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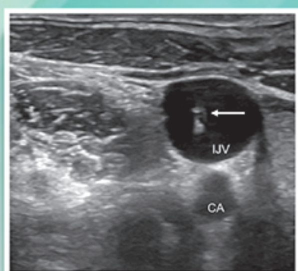
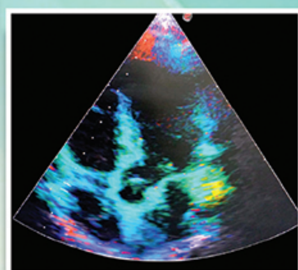
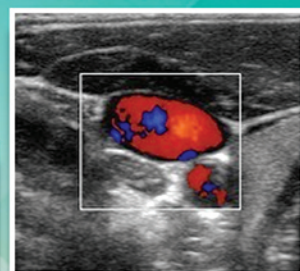
Emergency Ultrasound Guide







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CHAPTER 4

Lung Ultrasound

Alka Verma, Divya Srivastava, Pallav Singh

WHAT YOU WILL LEARN IN THIS CHAPTER?

A. Application of lung ultrasound (LUS) in emergency department (ED) and intensive care units (ICUs)

B. Differentiating normal and abnormal images

C. Recognition of common lung pathologies on ultrasound (USG)

INTRODUCTION

The ultrasound (USG) has gradually emerged as an important bedside tool in diagnosing pulmonary ailments, monitoring the effects of treatment given and guiding therapeutic interventions. Until 1989, USG was considered a useless modality as far as lung scans were concerned, as the air-filled organ did not allow passage of ultrasonic waves. A healthy lung is not visible in USG scanning. Indeed, the lung USG is primarily based on the interpretation of artifacts produced by the reflection of sound waves from healthy as well as unhealthy tissue. Pleural line, pleural effusions, and consolidated lung, however, are visible and easily recognized.

Since even the semiquantitative assessment of B-lines is subjected to operator, hardware, and image settings variability, the final interpretation must be an amalgam of the patient's clinical situation and other imaging done.

WHY DO ULTRASONIC SCANNING OF LUNGS?

Lung ultrasound (LUS) has crept into multiple settings as an important everyday tool and is rightly labeled as the "stethoscopes" of modern physicians. It can be performed at the bedside of the patients, and is reliable, repeatable, and provides immediate information on the condition of the organ scanned. **Table 1** deals with the uses of LUS in hospital settings.

PREPARATIONS FOR SCAN

Machine preparation: Irrespective of the make of the USG machine, the scan setting is kept at "lung scan". If the "lung scan" option is not available, care must be taken to deactivate the artifact-erasing software for proper interpretation of the scan.

No specific probe is recommended, but most used probes are phased array (2–8 MHz) or microconvex (3.5–8 MHz) as it enables scanning to greater depths and prevents repeated changing of probes. For assessing superficial aspects of the lungs, such as pleural movements and pneumothorax, the linear probe is used. It is particularly helpful in diagnosing pneumothorax. Both 2D and M-mode are used to scan each area.

Patient preparation: The machine and the clinician stand on the right side of the patient by convention. It is important to explain the procedure to all conscious patients before baring their chests for the scan. The patients must also be warned of the cold feel of USG jelly. The patient is made to lie with hands outstretched to enable scanning of the anterior zone **(Fig. 1)**. To enhance the scan of lateral and posterior zones,

TABLE 1: Uses of lung ultrasound.

Hospital settings	*Utility*	
Emergency department	• Aid in diagnosis • Monitoring	• As part of quick scan for patients presenting with dyspnea and acute respiratory failure • Effect of immediate management done
Trauma	• Diagnosis • Aid in intervention	• Bedside quick diagnosis of pneumothorax, hemothorax, rib fractures, pulmonary contusions, and chest wall hematomas • Ultrasound (USG)-guided chest drain insertion
Intensive care unit (ICU)	• Aid in monitoring • Patients on mechanical ventilation • Aid in diagnosing • Aid in intervention	• Day-to-day examination of lung conditions, much like auscultation • *Monitoring effect of treatment and guide the management:* Development of any iatrogenic pathology due to mechanical ventilation • US-guided drain of loculated pleural collections

Fig. 1: Anterior zones of lung scan, 18 scan zone.

the patient is tilted laterally with the help of an assistant **(Fig. 2)**. The marker of the probe is placed cranially.

