Pediatric Point of Care Lung Ultrasound: The Wave of the Future

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April 29, 2017
Canadian Respiratory Conference
Financial Interest Disclosure
(over the past 24 months)

Christopher Ewing

<table>
<thead>
<tr>
<th>Company</th>
<th>Speaker</th>
<th>Advisory</th>
<th>Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astra Zeneca</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

☐ I have no conflict of interest relevant to this presentation.
Objectives

• Review principles and physiology of lung ultrasound

• Demonstrate ultrasound findings in normal and diseased lung

• Review literature for clinical efficacy of ultrasound in bronchiolitis and pneumonia in children
Rationale for Lung Ultrasound (LUS)

• Bronchiolitis and pneumonia are primarily clinical diagnoses, but many children undergo one or more chest x-rays (CXR) during evaluation.

• Disadvantages of chest x-rays include patient and staff time, expense, patient transportation, and ionizing radiation exposure.
  • Areas of the world with highest pneumonia rate least likely to have access to CXR
  • Risk of cancer from radiation highest in infants and young children, those most susceptible to respiratory infection and most likely to have a chest x-ray.

• LUS can be performed at the bedside as an adjunct to physical exam to increase the clinician’s diagnostic accuracy and may reduce need for CXR.
6 zone scanning protocol (Copetti/Cattarossi)
- Anterior superior (1)
- Anterior basal (2)
- Lateral superior (3)
- Lateral basal (4)
- Posterior superior and basal (not shown)
Normal Lung

- Chest wall
- Pleural line
- Mirror effect
- A-line

Volpicelli. Praxis 2014
B-Lines

Volpicelli. Praxis 2014
Lung ultrasound in bronchiolitis: comparison with chest x-ray

- Compared accuracy of LUS and CXR in infants with bronchiolitis (AAP)
- 52 infants (median age 2m) with clinically driven CXR
  - LUS findings of bronchiolitis:
    - Subpleural lung consolidation
    - Compact B-lines (areas of white lung)
    - Irregular pleural line
    - Focal, multiple B-lines
- LUS suggestive of bronchiolitis in 47/52 (90%)
- CXR suggestive of bronchiolitis in 38/52 (73%)
- All patients with a normal LUS had normal CXR
- 9 patients with normal CXR had abnormal LUS
  - In these patients, clinical course was consistent with bronchiolitis

Caiulo et al, Eur J Pediatr 2011
Lung ultrasound in bronchiolitis: comparison with chest x-ray

Fig. 3  Comparison between the severity of bronchiolitis and imaging findings

Caiulo et al, Eur J Pediatr 2011
Lung ultrasound: a useful tool in diagnosis and management of bronchiolitis

- Observational cohort of 106 infants (median 71 days) admitted with AAP clinical diagnosis of bronchiolitis to evaluate accuracy of LUS and correlation with clinical severity

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Bronchiolitis ultrasound score</th>
</tr>
</thead>
<tbody>
<tr>
<td>US score</td>
<td>0</td>
</tr>
<tr>
<td>Anterolateral data</td>
<td></td>
</tr>
<tr>
<td>Normal lung sliding with horizontal artifacts (A-lines).</td>
<td>Diffuse and dishomogeneous interstitial syndrome with confluent, multiple B lines and spared areas.</td>
</tr>
<tr>
<td>Vertical artifacts (B-lines) in limited number or absent.</td>
<td></td>
</tr>
<tr>
<td>Paravertebral/posterior data</td>
<td></td>
</tr>
<tr>
<td>Interstitial syndrome</td>
<td>Individual B line or absent</td>
</tr>
<tr>
<td>Extension on interstitial syndrome</td>
<td>0-6 bilaterally involved intercostal spaces</td>
</tr>
<tr>
<td>Presence of subpleural lung consolidation</td>
<td>Absent</td>
</tr>
</tbody>
</table>

Basile et al, BMC Pediatrics 2015
Lung ultrasound: a useful tool in diagnosis and management of bronchiolitis

- Agreement between clinical and LUS severity = 90.6% \( (p=0.000) \)
- Inter-observer LUS diagnosis concordance = 89.6% \( (p=0.000) \)
- LUS identified infants needing supplementary oxygen \( (n=29) \)
  - Sensitivity 96.6%, specificity 98.7%, PPV 96.6%, NPV 98.7%

