# THE 5 MINUTE PLEURAL SPACE AND LUNG ULTRASOUND ANYONE CAN USE TO ANSWER SIMPLE BINARY QUESTIONS!

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## OVERVIEW OF THE ISSUE

Ever struggle with determining the cause of dyspnea in a cat that is too unstable to take radiographs or draw blood for ProBNP levels (cardiac, respiratory, pleural effusion)? Have you felt frustration at not being confident at diagnosing pleural effusion or pneumothorax? You are not alone! Recent studies have demonstrated very poor to moderate agreement between Thoracic Focused Assessment with Sonography for Trauma (T-FAST) protocols and CT scans when it comes to diagnosis pleural effusion and pneumothorax, and to some extent, lung pathology. **This should not be the case!** Using a binary approach, assessing the patient and asking the right clinical question based on clinical findings increases diagnostic accuracy, and makes point of care ultrasound rapid and easy to learn!

## OBJECTIVES OF THE PRESENTATION

- This lecture, which will focus on a practical approach to point of care ultrasound that considers clinical findings and challenges current protocols by asking the question; "where will pathology accumulate" and subsequently, "what should we be sonographically looking for to answer binary, relevant, rapid, clinical, and often lifesaving questions". Don't simply put the probe on the patient or expect a "one protocol fits all" approach to be applicable to all situations; ask the right question and know how to modify protocols to increase the chance of success with pleural space and lung pathology!

- By the end of this session attendees will be able to:
  - List and describe the common key structures that should be identified and assessed in all patients when performing pleural space and lung ultrasound
  - Describe how to differentiate wet and dry lung with confidence
  - List differential diagnosis for increased B lines
  - Explain how sonography can be used to decide if the underlying cause of B lines is cardiogenic in origin or not.
  - Describe how to increase the chance of detecting smaller quantities of pleural effusion
  - Describe ways to increase the chances of detecting pneumothorax
  - Discuss common mistakes and pitfalls to avoid when performing pleural space and lung ultrasound
  - Discuss the different subpleural lesions/consolidations that are seen with ultrasound and explain why they occur

## RECOMMENDED PLEURAL SPACE AND LUNG ULTRASOUND (PLUS) PROTOCOL

There are two key enemies of ultrasound; bone and air. Both are encountered when performing ultrasound of the pleural space and lung. This is advantageous as bone and the subsequent rib shadowing, as well as the soft tissue:air interface (transition from the soft tissue intercostal muscle to air filled lung) provide landmarks to work with. These landmarks allow the pleural line (superimposition of the parietal and visceral linings appearing as a single sonographic white line) to be identified with confidence. Identifying the pleural line is key, as all lung artifacts arise from the lung surface and may

change depending on the underlying status of the lung and pleural space. This is discussed in further detail and we will emphasize how all sonographic signs arise from the pleural line.

As a general rule of thumb, multiple regions of the lung and pleural space should be scanned when assessing the pleural space and lung. This is easily accomplished by using a bilateral thoracic sliding protocol that identifies lung borders, taking advantage of patient position and sites where pathology accumulate. The protocol also incorporates the subxiphoid site. The preferred protocol used is called the pleural and lung ultrasound (PLUS) protocol.

With the PLUS approach, the cardiovascular components of thoracic VPOCUS are scanned using a different format than the pleural space and lung. Separating the different organ systems of the thorax into components helps break point of care ultrasound into a binary approach by focusing questions to specific organs and anatomic structures (e.g. pericardial and cardiac are separated from pleural space and lung), thereby allowing learners to gain confidence by mastering specific aspects of VPOCUS in a sequential manner.

It is important to identify normal structures seen during lung and pleural space ultrasound. Important questions to ask include:

- Is the animal sternal/standing or lateral? This is important because pathology (such as pneumothorax or pleural effusion) will be affected by gravity and therefore patient positioning.
- Therefore, to rule out these pathologies it will be important to think about how patient position affects their location.
- This is one of the reasons a binary question approach is advantageous over a protocol-driven approach.
- In other words, if pneumothorax is suspected in a standing patient, look caudo-dorsally (where air will accumulate in the highest point of the thorax) vs. the widest part of the thorax in a patient that is lateral.