PROBE POSITIONING AND SURFACE ANATOMY

Images are obtained in six lung zones: Anterior, lateral, and posterior zones on either side to cover the entire lungs **(Fig. 3)**.

- *Anterior zone:* It covers the anterior aspect of upper, middle, and lower lung lobes on right side and anterior aspect of upper lobe on left side.
- *Lateral zone:* It scans the lateral part of upper lobes, parts of lower and middle lobe on right side, and lateral part of lower lobe on left side.
- *Posterior zone:* It covers the posterior aspect of both upper and lower lobes on either sides.

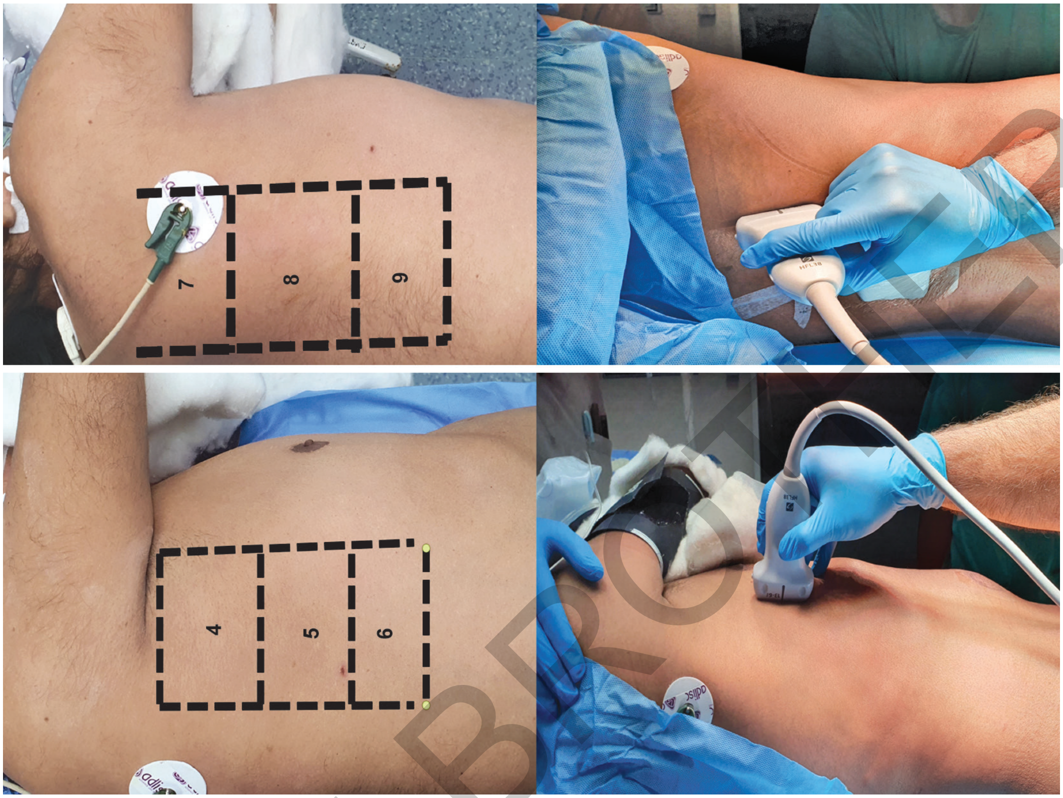


Fig. 2: Lateral and posterior zone scans require tilting of the patient, 18 scan zones.

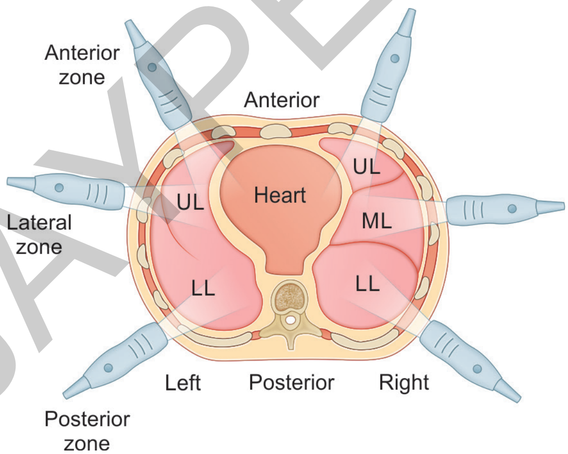


Fig. 3: Surface anatomy and lung lobes.