### Table 5

<table>
<thead>
<tr>
<th>LUS data</th>
<th>Mild</th>
<th>Moderate</th>
<th>( \chi^2 ) test</th>
<th>( p )</th>
<th>Oxygen No</th>
<th>Oxygen Yes</th>
<th>( \chi^2 ) test</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No presence of subpleural lung consolidations in the posterior and paravertebral area of the lung</td>
<td>53/76</td>
<td>5/30</td>
<td>24.4</td>
<td>0.00</td>
<td>53/77</td>
<td>5/29</td>
<td>22.6</td>
<td>0.00</td>
</tr>
<tr>
<td>(70 %)</td>
<td>(17 %)</td>
<td></td>
<td></td>
<td></td>
<td>(69 %)</td>
<td>(18 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcentimetersubpleural lung consolidations in the posterior and paravertebral area of the lung</td>
<td>20/76</td>
<td>12/30</td>
<td>1.9</td>
<td>0.16</td>
<td>20/77</td>
<td>12/29</td>
<td>2.3</td>
<td>0.1</td>
</tr>
<tr>
<td>(26 %)</td>
<td>(40 %)</td>
<td></td>
<td></td>
<td></td>
<td>(26 %)</td>
<td>(41 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subpleural lung consolidation of 1 cm or more in the posterior and paravertebral area of the lung</td>
<td>3/76</td>
<td>13/30</td>
<td>26.4</td>
<td>0.00</td>
<td>4/77</td>
<td>12/29</td>
<td>21.5</td>
<td>0.00</td>
</tr>
<tr>
<td>(4 %)</td>
<td>(43 %)</td>
<td></td>
<td></td>
<td></td>
<td>(5 %)</td>
<td>(41 %)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Basile et al, BMC Pediatrics 2015
Point-of-care lung ultrasound in young children with respiratory tract infections and wheeze. Terry Varshney, Elise Mok, Adam J Shapiro, Patricia Li, Alexander S Dubrovsky

- Prospective cross-sectional study in children ≤ 2y with respiratory infection and wheeze to characterize LUS findings, accuracy, and agreement between novice (peds ED fellow) and expert (radiologist)
- Clinical diagnosis used as reference standard
- Positive LUS findings:
  - 3 or more B-lines per intercostal space
  - Consolidation
  - Pleural abnormalities
- Diagnoses of interest:
  - Bronchiolitis
  - Pneumonia
  - Asthma
  - Concomitant asthma and pneumonia
Point-of-care lung ultrasound in young children with respiratory tract infections and wheeze. Terry Varshney, Elise Mok, Adam J Shapiro, Patricia Li, Alexander S Dubrovsky

Median age 11.1 months

Patients N=94

Positive ultrasound N=39

- Bronchiolitis N=33
- Pneumonia N=4
- Asthma N=0
- Asthma + Pneumonia N=2

42% accuracy

46% accuracy
46% sens / 73% spec

100% accuracy
100% sens / 61% spec

0% accuracy
0% sens / 51% spec

50% accuracy
50% sens / 59% spec

Negative ultrasound N=55

- Bronchiolitis N=39
- Pneumonia N=0
- Asthma N=14
- Asthma + Pneumonia N=2

Admitted: 67% accuracy (4/6)
Required CXR: 54% accuracy (14/26)

Ultrasound diagnosis of pneumonia in children

• Prospective study comparing accuracy of LUS and CXR for pneumonia
  • Ultrasound findings of pneumonia:
    • Hypoechogenic area with poorly defined borders
    • Compact B-lines adjacent to consolidation
    • Reduced echogenicity of pleural line and absent sliding
    • Air bronchograms
    • Pleural effusion

• 60/79 patients (mean age 5y) had pneumonia; in 19 other infection source

Table 1 Summary of patients with suspected pneumonia, ultrasound and chest X-ray findings

<table>
<thead>
<tr>
<th>Suspected pneumonia (n=79)</th>
<th>CXR +</th>
<th>CXR –</th>
<th>US +</th>
<th>CXR – / US –</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>53</td>
<td>7</td>
<td>60</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>4 CT +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 DC +</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CXR, chest X-ray; US, ultrasound; +, positive; –, negative; CT, computed tomography; DC, clinical course

Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis

- Meta-analysis including 8 studies for LUS in pediatric pneumonia

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Origin</th>
<th>Design</th>
<th>Sample size</th>
<th>Age (Mean ± SD), y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reali et al\textsuperscript{21}</td>
<td>2014</td>
<td>Italy</td>
<td>Prospective</td>
<td>107</td>
<td>4 ± 3</td>
</tr>
<tr>
<td>Liu et al\textsuperscript{22}</td>
<td>2014</td>
<td>China</td>
<td>Prospective</td>
<td>80</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>Esposito et al\textsuperscript{14}</td>
<td>2014</td>
<td>Italy</td>
<td>Prospective</td>
<td>103</td>
<td>5.6 ± 4.6</td>
</tr>
<tr>
<td>Shah et al\textsuperscript{15}</td>
<td>2013</td>
<td>USA</td>
<td>Prospective</td>
<td>191</td>
<td>2.9 ± 6.2</td>
</tr>
<tr>
<td>Caiulo et al\textsuperscript{23}</td>
<td>2013</td>
<td>Italy</td>
<td>Prospective</td>
<td>102</td>
<td>5 ± 3</td>
</tr>
<tr>
<td>Seif El Dien et al\textsuperscript{24}</td>
<td>2013</td>
<td>Egypt</td>
<td>Prospective</td>
<td>95</td>
<td>0.03 ± 0.02</td>
</tr>
<tr>
<td>Iuri et al\textsuperscript{16}</td>
<td>2009</td>
<td>Italy</td>
<td>Prospective</td>
<td>28</td>
<td>4.5 ± 4.9</td>
</tr>
<tr>
<td>Copetti and Cattarossi\textsuperscript{13}</td>
<td>2008</td>
<td>Italy</td>
<td>Prospective</td>
<td>79</td>
<td>5.1 ± 5</td>
</tr>
</tbody>
</table>