**NORMAL FINDINGS ON THORACIC VPOCUS**

For novices, placing the probe perpendicular to the ribs will aid in identifying the pleural line, which is of paramount importance when assessing pleural space and lung pathology.

There are several structures visible when performing PLUS, however, as a starting point there are 6 key structures/components that scanners must be comfortable identifying during thoracic VPOCUS of the pleural space and lungs.

1. **Pleural line and Bat sign**
2. **Glide sign**
3. **A lines**
4. **B lines**
5. **Dry lung**
6. **Curtain sign**

**1. PLEURAL LINE AND BAT SIGN**

- *Bat sign/Gator sign*: When the ultrasound probe is placed over the lung and perpendicular to the ribs, we can see the rib heads, rib shadowing, and the pleural line. The image obtained is called a “bat sign” or “gator sign” as the rib heads and pleural line resemble the wings and body of a bat, or a gator’s eyes peaking above the water line, respectively. The BAT sign is the preferred term of the authors as the letters help identify the key features using the following pneumonic: the ultrasound beam will not traverse Bone or Air when the probe is held Transverse to the ribs). The rib heads (bone) make up the wings of the bat while the pleural line (soft tissue air interface) makes up the body of the bat when the probe is

transverse to the ribs. Identifying the Bat sign assists novice sonographers in locating the pleural line; the first white line below the rib heads that joins the rib shadows

- The pleural line is essential to identify as it is the interface between the parietal pleura of the thorax and the visceral pleura of the lung and is the location we assess for most pleural and lung pathology.

### 2. GLIDE SIGN

- The glide sign is visualized as a shimmering along the pleural line (pulmonary-parietal interface), which represents the normal to-and-fro motion of the lung sliding along the chest well during respiration. This is normal.
  - There are two key rules to remember when assessing the glide sign: 1) the lining of the lung (visceral pleura) MUST be in contact with the thoracic pleura (parietal pleura) to create the shimmer of the glide sign and 2) the patient must breathe to create the shimmering glide sign.
  - The glide sign is most obvious where lung movement is greatest, which tends to be the most caudal and dorsal sites of the thorax (easier to see the glide sign dorsally than ventrally). It is not always easy to identify the glide sign and making the pleural line less white and grayer and/or “grainy” will make it easier to identify the glide sign. The glide sign can be made “grainier” by changing the angle the ultrasound beam strikes the pleural line (changing the angle from perpendicular), by placing the probe over a single rib head (one eyed gator), and by adjusting the gain setting on the ultrasound machine.
  - The glide sign is difficult to identify in patients that are panting or have rapid shallow breathing.
  - Keep your hand stationary and only interpret the glide sign when the patient is not moving (movement creates a false positive).
  - The animal must take a breath to assess the glide sign - won’t be seen with apnea – i.e. opioid induced, unless you are near the heart (the beating heart causes beat to beat small shifts (mini glide) of the lung along the thoracic wall known as the “lung pulse”).

### 3. A-LINES

- A-lines are horizontal white lines equidistant from the skin surface to the pleural line that project through the far field of the ultrasound image.
- They are a type of reverberation artifact that occurs when ultrasound beams are reflected back and forth between the probe and pleural line due to the presence of air below the pleural line
- When considering A-lines it is important to remember A stands for air. Air is located below the pleural line when the lungs are filled with air and when there is air in the pleural space which occurs with pneumothorax. Therefore, A lines are seen with normal lung and when a pneumothorax is present.
- If only A-lines are present, AND a glide sign is present, it means the lungs are “dry” at that lung site. In other words, dry lung at this region.

### 4. B-LINES

- B-lines are laser like vertical white lines arising from the pleural line.
- They appear as hyperechoic streaks originating from the lung surface of the pleural line, extending through the far field without fading, and swing to-and-fro with the motion of the lung during respiration.
- B-lines occur as the result of air and fluid in proximity to each other at the lung surface.
- The presence of a small number of isolated B-lines may be normal in healthy dogs and cats (noted in 10-30% of patients). Normal b-lines are most often seen as a single B-lines but up to 3 b-lines at a single site can still be normal. Anything more than 3 B-lines at a single site is associated with

pathology (AIS). B-lines are also called ultrasound lung rockets (ULRs), ring down artifact, or comet tail artifacts.