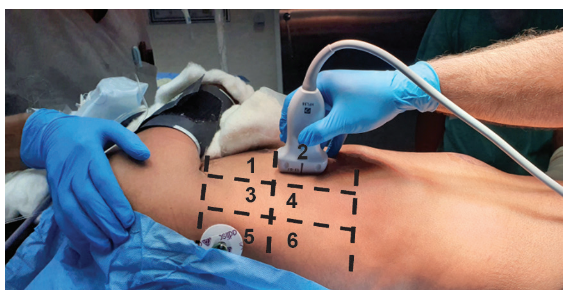


Fig. 4: 12 scan zones.

Some practitioners scan two sections: (1) Upper and (2) lower in each zone, creating a total of 12 scan areas **(Fig. 4)**, while few others prefer scanning three interspaces in each zone creating 18 scan areas **(Figs. 1 and 2)**.[1] The literature is crammed with protocols for LUS; BLUE, RADIUS, FALLS, FLUID, and ETUDES. No matter what protocol is followed, it is important to scan the entire chest thoroughly before concluding on the findings.

NORMAL LUNG INTERPRETATION

Lung ultrasound images are basically artifacts created by the movement of sound waves through acoustically different subcutaneous tissue and air-filled lungs. Each area of the lung is scanned to confirm the presence or absence of these artifacts; lung sliding sign, A- and B-lines, and air bronchograms.

Bat wing sign: The first placement of the probe is longitudinal between the two ribs. The probe is then tilted on either side to obtain an image of dark rib shadows of upper and lower ribs with a shinning hyperechoic pleural line in-between. This happens when the probe is perfectly perpendicular to the pleura. **Figure 5** shows what is classically known as "bat wing sign", determining the proper placement of the USG probe.

Once an area is localized in a longitudinal scan the probe is rotated transversely to get a better view of the pleura and its related artifacts without hindrance from rib shadows.

A-lines: Air-filled alveoli in the lungs scatter most of the sound waves. The parietal pleura, however, is visualized as a shiny white line called the pleural line. Healthy alveolar tissue beyond this is not seen. Instead, parallel horizontal hyperechoic lines that are reverberations of the pleural line are visualized. The distance between two A-lines is the same as the distance between the pleura and the USG probe. These lines are called A-lines **(Fig. 6)**.

Lung sliding sign: As the lungs expand and contract with each breath the parietal and visceral pleura slide on each other. The impression given by movement of visceral pleura over parietal pleura on USG imaging is like waves produced in a