n=765  Mean age 5y

Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis

- Meta-analysis including 8 studies for LUS in pediatric pneumonia

**TABLE 3** Chest Imaging and Diagnostic Criteria of Selected Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Imaging</th>
<th>Pneumonia Diagnosis</th>
<th>Patient Type</th>
<th>Inclusion Criteria</th>
<th>LUS Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reali et al(^{21})</td>
<td>CR</td>
<td>Clinical diagnosis + CR + blood results</td>
<td>Hospitalized</td>
<td>Pneumonia signs and symptoms</td>
<td>Pulmonologists and trained residents</td>
</tr>
<tr>
<td>Liu et al(^{22})</td>
<td>CR</td>
<td>Clinical diagnosis + CR + blood results</td>
<td>Critically ill</td>
<td>Pneumonia signs and symptoms, laboratory results</td>
<td>Experienced physician</td>
</tr>
<tr>
<td>Esposito et al(^{14})</td>
<td>CR</td>
<td>CR</td>
<td>Hospitalized</td>
<td>Pneumonia signs and symptoms</td>
<td>Trained pediatric resident</td>
</tr>
<tr>
<td>Shah et al(^{15})</td>
<td>CR</td>
<td>CR</td>
<td>Presented to emergency department</td>
<td>Clinical suspicion of community-acquired pneumonia requiring CR</td>
<td>Fifteen pediatric emergency physicians with different degrees of expertise</td>
</tr>
<tr>
<td>Caiulo et al(^{23})</td>
<td>CR</td>
<td>Clinical diagnosis + CR</td>
<td>Hospitalized</td>
<td>Pneumonia signs and symptoms</td>
<td>Experienced physician</td>
</tr>
<tr>
<td>Seif El Dien et al(^{24})</td>
<td>CR</td>
<td>Clinical diagnosis + CR + blood results</td>
<td>Critically ill</td>
<td>Pneumonia signs and symptoms</td>
<td>Experienced physician</td>
</tr>
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<td>Iuri et al(^{16})</td>
<td>CR</td>
<td>CR</td>
<td>Presented to emergency department</td>
<td>Pneumonia signs and symptoms</td>
<td>Experienced physician</td>
</tr>
<tr>
<td>Copetti and Gattarossi(^{13})</td>
<td>CR</td>
<td>Clinical diagnosis + CR</td>
<td>Presented to emergency department</td>
<td>Pneumonia signs and symptoms</td>
<td>Emergency physician</td>
</tr>
</tbody>
</table>
Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis

Sensitivity
96%
95% CI 94-97

Specificity
93%
95% CI 90-95.7

Negative LR
0.06
95% CI 0.03-0.11

Positive LR
15.3
95% CI 6.6-35.3

Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis

Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis

**CXR diagnosis alone** (3 studies)
- Sensitivity 96% (94-98)
- Specificity 84% (80-88)

**Pediatric subgroup** (6 studies)
- Sensitivity 96% (93-98)
- Specificity 92% (88-95)

**Neonatal subgroup** (2 studies)
- Sensitivity 96% (90-98.5)
- Specificity 100% (92-100)

**ED subgroup** (3 studies)
- Sensitivity 94% (88-98)
- Specificity 90% (85-94)

**Experienced sonographer** (4 studies)
- Sensitivity 97% (93-99)
- Specificity 99% (94-100)

**Novice sonographer** (4 studies)
- Sensitivity 95% (91-97)
- Specificity 91% (87-95)
Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: A randomized controlled trial

