CHEST ULTRASOUND:
PULMONARY EDEMA

Bill Beninati, MD
Intermountain Healthcare
Normal findings

- **Pleural Line**
- **Pleural Sliding**
- **A lines**

Normal semiology of the healthy lung is represented exclusively by artifacts. These are 3:

1. A transversal hyperechoic line in the intercostal space, placed 1 or half centimeter below the outer surface of the ribs, the so called **pleural line** (this is the physical site of the tissue-air interface, represented by the parietal and visceral pleura in touch).
2. The motion of this line with respiration, seen as a sort of glittering. This is called **pleural sliding or gliding** (it derives from the continual coming and going of the visceral pleura with the tide of lung inflation and deflation).
3. Transversal hyperechoic artifacts, parallel to the pleural line and placed at a regular distance which is a multiple of the distance between the probe footprint and the pleural line itself. These are called **A lines**.

Pleural sliding when minimal can be anyway appreciated with M-Mode. If we hold steadily the probe on the chest, pre-pleural tissues are viewed with M-Mode as steady dots always at the same depth, appearing on the time scale as straight lines. The moving visceral pleura, with its natural irregularity, viceversa generates non aligned artifactual dots, represented on the time scale as irregular lines.
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• The lung sliding sign indicates normal movement, or sliding, of the visceral pleura against the parietal pleura as seen in this clip
• Again, please notice the difference between a curvilinear and linear probes. Although we don’t see the classical bat sign (as this is a linear probe), we can still see hypoechoic areas in both sides of the clip, indicating shadow arising from the ribs.
• Point to the pleural line and show the sliding of the pleura against each other
The lung sliding sign indicates normal movement, or sliding, of the visceral pleura against the parietal pleura as seen in this clip. Again, please notice the difference between a curvilinear and linear probes. Although we don’t see the classical bat sign (as this is a linear probe), we can still see hypoechoic areas in both sides of the clip, indicating shadow arising from the ribs. Point to the pleural line and show the sliding of the pleura against each other.
A-line artifact

- An artifact observed in
  - Normal lungs
  - Certain diseased lungs
  - Pneumothorax
  - Roughly horizontal, hyperechoic line
  - Parallel to the pleural line and arising below it
  - Arising at a distance equal to the distance between the skin and the pleural line

The physical reason for this artifactual picture to appear on the screen, is that the ultrasound beams bounce between the footprint of the probe and the specular reflector represented by the pleural line, which is a homogeneous tissue-air interface. The machine interprets the going and coming double travel of the beam as a single travel twice or three times the distance, and projects as artifact the pleural line at distances which are a multiple of the distance from probe surface to pleural line. It is the phenomenon of reverberation.
Abnormal findings

- **Pleural Effusion**
  - Hypoechoic space
  - Bounded by chest wall, lung, diaphragm
  - Appropriate dynamic change
Abnormal findings

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- **Lung Consolidation**
  - Loss of aerated lung – transmits ultrasound
  - Sonographic air bronchograms – punctate, echo bright
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Abnormal findings

• B-line
• Lung rockets
the b-line (lung comet)

• “B-Line”: Longitudinal artifact, well defined, narrow base spreading to screen edge

• Arising and moving from pleural line, Abolition of A lines

• Physiological (28% healthy pts) if postero-lateral

It is important to understand that the B-lines are comet-tail artifact (a type of reverberation artifact)
Comet-tail artifact arises from anatomic structure with significant acoustic impedance gradient (i.e. air and water)
It is characterized by artifacts, that can be clearly distinguished from normal artifacts, as you can see by comparison with the normal pattern on the right. Hallmark of this ultrasound pattern is a longitudinal artifact called B line or ULC (depending on which literature you are referring to). It originates from the pleural line, it moves together with it, it is a laser-like well defined artifact reaching the edge of the screen and erasing A lines. When grouped in number greater than 3 per Ultrasound scan sector and distributed at the antero-lateral surface of the lung, B-lines define the A-I Syndrome, and have been named Lung rockets (they resemble the trail of a rocket at its take-off) (again from the fantasy of D. Lichtenstein).
the b-line (lung comet)

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Lung rockets

- ALVEOLAR INTERSTITIAL SYNDROME: “Lung Rockets”,
  Multiple (≥ 3) grouped B lines, Diffused anterolateral distribution

- Lung rockets are pathological
- They indicate thickened interlobular septa reaching the periphery
On the left we see a cartoon of normal lung parenchyma with associated normal lung ultrasound.

