**Muscle Ultrasound**

**Diaphragm**

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**Study of Diaphragm**

- Chest XR  
- Fluoroscopic sniff test of Hitzenburger  
- Computed Tomography  
- Dynamic Magnetic Resonance Imaging  
- Pulmonary Function testing / Spirometry  
- EMG / NCS

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**ANATOMY**

**Diaphragm**

- 4 components  
  - the transverse septum (anterior and becomes the central tendon of the diaphragm)  
  - pleuroperitoneal folds  
  - esophageal mesentery  
  - muscular body wall laterally
Respiratory Mechanics

Inspired volume generation during intercostal stimulation alone, diaphragm stimulation alone and combined intercostal and diaphragm stimulation in an animal model. Volumes generated during combined stimulation were equal to those generated by the sum of intercostal and diaphragm stimulation alone.


ULTRASOUND OF THE DIAPHRAGM

Neuromuscular ultrasound

- Non-invasive
- Radiation-free
- Relatively inexpensive
- Readily accessible in intensive care units
- Provides high-resolution images of muscle movement, thickness and echogenicity

Neuromuscular ultrasound

Advantage

- Ultrasound focuses mainly on the posterior and lateral parts of the diaphragm, which are the muscular crural components innervated by the phrenic nerve, rather than the anterior central tendon seen in fluoroscopy, which moves 40% less with respiration.

Diaphragm Ultrasound

- 1969 – Diaphragm (Cohen)
- 1989 – Diaphragm thickness (Wait)
- 1997 – Validated thickness with autopsy (Cohn)
- 2011 – Excursion in ICU patients (Kim)
- 2012 – Validated thickness in healthy (Boone)

Diaphragm Ultrasound

- Probes
- Mode B and M
- Image Acquisition and Analysis
  - Techniques
  - Measurements


PROBES

Probe

- Low frequency probe
  - 1-3 MHz
  - Greater depth
  - Less spatial resolution
  - Excursion
- High frequency probe
  - 5-18MHz
  - Superficial range
  - Great spatial resolution
  - Thickness

Modes

- B mode
  - real-time imaging
- M mode
  - a single beam of a B-Mode image on the y axis as it changes over time on the x axis

TECHNIQUE AND MEASUREMENT

Image Acquisition and Analysis

Patient position

- Spontaneous respiration to help identify the moving diaphragm
  - deep breathing or sniff maneuver
- Supine position
  - less overall variability
  - less side-to-side variability
  - greater reproducibility
  - excursion is known to be greater in the supine position for the same volume inspired than in the sitting or standing positions
  - relationship between inspired volume and diaphragm movement has been shown to correlate better in the supine than the sitting position

Windows

- Liver window – right diaphragm
- Spleen windows – left diaphragm
  - Difficult to visualize
- Pleural effusion, hepatomegaly, splenomegaly make it easier to visualize
Axillary/Intercostal approach

- High frequency transducer 7-18 MHz
- Anterior axillary line
- Sagittal image at the intercostal space between the 7th/8th, 8th/9th ribs
- Visualization of both the pleural and peritoneal membranes at all times while imaging the diaphragm for thickness measurements.
- Zone of apposition

Mobile normal diaphragm B mode video

Pathology

- Average thickness of the diaphragm
  - 0.22–0.28 cm in healthy volunteers
  - 0.13–0.19 cm in a paralyzed diaphragm
- Thickness <0.2 cm, measured at the end of expiration, has been proposed as the cutoff to define diaphragm atrophy
- Define the intercostal space where the thickness of the diaphragm

Thickness

- Mobile normal diaphragm B mode video
- Pathology

Change in Thickness

- A chronically paralyzed diaphragm is thin, atrophic, and does not thicken during inspiration
  
  $T_{\text{end-inspiration}} - T_{\text{end-expiration}}$

- Diaphragm thickening <20% is proposed to be consistent with paralysis

Normative Values in Healthy

- Diaphragm thickness and the change in thickness that occurs with maximal inspiration in 150 normal subjects
  - Minimal normal diaphragm thickness end expiration or FRC is 0.15 cm
  - An increase of at least 20% in diaphragm thickness from FRC to TLC is normal.
  - A side to side difference in thickness at end expiration of > 0.33 cm is abnormal.
  - Diaphragm thickness and contractility are minimally affected by age, gender, body habitus, or smoking history.

- Arora and Rochester showed that diaphragm thickness correlates with muscularity and nutritional state. Diaphragm muscle mass was 43% lower in patients who were underweight.

Echodensity

<table>
<thead>
<tr>
<th>Thickness of diaphragm (mm)</th>
<th>Echodensity on Gray Scale analysis in Image J</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
</tr>
<tr>
<td>Wild Type (WT)</td>
<td>3.69</td>
</tr>
<tr>
<td>X-linked Myotubular Myopathy (XLMTM)</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>XLMTM after experimental gene therapy (XLMTM-Tx)</td>
<td>3.5 mm</td>
</tr>
</tbody>
</table>

Pathology

Healthy diaphragm. Ultrasound of diaphragm with gray scale echogenicity analysis at the end of inspiration in a healthy beagle.