TABLE 1] Baseline Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Investigational Group (n = 103)</th>
<th>Control Group (n = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, median, y^a</td>
<td>3 (1.6, 6.0)</td>
<td>3 (1.7, 5.7)</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>49.5 (51)</td>
<td>55.7 (49)</td>
</tr>
<tr>
<td>Tachypnea for age</td>
<td>26.2 (27)</td>
<td>28.4 (25)</td>
</tr>
<tr>
<td>Fever at triage ≥ 38^oC</td>
<td>46.6 (48)</td>
<td>46.6 (41)</td>
</tr>
<tr>
<td>Cough</td>
<td>98.1 (101)</td>
<td>97.7 (86)</td>
</tr>
<tr>
<td>Difficulty breathing</td>
<td>54.4 (56)</td>
<td>54.5 (48)</td>
</tr>
<tr>
<td>Chest pain</td>
<td>16.5 (17)</td>
<td>11.4 (10)</td>
</tr>
<tr>
<td>Abdominal pain</td>
<td>11.7 (12)</td>
<td>11.4 (10)</td>
</tr>
<tr>
<td>History of fever</td>
<td>84.5 (87)</td>
<td>85.2 (75)</td>
</tr>
<tr>
<td>Pneumonia +</td>
<td>13.6% (14)</td>
<td>13.6% (12)</td>
</tr>
</tbody>
</table>
Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: A randomized controlled trial

- 38.8% reduction in CXR use in LUS arm (NNT = 2.5 to prevent 1 CXR)

- 30% reduction for novice sonologist; 60.6% reduction for experienced
  - Agreement = 0.81 (0.71-0.9) between novice and radiologist reviewing all scans

- 47.9% reduction in children ≤ 2y; 30.9% reduction in children > 2y

- Excluding CXR performed at request of admitting service (n=16), referring primary care physician (n=6), or parent/guardian (n=7), showed a potential maximum reduction in CXR of 67% (NNT = 1.5)
  - No changes in treatment or missed pneumonia resulted with these CXR

### TABLE 2  Secondary Outcomes

<table>
<thead>
<tr>
<th>Secondary Outcome Measure</th>
<th>Investigational Group (n = 103)</th>
<th>Control Group (n = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missed pneumonia</td>
<td>0.0 (0.0-2.9)</td>
<td>0.0 (0.0-3.0)</td>
</tr>
<tr>
<td>Unscheduled health-care visits</td>
<td>8.7 (3.3-14.1)</td>
<td>11.4 (4.8-18.0)</td>
</tr>
<tr>
<td>Antibiotic use at index ED visit</td>
<td>37.9 (28.5-47.2)</td>
<td>27.3 (17.9-36.6)</td>
</tr>
<tr>
<td>LUS or CXR confirmed pneumonia</td>
<td>28.2 (20.0-36.9)</td>
<td>18.1 (10.1-26.1)</td>
</tr>
<tr>
<td>CXR positive for pneumonia</td>
<td>13.6 (6.9-20.2)</td>
<td>13.6 (6.4-20.8)</td>
</tr>
<tr>
<td>LUS positive for pneumonia (≤ 1 cm)</td>
<td>14.6 (7.8-21.4)</td>
<td>4.5 (0.2-8.8)</td>
</tr>
<tr>
<td>Median EDLOS overall, a min</td>
<td>153 (120, 252)</td>
<td>180 (139, 241)</td>
</tr>
<tr>
<td>Median EDLOS (LUS only vs control), a min</td>
<td>LUS only (n = 40) 132 (103, 138)</td>
<td>180 (139, 241)</td>
</tr>
<tr>
<td>Median EDLOS (LUS only vs LUS and CXR), a min</td>
<td>LUS only (n = 40) 132 (103, 138)</td>
<td>LUS and CXR (n = 63) 190 (129, 272)</td>
</tr>
<tr>
<td>Admission rate</td>
<td>19.4 (11.8-27.0)</td>
<td>17.0 (9.2-24.8)</td>
</tr>
</tbody>
</table>

Data are presented as % (95% CI) unless indicated otherwise. All $P > .05$ except LUS only vs control EDLOS. CXR = chest radiography; EDLOS = ED length of stay; LUS = lung ultrasonography.

aData are presented as the median (interquartile range).
Conclusion/Questions

• Lung ultrasound artifacts become distorted in typical ways when the air/fluid balance of the lung is altered, which can be interpreted as specific lung diseases.

• Both bronchiolitis and pneumonia are diagnosed with high sensitivity and specificity when clinically severe enough to require chest x-ray or hospital admission.

• Novice sonographers are able to perform near to that of experienced operators, and LUS is a basic sonographic skill that is easy to learn, and fast to perform at the bedside without causing radiation exposure.
Other Diagnostic Uses

• Transient tachypnea of the newborn – Copetti et al, Neonatology 2007
• Respiratory distress syndrome – Copetti et al, Neonatology 2008
• Pneumothorax – Alrajhi et al, Chest 2012
• Bronchopulmonary dysplasia – Liu et al, Medicine 2014
• Meconium aspiration – Piastra, et al. Early Hum Develop 2014
• Predicts failure of NIV in neonates – Raimondi et al, Pediatrics 2014
• PJP and pulmonary lymphoma in HIV – Heuvelings et al, Infection 2016