Things become different when fluid accumulates in the lung interstitium leading to thickened interlobular septa and high acoustic impedance gradient, which in turn lead to the numerous B-lines, or lung rockets as seen in the associated ultrasound image on the right.
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• Things become different when fluid accumulates in the lung interstitium leading to thickened interlobular septa and high acoustic impedance gradient, which in turn lead to the numerous B-lines, or lung rockets, as seen in the associated ultrasound image on the right.
Lung rockets are not synonymous with a single disease, not even with cardiogenic pulmonary edema, which is the most frequent pathology associated with them.
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alveolar-interstitial syndrome:
example 2

“LUNG ROCKETS”

ARDS / ACUTE LUNG INJURY

They can be found also in lesional edema.
alveolar-interstitial syndrome: example 2

"LUNG ROCKETS"

ARDS / ACUTE LUNG INJURY

They can be found also in lesional edema.
alveolar-interstitial syndrome: example 3

“LUNG ROCKETS”

PULMONARY FIBROSIS

also in fibrosis
alveolar-interstitial syndrome: example 3

“LUNG ROCKETS”

PULMONARY FIBROSIS

also in fibrosis
alveolar-interstitial syndrome:
example 4

“LUNG ROCKETS”

PROTEINOSIS

in other diffuse chronic diseases such as alveolar proteinosis
alveolar-interstitial syndrome:
example 4

“LUNG ROCKETS”

in other diffuse chronic diseases such as alveolar proteinosis
alveolar-interstitial syndrome: example 5

“LUNG ROCKETS”

LUNG CONTUSION

in contusions, especially associated with peripheral consolidations
alveolar-interstitial syndrome: example 5

"LUNG ROCKETS"

LUNG CONTUSION

in contusions, especially associated with peripheral consolidations
alveolar-interstitial syndrome: example 6

“LUNG ROCKETS”

PNEUMONIA

and in pneumonia with the characteristics of interstitial diseases
alveolar-interstitial syndrome: example 6

“LUNG ROCKETS” PNEUMONIA

and in pneumonia with the characteristics of interstitial diseases
Alveolar-interstitial syndrome

LUNG ROCKETS

DIFFUSE, BILATERAL

- Cardiogenic Pulmonary Edema
- ARDS / ALI
- Interstitial Fibrosis
- Alveolar Proteinosis

LOCALIZED

- Pneumonia
- Lung Contusion
- Non-ventilated area

They are a sonographic finding common to many pathologies, where the common issue is a partial loss of aeration, and the differences are based mainly on distribution...
In terms of physical explanation (which is important to understand their clinical meaning) they were at first associated with **thickened interlobular septa**.
Recent bench studies demonstrated that the so-called B-Lines or Ultrasound Lung Comets can be produced by artificial double layers of bubbles, creating a sort of wet foam: discrete 3-dimensional aerated structures at the critical point for reverberation, where fluid-rich bubble interfaces act as specular reflectors.
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Roughly what is depicted in this diagram on the left..
As we were saying this lecture is meant to give you the tools to use ultrasound to diagnose pulmonary edema.

An important concept, once the bilateral symmetrical presentation has been confirmed, is that the level of crowding of these artifacts (here you see the most recent nomenclature) is correlated in pulmonary edema to the amount of extra vascular fluid accumulation.
As we were saying this lecture is meant to give you the tools to use ultrasound to diagnose pulmonary edema.

An important concept, once the bilateral symmetrical presentation has been confirmed, is that the level of crowding of these artifacts (here you see the most recent nomenclature) is correlated in pulmonary edema to the amount of extra vascular fluid accumulation.
Ultrasound vs. EVLW & pulmonary capillary wedge pressure

Agricola E, et al. CHEST 2005;127:1690-1695

This has been measured with PICCO and correlated with the number of B-Lines per scan sector. In cardiogenic APE there also is a correlation with PAOP (even if weaker)
Comet-Tail Score in Pulmonary Edema: correlation with Wedge Pressure \( r = 0.48, \ p < 0.0001 \) and PiCCO EVLW (90% sensitivity, 86% specificity for EVLW > 500 ml)

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The presence of 4 ULCs was found to maximize overall diagnostic accuracy with a sensitivity of 81% and a specificity of 85%.

9 ULCs had a sensitivity of 73% and a specificity of 100%.

The negative predictive value was higher for NT-proBNP (100% vs 45%).
The positive predictive value was slightly higher for ULCs (97% vs 92%).


...With Natriuretic peptides.
Even if with a smaller negative predictive value, but with a higher positive predictive value than BNP.

Both tests showed excellent AUC, which was slightly better for NT-proBNP.
### Pulmonary edema vs. COPD exacerbation

<table>
<thead>
<tr>
<th>Ultrasound</th>
<th>Pulmonary edema group</th>
<th>COPD group</th>
<th>Control group</th>
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<tbody>
<tr>
<td>Positive test</td>
<td></td>
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<tr>
<td>Diffuse pattern</td>
<td>38</td>
<td>1</td>
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<tr>
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<td>0</td>
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Pulmonary edema vs. COPD exacerbation

The ultrasound test (A-I Syndrome) was positive in 100% of patients with pulmonary edema, negative in 92% of patients with COPD, and negative in 98.75% of the control group.

The comet tail artifact had a sensitivity of 100% and a specificity of 92% in the diagnosis of pulmonary edema when compared with COPD.

early detection of pulmonary edema

Oleic Acid-Induced ALI in Pigs

And even more interestingly, B lines appear earlier than crackles or chest X-Ray findings. In an experimental model of ALI in pigs, both PaO2/FIO2 ratio decrease and the number of ultrasound lung comets increase correlate with time elapsed from oleic acid administration, but ULC appear even earlier (considering that the variation in oxygenation reaches statistical significance later).