- *Key criteria to identify a B-line (ALL criteria must be present):*
    - *Vertical white lines*
    - *Originate at the lung surface*
    - *Moves with the pleura*
    - *Extends to the far field*
    - *Obscures A-lines if present*

**5. DRY LUNG**

• The sonographic diagnosis of dry lung, at the probe location, can be diagnosed when the following 2 criteria are present:

i. The patient has a glide sign: As stated, this indicates the lung is in contact with the chest wall and it is therefore possible to assess if the lung surface as wet or dry – lungs should not be assessed if they are not in contact with the chest wall

ii. If there are ≤ 3 B-lines present. Up to 3 B-lines in a single window can be considered normal and therefore, ≤ 3 B-lines at a single window suggests the lungs are dry at the surface over which the ultrasound probe is located.

NOTE: The presence of only A lines (which by definition means there are ≤ 3 B-lines present) is also used to diagnose dry lung, however, given A-lines are not always visible (there presence varies depending on the angle at which the ultrasound beam strikes the pleural line and reflected back to the ultrasound probe), the authors prefer to use the criteria of ≤ 3 B-lines when making the decision the lung surface is dry.

**6. CURTAIN SIGN**

- The curtain sign marks the caudal border of the lungs; the transition between the thorax and abdomen, which is easily seen with sonography as a sharp vertical demarcation.
- The abdominal structures are seen because they are soft tissue, contrary to the thorax (air and bone).
- When the ultrasound probe is positioned such that it is both over the thorax and the abdomen with the marker of the probe directed cranially, the cranial half of the image (thorax) will not allow the ultrasound beam to extend past the pleural line (produces A-lines), while the caudal half of the image (abdomen) allows the beam to be transmitted through the far field permitting soft tissue structures to be visible.
- The curtain sign is not the actual diaphragm. As the diaphragm curves, it detaches from the thoracic wall and therefore air will be present between it and the parietal pleura. As such, we only see the diaphragm where it is in contact with the thoracic wall. Once the diaphragm curves away from the thorax we only see the sharp vertical interface between the caudal border of the lung. It is abnormal to see the actual curved diaphragm, and therefore seeing it tells us we have pathology present, usually pleural effusion or lung consolidation (which allow the ultrasound beam to traverse them making the diaphragm visible after it curves away from the chest wall).
- It is important not to confuse the curtain sign (back and forth movement of the diaphragm) with a glide sign. The curtain sign is seen in both healthy patients and patients with pneumothorax.
- The curtain sign is key to defining lung borders where pathology often accumulates.

**Important binary questions to be asked when performing thoracic VPOCUS**

- Regarding the pleural space, the broad clinically relevant questions to ask include:

- Is there alveolar interstitial syndrome (AIS): are there an increased number of B lines?
- If increased in number, are the B lines due to cardiogenic causes?
- Is there pleural effusion?
- Is there pneumothorax: is there a glide sign or B-lines (if we see b-lines originating from the pleural lune between the ribs, then we can rule out pneumothorax at this site)?
- Regarding the lung, the broad clinically relevant questions to ask include:
- Is there subpleural consolidation and/or thickening of the pleural line?

**ALVEOLAR INTERSTITIAL SYNDROME (AIS)**

- Alveolar interstitial syndrome (AIS), also referred to as "wet lung", is diagnosed when there are an increased number of B-lines.
- "Dry lungs" are present when there is a glide sign and ≤ 3 B lines or only A lines noted at the probe location. Check multiple lung regions as AIS can be localized.
- A few scattered B-lines at different lung field sites is considered normal and indicative of "dry lung".
- AIS or "wet lungs" are present when there are >3 B lines at a single site.