Beagle affected by Myotubular Myopathy. Ultrasound of diaphragm with gray scale echogenicity analysis in a beagle known to have myopathy including the respiratory muscle confirmed by respiratory kinematics.

Beagle affected by Myotubular atrophy but given experimental therapy. B mode ultrasound of diaphragm with gray scale echogenicity analysis in a beagle known to have myopathy including the respiratory muscle confirmed by respiratory kinematics but infused with experimental therapy to restore muscle strength.

Guided EMG


Guided EMG-Video

Anterior Subcostal approach

Mobile normal diaphragm M mode video

Excursion

- Lower frequency, ideally curvilinear, transducer (2 to 6 MHz)
- Anterior subcostal region
- Transducer is directed medially, cranially, and dorsally, so that the ultrasound beam reaches the posterior third of the right diaphragm approximately 5 cm lateral to the inferior vena cava foramen
- B mode to visualize, M mode to measure

Excursion

- Normal range of motion from the resting expiratory position to full inspiration in adults
  - 1.9 to 9 cm
  - Higher values reported in deep breathing or sniff
- Excursion >2.5 cm in adults cut off for excluding severe diaphragm dysfunction
- Diaphragmatic Inspiratory amplitude <2.41 cm correlates with a 50% decrease of vital capacity from the baseline.
Excursion

• The range of motion of the diaphragm
  – greater posteriorly than anteriorly
  – greater laterally than medially
• Normal range of side-to-side variability as defined by the right-to-left ratio of maximal excursion
  – 0.5 to 2.5 in quiet
  – 0.5 to 1.6 during deep breathing
• Normal difference in excursion between the hemi-diaphragms should be < 50%.

Movements with breathing

M-mode tracing shows
(1) normal quiet breathing
(2) normal sniffing
(3) normal deep breathing

Paradoxical motion

Side to side comparison

Paralysis

Normal diaphragm movement showing the diaphragm moving closer to the transducer with inspiration

Lack of movement of the diaphragm during deep breathing

Posterior Subcostal approach
Clinical applications

- Identification of Diaphragm Paralysis
- Tease etiology coupled with phrenic nerve stimulation
- Prognosis after Diaphragm Paralysis
  - an increase in thickness of the diaphragm during inspiration, which probably correlates with reinnervation, has been associated with improvement in inspiratory function
- Selecting patients for Surgical Plication
  - Plication is reserved for patients who have paradoxical motion, where mediastinal shifts cause dyspnea
- Adjusting Diaphragmatic Pacemakers
- Understanding Respiratory Dysfunction after Acute Stroke
- Guidance for Needle EMG

Diaphragm USG in ICU-thickness

- 7 intubated patients receiving MV during acute care were included.
- Using sonography, diaphragm muscle thickness was measured daily from the day of intubation until the patient underwent extubation or tracheostomy or died
- Rate of decrease in the diaphragm thickness of all seven patients over time averaged 6% per day of MV,

Diaphragm USG in ICU-excision

- 88 consecutive patients in the medical intensive care unit who required mechanical ventilation over 48 hrs and met the criteria for a spontaneous breathing trial
- Dysfunction was diagnosed if an excursion was < 10 mm or paradoxical
- Prevalence of ultrasonographic diaphragmatic dysfunction among the eligible 82 patients was 29%
  - longer weaning time, total ventilation time, weaning failure

Diaphragm USG in ICU-echodensity

- 16 individuals (9 women and 7 men) mean age of 59.3 years and mean BMI of 30.0
- 3 measurements over 14 days
- Significant increase in the mean grayscale value (tibialis anterior only), indicating increased muscle echogenicity
- A decrease in the grayscale standard deviation, indicating that the muscle is more homogeneous
- Similar muscle echotexture changes have been reported in muscular dystrophies and chronic inflammatory myopathies
- Subcutaneous tissue over the diaphragm and rectus femoris increased in thickness during hospitalization

Muscle and Subcutaneous (Sc) Tissue Measurements During Hospitalization

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Day 0</th>
<th>Day 3</th>
<th>Day 7</th>
<th>Day 14</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis Anterior</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>2.14</td>
<td>2.25</td>
<td>2.33</td>
<td>2.40</td>
<td>0.423</td>
</tr>
<tr>
<td>Grayscale Mean</td>
<td>138.29</td>
<td>132.80</td>
<td>143.89</td>
<td>166.39</td>
<td>0.027 *</td>
</tr>
<tr>
<td>Grayscale SD</td>
<td>33.87</td>
<td>31.90</td>
<td>31.50</td>
<td>28.01</td>
<td>0.001 *</td>
</tr>
<tr>
<td>SQ tissue thickness</td>
<td>0.46</td>
<td>0.40</td>
<td>0.48</td>
<td>0.46</td>
<td>0.116</td>
</tr>
<tr>
<td>Diaphragm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>0.33</td>
<td>0.26</td>
<td>0.28</td>
<td>0.34</td>
<td>0.392</td>
</tr>
<tr>
<td>SQ tissue thickness</td>
<td>0.88</td>
<td>0.81</td>
<td>0.97</td>
<td>1.03</td>
<td>0.024 *</td>
</tr>
</tbody>
</table>

Thanks !!!!