Top, PaO2/FIO2 data. PaO2/FIO2 decreased over time, but only at 90 mins was a statistically significant decrease registered. *p < 0.05 vs. baseline. Bottom, data on ultrasound lung comets (ULCs). The ULC score index (mean number of the 12 scanning sites) increased over time, with statistically significant differences at all time points.
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The ULC score index (mean number of the 12 scanning sites) increased over time, with statistically significant differences at all time points.
APE both share a common LUS typical pattern of bilateral A-I syndrome, but interesting clues to differentiate them can be observed. These are consistent with the "non hydrostatic" but rather inflammatory genesis of lesional edema.
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### Cardiogenic Edema vs. ALI/ARDS

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“Spared areas”
Cardiogenic Edema vs. ALI/ARDS

**CARDIOGENIC EDEMA**
- Homogeneous distribution
- Normal sliding
- Normal pleural thickness
- Often pleural effusions

**ARDS / ALI**
- Inhomogeneous distribution
- Reduced sliding
- Thickened irregular pleura
- Peripheral consolidations
- “Spared areas”
### 28 point exam

<table>
<thead>
<tr>
<th>right side</th>
<th>left side</th>
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<tbody>
<tr>
<td>Mid-axillary</td>
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<tr>
<td>Anterior axillary</td>
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<tr>
<td>Mid-clavicular</td>
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<tr>
<td>Parasternal</td>
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Pratai et al Crit Care Med 2010
18 High Altitude Trekkers

* Clinical HAPE
Differential diagnosis in pulmonary edema

Likely CARDIOGENIC

Likely ARDS / ALI

- History, Physical Examination
- LUNG ULTRASOUND
- ECHO
- CHEST X-RAY
- BNP
- PAC

All in all, if we compare the tools we have to make a differential diagnosis between cardiogenic and non-cardiogenic APE, each one has its semiology in favour of one or the other option.
Differential diagnosis in pulmonary edema

Likely CARDIOGENIC
Homogeneous distribution
Normal sliding
No spared areas

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- "Patchy" distribution
- Reduced/abolished sliding
- Spared areas
- Peripheral Consolidations

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Differential diagnosis in pulmonary edema

**Likely CARDIOGENIC**

- Homogeneous distribution
- Normal sliding
- No spared areas
- Depressed Systolic LV function
  - LV Valvular dysfunction
  - LVOT Obstruction
  - Left atrial hypertension
- Gravitational distribution
  - Enlarged heart & vasculature
  - Septal lines, Pleural Effusion
  - Peribronchial cuffing
- BNP > 1200 pg/ml
- PCWP > 18 mmHg

**Likely ARDS / ALI**

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**History, Physical Examination**

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### Likely ARDS / ALI

- “Patchy” distribution
  - Reduced/abolished sliding
  - Spared areas
  - Peripheral Consolidations
- No Left sided cardiac disease
  - Non elevated LAP
- Peripheral, “patchy” distribution
  - Air bronchograms
  - No septal lines

  - BNP < 200pg/ml
  - PCWP ≤ 18 mmHg

---

All in all, if we compare the tools we have to make a differential diagnosis between cardiogenic and non-cardiogenic APE, each one has its semiology in favour of one or the other option.
Differential diagnosis in pulmonary edema

Likely CARDOGENIC

Likely ARDS / ALI

History, Physical Examination

LUNG ULTRASOUND

ECHO

CHEST X-RAY

BNP

PAC

But if history and clinics are important, we all know how inaccurate they are. Among the other tools, the quickest are with no doubt Echo and LUS. And combined they reach very high PPV and NPV.
Differential diagnosis in pulmonary edema

Likely CARDIOGENIC

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- **LUNG ULTRASOUND**
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History, Physical Examination

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take home message
take home message

• Easy and accurate detection of APE (Diffuse bilateral AIS):
  
  *High sensitivity & specificity: 100% and 92% vs COPD;*
  
  *90% overall accuracy vs other causes of dyspnea*
take home message

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- Cardiogenic vs. ALI/ARDS: clues to differential DGN
  esp.: “GREY AREA of BNP”, COEXISTENCE OF COPD
  (early APE, wheezing) CHRONICALLY ELEVATED WEDGE
take home message

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  *(early APE, wheezing) CHRONICALLY ELEVATED WEDGE PRESSURE*
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  PRESSURE

• Correlation with EVLW: Monitoring!
take home message

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- Cardiogenic vs. ALI/ARDS: clues to differential DGN
  
  esp.: “GREY AREA of BNP”, COEXISTENCE OF COPD
  (early APE, wheezing) CHRONICALLY ELEVATED WEDGE PRESSURE

- Correlation with EVLW: Monitoring!

- Integration with ECHO
That's why I strongly suggest you to put your probe no only on the heart but also on the lung.
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