**PLUS PROTOCOL TO DIAGNOSE AIS**

- The thorax is generally divided into thirds from dorsal to ventral
- The dorsal third of the thorax is scanned first. Start at the same caudal dorsal location as described for identification of pneumothorax (the most caudo-dorsal site of the thorax – see pneumothorax section)
- From this site, the probe is slid cranially between intercostal spaces, pausing as necessary to assess the presence of lung pathology.
- Once the dorsal sites of the thorax have been examined, the probe is slid ventrally within the intercostal space just caudal to the scapula until the middle third of the thorax is reached (roughly the height of the heart base or peri-hilar region). The probe is then slid caudally, pausing as necessary to assess lung the presence of lung pathology, until the curtain sign is encountered.
- Lastly, the probe is slid cranially and ventrally along the curtain sign until the pericardio-diaphragmatic window is identified. The probe is then turned parallel to the ribs at this location and slid ventrally until the sternal muscles are seen. The probe is then slid cranially a rib space at a time until the cranial thoracic inlet is identified at roughly the third intercostal space.
- The heart will be encountered using this technique, at which point the probe can be slide dorsally from the ventral region until lung is encountered to look for the lung pathology overlying the heart. The probe remains parallel to the ribs while it is slid dorsally.
- The probe is then returned to the ventral regions, remaining parallel to the ribs (to ensure pleural effusion is not missed while also looking for lung pathology) and advanced cranially until the thoracic inlet is encountered.
- The protocol essentially makes an "S" (left side) or reverse "S" (right side) shape of scanning to maximize lung and pleura examined.
- The same protocol is used on opposite side of the thorax
- B-lines can also be identified at the subxiphoid site and this view should be included in the lung ultrasound search for B-lines.

**KEY CONSIDERATIONS OF B-LINES:**

- B-lines can originate anywhere, which is why it is important to scan multiple lung regions. See protocol above at the start of this section.
- The number of B-lines correlates with the severity of AIS (the more B lines the "wetter" the lungs). However, the prognosis varies with the underlying cause of B lines.

- If B lines become so numerous, they coalesce it can be difficult to identify their presence. When this occurs A-lines will not be visible, the pleural line is often irregular and if the probe is moved to other regions individual B lines will often become visible as less severely affected lung regions are encountered.
- When AIS is identified on lung ultrasound, the same differential diagnosis should be considered as an interstitial-alveolar pattern on thoracic radiographs: Aspiration pneumonia in the vomiting dog, pulmonary contusions in the hit by care ect.
- Although the distribution of AIS can help with the diagnosis (e.g. a cranial ventral pattern of AIS on lung ultrasound, particularly with concurrent lung consolidation is consistent with bronchopneumonia), similar to the distribution of interstitial-alveolar syndrome on radiographs, the differential diagnosis for AIS on lung ultrasound should be considered in light of the history and other clinical findings.

**NOTE:** Lung ultrasound will only detect lung pathology if the pathology is at the periphery of the lung (outer 3mm) – fortunately most diseases that cause AIS (cardiogenic pulmonary edema, trauma induced contusions, aspiration pneumonia, etc.) will reach the lung surface.

**SOME PITFALLS TO NOTE WHEN PERFORMING LUNG ULTRASOUND:**

- Z-lines: these lines arise from the parietal pleura (thoracic wall side of the pleural line), not the lung surface. Therefore, they do not move with the glide sign and the do not erase A-lines. They are ill-defined and disappear after 2-5 cm. Significance unknown (not associated with known pathology). They are present in > 80% of healthy dogs. They can be seen in patients with pneumothorax.
- E-lines: These lines come from subcutaneous emphysema and they do form a comet tail like B-lines. They are identified by the fact they originate proximal (superficial) to the pleural line and therefor pass through and obliterate the pleural line. Caused by accumulation of air in the subcutaneous tissues. They do extend to the bottom of the ultrasound screen, but do not move with respirations.
- Placing the probe over the stomach or at the curtain sign and failing to realize the probe location can sometime lead to a false positive finding of B lines.

**PLEURAL EFFUSION**

- Pleural effusion appears as hypoechoic accumulations between the thoracic wall and lungs. Often irregular in shape and distribution, forming angles.
- It curves up and around the diaphragm at the pericardio-diaphragmatic window.
- The presence of a glide sign excludes pleural effusion at the site of probe placement, as the presence of a glide sign requires contact of the surface of the lung with the chest well (air or fluid in the chest cavity prevent the lung from contacting the chest wall).
- Pleural effusion appears as the absence of a glide sign with anechoic fluid between the chest wall and the hypoechoic lung, or as anechoic triangles adjacent to the heart and outlining the diaphragm (outside the pericardial sac).
- Important thoracic findings when looking for pleural effusion:
- The two pleural VPOCUS regions used to identify pleural effusion include 1) subxiphoid window and 2) the transthoracic windows in the ventral regions of the thorax.
- Patient positioning is important to consider when searching for pleural effusion and different techniques are required to identify small quantities of fluid with patients in lateral vs. sternal/standing positions.
- In lateral recumbency, fluid accumulates at the widest gravity dependent sites of the thorax, generally at the pericardial window.

