, FCCP; Paolo Balzaretti, MD; Alessandra Banderali, MD; Antonello Jacobucci, MD; Stefania Locatelli, MD; Giovanna Casoli, MD; Michael B. Stone, MD; Milena M. Maule, PhD; Ileana Baldi, PhD; Franco Merletti, MD; and Gian Alfonso Cibinel, MD; for the SIMEU Group for Lung Ultrasound in the Emergency Department in Piedmont

<table>
<thead>
<tr>
<th>Clinical work-up</th>
<th>Area under curve (AUC) = 0.876</th>
<th>p &lt; 0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUS-implemented</td>
<td>0.972</td>
<td></td>
</tr>
<tr>
<td>LUS-alone</td>
<td>0.920</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Chest radiography</td>
<td>0.758</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>LUS-implemented</th>
<th>Area under curve (AUC) = 0.966</th>
<th>p &lt; 0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUS-alone</td>
<td>0.895</td>
<td></td>
</tr>
<tr>
<td>BNP/NT-pro-BNP</td>
<td>0.733</td>
<td></td>
</tr>
</tbody>
</table>
Potential relevance

Early detection
Improved diagnostic accuracy
Prognosis
Surrogate for trials (proof of concept)
Goal directed therapy / titration of therapy
Extravascular Lung Water and Pulmonary Vascular Permeability Index as Markers Predictive of Postoperative Acute Respiratory Distress Syndrome: A Prospective Cohort Investigation*

Daryl J. Kor, MD1; David O. Warner, MD1,2; Rickey E. Carter, PhD3; Laurie A. Meade, RN1; Greg A. Wilson, RRT4; Man Li, MD5; Marvin J. Hamersma, CVMT6; Rolf D. Hubmayr, MD1,4; William J. Mauermann, MD1; Ognjen Gajic, MD1,4

TABLE 4. Correlation of EVLW₁ and PVPI With Secondary Patient Outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Peak EVLW₁</th>
<th></th>
<th></th>
<th>Peak PVPI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Worst postoperative ratio of Pao₂ to Fio₂</td>
<td>-0.314</td>
<td>&lt; 0.001</td>
<td></td>
<td>-0.250</td>
<td>0.04</td>
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<tr>
<td>Duration of mechanical ventilation</td>
<td>0.357</td>
<td>&lt; 0.001</td>
<td></td>
<td>0.140</td>
<td>0.11</td>
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<tr>
<td>Duration of ICU stay</td>
<td>0.438</td>
<td>&lt; 0.001</td>
<td></td>
<td>0.149</td>
<td>0.09</td>
</tr>
<tr>
<td>Duration of hospital stay</td>
<td>0.186</td>
<td>0.01</td>
<td></td>
<td>0.114</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Crit Care Med 2015; 43:665
Comparison of the Berlin Definition for Acute Respiratory Distress Syndrome with Autopsy

Arnaud W. Thille¹, Andrés Esteban¹, Pilar Fernández-Segoviano², José-Maria Rodríguez², José-Antonio Aramburu², Oscar Peñuelas¹, Irene Cortés-Puch¹, Pablo Cardinal-Fernández¹, José A. Lorente¹, and Fernando Frutos-Vivar¹

Extravascular Lung Water is an Independent Prognostic Factor in Patients with Acute Respiratory Distress Syndrome*

Mathieu Jozwiak, MD; Serena Silva, MD; Romain Persichini, MD; Nadia Anguel, MD; David Osman, MD; Christian Richard, MD; Jean-Louis Téboul, MD, PhD; Xavier Monnet, MD, PhD

Measurement of extravascular lung water following human brain death: implications for lung donor assessment and transplantation

Rajamiyer V. Venkateswaran¹*, Vamsidhar Dronavalli¹, Val Patchell³, Ian Wilson⁴, Jorge Mascaro⁵, Richard Thompson⁴, John Coote⁴ and Robert S. Bonser⁴

Am J Respir Crit Care Med, 2013;187(7);761

Crit Care Med 2013; 41:472

America will never be destroyed from the outside. If we falter and lose our freedoms, it will be because we destroyed ourselves.

Abraham Lincoln