US imaging of the diaphragm

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• No disclosures
• But...
M-mode sonography of diaphragmatic motion: description of technique and experience in 278 pediatric patients
Background

• Why is this important?
Why is this important?

Diaphragm ➔ most important muscle of respiration

Contraction of the diaphragm has the following effects:

- Decreases intrapleural pressure
- “inflates” the rib cage using the abdomen as a fulcrum on which to lean
- Expands the rib cage by generating positive intraabdominal pressure
Despite “misleading” benign presentation → high morbidity → 4 main consequences:

**Analogy with obstructive sleep apnea**

- **Sleep fragmentation**
  - Daytime sleepiness
  - Hyperactivity
  - Aggressive behaviour
  - Inverse correlations between memory and learning performance and the severity of OSA

- **Increased work of breathing**
  - Major cardiovascular consequence in adults → Arterial Hypertension → heightened sympathetic tone and enhanced sympathetic discharge
  - Children → FTT

- **Alveolar hypoventilation**
  - Hypercapnia, particularly while asleep

- **Intermittent hypoxemia**
  - ↑pulmonary vasoconstriction
  - ↑pulmonary artery Pressure
  - Pulmonary HTN
  - Cor pulmonare
Pathophysiology - complications

- Desaturations
- Hypercapnia with pulmonary hypertension
- Systemic hypertension
- Arrhythmiases
Pathophysiology

- Infants are more severely affected than older children and adults with ↑morbidity (more vulnerable to resp failure):
  - Diaphragmatic contraction is less efficient in infants
  - Horizontal orientation of the ribs and greater compliance of the rib cage
  - Accessory muscles of respiration (intercostals) → poorly developed and adequate ventilation is almost totally dependent on diaphragmatic function
  - Increased mediastinal mobility
  - Paralyzed diaphragm → ascends into the thorax → reduction of vital capacity especially in the recumbent position
  - Small caliber of the bronchial tree → easier to become occluded
Clinical conditions suspicious for diaphragmatic dysfunction:

- Unexplained difficulties in weaning a patient from mechanical ventilation
- Persistent elevated hemidiaphragm on chest radiographs
- Unexplained respiratory distress or dependence on oxygen supplementation
- Signs of respiratory distress
- Asymmetric breathing pattern
- Paradoxical movement of the epigastrium
- Recurrent pneumonia
- Recurrent unilateral lung collapse
- Tachypnea / polypnea
<table>
<thead>
<tr>
<th>Conditions/indications for diaphragmatic evaluation in 278 pts</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac surgery</td>
<td>133</td>
</tr>
<tr>
<td>Heart transplant</td>
<td>12</td>
</tr>
<tr>
<td>Chest surgery</td>
<td>8</td>
</tr>
<tr>
<td>Lung transplant</td>
<td>4</td>
</tr>
<tr>
<td>Brachial plexus injury</td>
<td>78</td>
</tr>
<tr>
<td>Abnormality on CXR</td>
<td>12</td>
</tr>
<tr>
<td>Abdominal surgery</td>
<td>7</td>
</tr>
<tr>
<td>Neurological disease</td>
<td>4</td>
</tr>
<tr>
<td>Myopathy</td>
<td>2</td>
</tr>
<tr>
<td>Trauma</td>
<td>2</td>
</tr>
<tr>
<td>Spinal surgery</td>
<td>1</td>
</tr>
<tr>
<td>Neck surgery</td>
<td>1</td>
</tr>
</tbody>
</table>

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Diagnosis

- CXR $\rightarrow$ non-specific $\rightarrow$ may or may not show elevation of hemidiaphragm

<table>
<thead>
<tr>
<th></th>
<th>Abnormal M-US</th>
<th>Normal M-US</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal chest radiograph</td>
<td>62 (true positive)</td>
<td>11 (false positive)</td>
<td>73</td>
</tr>
<tr>
<td>Normal chest radiograph</td>
<td>118 (false negative)</td>
<td>69 (true negative)</td>
<td>187</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>180</td>
<td>80</td>
<td>260</td>
</tr>
</tbody>
</table>
10 y.o. F with fever and cough on ventilator
2 weeks old
Post EA/TEF repair
Diagnosis

- Fluoroscopy → “gold standard”
  - May show conflicting results 😞
  - Radiation exposure 😞
  - Need to transport patient to fluoroscopy unit 😞
  - Need of an assistant to observe the phases of respiration 😞
  - Visualization least mobile anterior third of diaphragm on A-P view 😞
  - Potential misinterpretation if paralysis is bilateral 😞
6 y.o. post surgery for Chiari I and a small syrinx, difficult intubation/extubation, history of LT brachial plexus injury
Assessment of VC in sitting and supine positions 😞