- In sternal recumbency (preferred position to scan acutely dyspneic patients), effusion will accumulate ventrally.

**PLUS PROTOCOL TO DIAGNOSE PLEURAL EFFUSION:**

Subxiphoid scanning

- The subxiphoid view with the depth increased beyond the level of the diaphragm can be used to detect pleural effusion.
- The probe needs to be more parallel in orientation (relative to the spine) and the depth setting adjusted (set deeper) compared to the angle and depth used for VPOCUS of the abdomen, to allow the ultrasound beam to extend into the thorax via the liver.
- At the subxiphoid location the probe should be fanned and rocked in long and short axis to increase the chance of finding smaller accumulation of pleural fluid

Transthoracic windows; lateral vs. sternal

- Moving the probe off the heart and into the ventral regions between the heart and the diaphragm (pericardio-diaphragmatic window) allows easy differentiation of pleural from pericardial effusion and is a good area to identify large and small quantities of pleural effusion.
- *Lateral patient:* Transthoracic windows with the patient in lateral recumbency, at the pericardial gravity dependent and widest point of the thorax are good sites to identify pleural effusion.
- *Sternal patient*: With the patient in sternal recumbency, a different transthoracic technique is used to identify smaller quantities of fluid.
- At the most ventral areas of the thorax, including the pericardio-diaphragmatic sites, if pleural effusion is not identified with the probe at perpendicular to the ribs, the probe can be turned parallel to the ribs to try and identify smaller accumulations of fluid between the lung and ventral body wall.
- When the probe is parallel to the ribs and there is no pleural effusion, the pleura will be in contact with each other and the authors have called this the “ski slope” sign.
- When there is pleural effusion, the fluid will separate the pleura. The presence of fluid between the lung and ventral sternal muscles, with the probe parallel to the ribs creates a curved triangular shape similar to a sail. As the animal breathes and the lung expands and contracts the fluid pocket increases and decreases in size giving the appearance of a sail in the wind. As such, the authors have termed this the “sail sign”.

**PNEUMOTHORAX**

It is essential that patient positioning and the underlying pathology be considered when it comes to diagnosing pleural space pathology. Air and fluid accumulate in different regions of the pleural space depending on the position in which the patient is evaluated. Fluid tends to accumulate in the most gravity dependent areas while air tends to rise to the non-gravity dependent areas of the pleural space. Adhesions and loculated fluid accumulations may contain fluid and prevent it from reaching the most gravity dependent locations with a change in patient position.

**There are 3 key findings that help identify the presence of a pneumothorax, two are exclusion criteria, one is an inclusion criteria.**

**1)** Pneumothorax appears as the absence of a glide sign. The presence of a glide sign rules out pneumothorax with confidence. Lack of a glide sign should prompt consideration of pneumothorax, but a glide sign is not always easy to identify, even in healthy patients.

**2)** The presence of B-lines excludes pneumothorax at those focal probe placement sites because B-lines originate from the lung surface. B lines are not always visible in healthy patients.

**3)** Finding a lung point confirms a pneumothorax on that side of the thorax. If the glide sign is not seen and there is strong suspicion of a pneumothorax a search for the lung point should be undertaken as identification of the lung point is pathognomonic for a pneumothorax.