Real time US “alone”:
- Direct assessment, +/- “sniff” test 😞
- Indirect assessment:
  - Measurement of renal excursion 😞
  - Measurement of cranio-caudal displacement of the left branches of the portal vein 😞
Purpose

• To describe our experience with M-US for the assessment and quantitative evaluation of diaphragmatic motion in a large series of children

• To describe the sonographic technique
Materials & methods

- Retrospective analysis
- 371 exams - 742 hemidiaphragms
  - 278 consecutive patients
- 3 days old–17 years old
  - mean age: 1 y 10m
- September 1999-December 2003
Technique

• Initial conventional B-mode US:
  – Evaluation of upper quadrants and lower chest in longitudinal and transverse planes
  – Midline transverse subxyphoid plane
Technique

• M-mode US:
  – Interrogation of each hemidiaphragm in the longitudinal plane
  – Recording of at least 4 respiratory cycles during spontaneous respiration
  – If patient is mechanically ventilated \(\rightarrow\) temporary disconnection & recordings in both situations

Technique

• **Normal excursion:**
  – Diaphragmatic motion towards the transducer on inspiration
  – Excursion exceeds 4-5mm
  – Difference of excursion between hemidiaphragms less than 50%

• **Decreased excursion**

• **Paradoxical motion**

• **Absent motion**
### Table 2—Right Diaphragmatic Excursions and Limit Values in Men and Women*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men, cm</th>
<th>Women, cm</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet breathing</td>
<td>$1.8 \pm 0.3$ (1.1–2.5)</td>
<td>$1.6 \pm 0.3$ (1–2.2)</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>Voluntary sniffing</td>
<td>$2.9 \pm 0.6$ (1.8–4.4)</td>
<td>$2.6 \pm 0.5$ (1.6–3.6)</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>Deep breathing</td>
<td>$7 \pm 1.1$ (4.7–9.2)</td>
<td>$5.7 \pm 1$ (3.6–7.7)</td>
<td>$&lt; 0.001$</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD (5th to 95th percentile).

### Table 3—Left Diaphragmatic Excursions and Limit Values in Men and Women*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men, cm</th>
<th>Women, cm</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet breathing</td>
<td>$1.8 \pm 0.4$ (1–2.6)</td>
<td>$1.6 \pm 0.4$ (0.9–2.4)</td>
<td>$0.002$</td>
</tr>
<tr>
<td>Voluntary sniffing</td>
<td>$3.1 \pm 0.6$ (1.9–4.3)</td>
<td>$2.7 \pm 0.5$ (1.7–3.7)</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>Deep breathing</td>
<td>$7.5 \pm 0.9$ (5.6–9.3)</td>
<td>$6.4 \pm 1$ (4.3–8.4)</td>
<td>$&lt; 0.01$</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD (5th to 95th percentile).

## Technique

<table>
<thead>
<tr>
<th>Age</th>
<th>1-14 months</th>
<th>2.5 – 5 years</th>
<th>7-10 years</th>
<th>12-15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right (mm)</td>
<td>6.4 (+/- 2.1)</td>
<td>10 (+/- 2.3)</td>
<td>11.6 (+/- 2.7)</td>
<td>13.1 (+/- 2.5)</td>
</tr>
<tr>
<td>Left (mm)</td>
<td>6.6 (+/- 1.7)</td>
<td>9.5 (+/-2)</td>
<td>10.6 (+/- 2.6)</td>
<td>11.9 (+/- 2.2)</td>
</tr>
</tbody>
</table>

400 healthy volunteers

How to measure?

LONG RT

Dist = 1.14cm
ΔT = 0.158s
ΔT→ = 379bpm
Slope = 7.20cm/s

Cal = 5mm

LONG RT

Dist = 1.37cm
ΔT = 0.467s
ΔT→ = 128bpm
Slope = 2.93cm/s

Cal = 5mm
13 y.o. M with a history of transverse myelitis and quadriplegia
13 y.o. M with a history of transverse myelitis and quadriplegia
4 days later

3 months later

3 month old post Glenn shunt
Addition of M-US:

- Allows precise measurement of absolute distance of diaphragmatic displacement
- Permits continuous recording of diaphragm displacements, with measurements of:
  - Amplitude
  - Duration
  - Velocity
- Allows quantification of motion → more “objective” evaluation
- Better for comparison with contralateral hemidiaphragm
- Particularly helpful in tachypnea
- More helpful for comparison on F/U studies
Thank you for your attention!

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