- The presence of a glide sign excludes pneumothorax at the probe placement site, as the presence of a glide sign requires contact of the surface of the lung with the chest well (air or fluid in the pleural space will prevent the lung from contacting the chest wall and prevent shimmer of the glide sign from occurring).
- It is important to hold the probe stationary on the skin surface when evaluating the glide sign, as movement of the probe along the skin surface can create a false appearance of a glide sign.
- Sonographically standardizing the most sensitive thoracic site to diagnose pneumothorax.
- Air will accumulate at the most caudal dorsal portion of the thorax when the patient is sternal recumbency or in the standing position.
- Sternal recumbency is the preferred position in which to scan acutely dyspneic patients as it minimizes respiratory distress and subsequently the work of breathing associated with restraining the patient in lateral recumbency.
- To begin with, the “bat” or “gator sign” should be identified by placing the probe perpendicular to 2 ribs.
- MAKE sure you are over lung! To ensure this, place the probe just caudal to the scapula/biceps/triceps muscles 1/2 to 2/3 of the way up the thoracic wall at about the 6th or 7th intercostal space to ensure the probe is initially place over lung. The bat sign is confirmed, and glide sign assessed.
- If a glide sign is present, the probe rapidly moved caudally a rib at a time until the curtain sign identified.
- Once the curtain sign is seen, the dorsal border of the thorax is identified by sliding the probe dorsally into the epaxial muscles until the pleural line is no longer visible, then sliding the probe ventrally until the pleural line is just visible again.
- Now you have identified the most caudal-dorsal site, which is the most sensitive site for air to accumulate with the patient in sternal, and also the region that has the most lung movement making it easier to identify a glide sign.
- If the patient is scanned in lateral recumbency air will accumulate at the widest part of the chest and probe location should change to reflect this. It is important not to move the probe when assessing the presence of a pneumothorax as moving the probe creates a false “glide sign”.

**DEFINING THE LUNG POINT:**

If the glide sign is identified with confidence it rules out pneumothorax. Unfortunately, it is not always easy to identify a glide sign with confidence. If this is the case, a pneumothorax can be confirmed by identifying the lung point. The lung point is defined as the site within the thorax where the lung recontacts the parietal pleura and creates an intermittent glide sign within half the ultrasound beam when the patient breathes. It is the exact point within the thorax where there is a return of the glide sign: movement of the probe from an area where there is no perceived glide sign, to an area where the glide sign reappears intermittently within a region of the ultrasound image.

- If there is a glide when the probe is initially placed on the patient (at the 6th intercostal space near the heart base) proceed with the steps described above to ensure there isn’t a pneumothorax at the most caudal-dorsal site.

- If a glide sign is noted at the most caudal-dorsal site, then there is no pneumothorax on that side of the patient. Other lung pathology and pleural effusion should be sought out, but it is not necessary to look for a glide sign on that side of the thorax with the patient in sternal recumbency. Make sure to check the other side of the thorax as well.
- If there is no glide when the probe is initially placed on the patient (at the 6th intercostal space near the heart base), or the glide sign is not present at the caudo-dorsal location of the pleural space with the patient in sternal/standing, then slide the probe cranially and ventrally until the lung point is found.
- It is important to allow the patient to take a breath as the probe is moved ventrally as the lung point/glide sign is only visible during the respiratory cycle
- To find the lung point the probe is slid cranially and ventrally (remembering that the diaphragm curves inwards and therefore the probe must be slid ventrally and cranially), until you note a point of lung reconnecting with the thorax wall OR you see a glide again.
- Occasionally the exact location where the lung recontacts the parietal surface of the thorax is not seen. In this case, if there is a pneumothorax and the lung recontacts the parietal surface of the thorax then the probe will move from the absence of a glide sign to the presence of a glide sign (intermittent glide within a portion of the ultrasound beam is not seen).

**LUNG CONSOLIDATION**

Sonographically-detected subpleural consolidations can occur as a result atelectasis, bronchopneumonia, thromboembolism, neoplasia and in cases of pulmonary contusions and ARDS. The differential diagnosis for subpleural consolidation should be considered in light of the entire clinical picture, history and to some degree, the shape and distribution/severity of the consolidation.

Criteria to diagnose lung consolidation:

- Abnormal pattern should be in thorax (should be differentiated from the liver or spleen)
- Should arise from the pleural line
- There should be a tissue like pattern (similar to liver echotexture)
- Anatomic boundaries must be present:
- Superficial boundary of consolidation
- At the pleural line in the absence of pleural effusion
- At the deep boundary of a pleural effusion if effusion present
- Deep boundary of the consolidation may be irregular (aerated lung boundary) or regular (if whole lobe is consolidated)
- Where consolidation fails to reach the deep border of the lung and comes in contact with air an irregular consolidation/air interface is created referred to as a “shred sign”, or if the border is smooth and circular-like this can represent a nodule.
- Where consolidation extends through the entirety of the lung, from one surface to the other, hepatization or a tissue sign is seen.
- Air bronchograms can be seen within the consolidation.

**References/Suggested Reading: Available upon request**