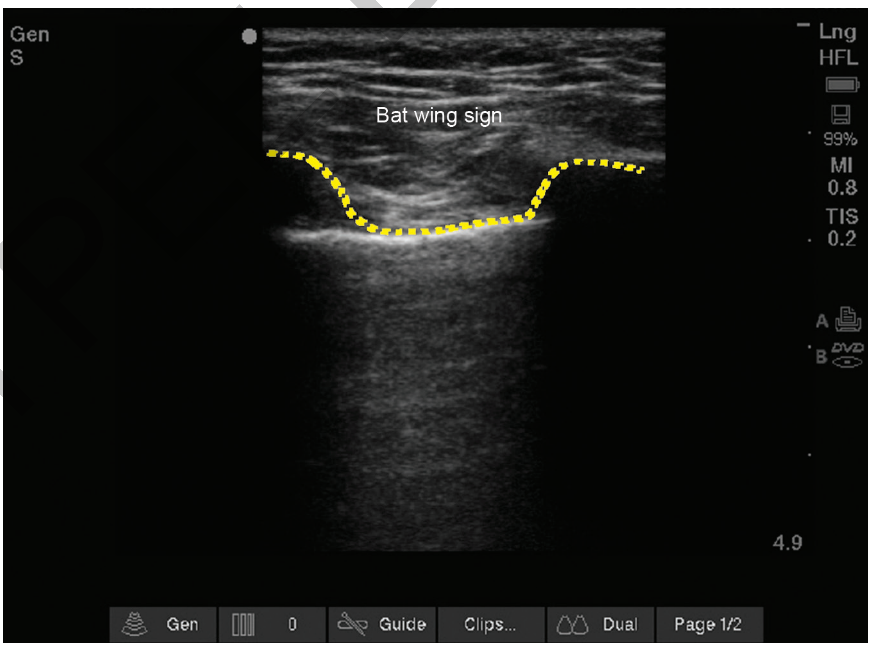


Fig. 5: Bat wing sign.

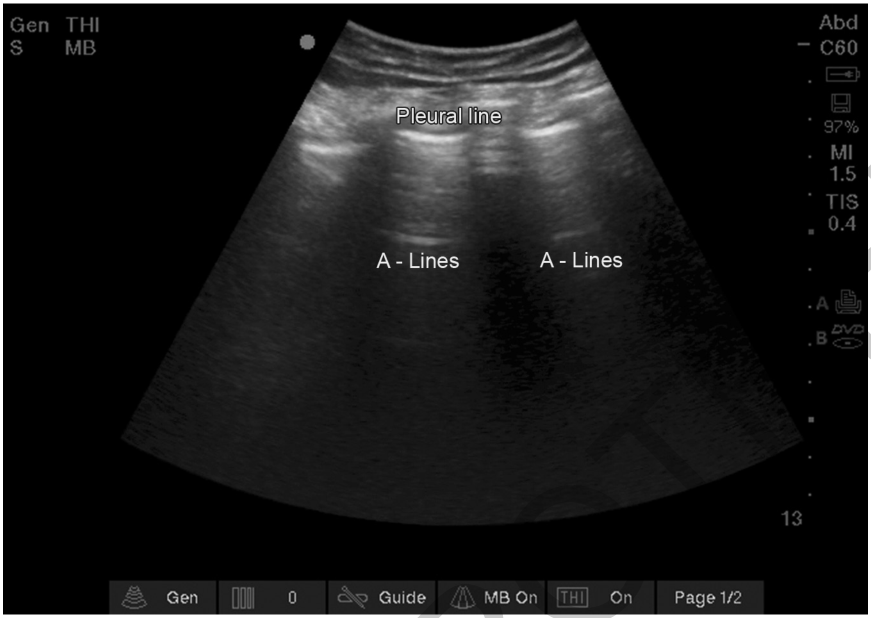


Fig. 6: A-lines.

curtain. This is called "lung sliding sign". Presence of this sign ensures presence of ventilation in the scanned zone. Absence of lung sliding points toward a diagnosis of pneumothorax or hyperinflated lungs.

Seashore sign: When M-mode is placed in the center of the pleural line, a "seashore sign" appears on the screen. The tissue above the pleural line is seen as static, linear lines while due to the scattering of sound waves by lung tissue below the pleura, sand-like granules are seen below the pleural line. The image resembles that of a sandy shore and sea junction, hence the name. Its presence again is interpreted as a normally ventilated lung zone **(Fig. 7)**.

Lung pulse: Pulses generated by the beating heart are normally transmitted to pleura. In the absence of lung sliding, movement of the pleural line may still be visible synchronous to the heartbeat. Though similar to the lung sliding sign prima facie, its coinciding with heartbeats helps in differentiation. This indicates that the lung zone is not being ventilated; bronchial intubation, lung contusion, hyperinflation of lung zone, or early atelectasis.

B-lines: The first International Consensus Conference on LUS defined B-lines as "discrete laser-like vertical hyperechoic reverberation artifacts that arise from the pleural line and extend to the bottom of the screen without fading".[2] These lines move synchronously to the pleural lines. Increased density in interstitial spaces generates these lines. The presence of up to three discrete lines in each zone is considered normal. An increase in their number or coalescence of B-lines is an indication of deteriorating lung aeration and presence of an underlying pathology.

LUNG SCORING FOR SEMIQUANTITATIVE ASSESSMENT

Several LUS scoring systems are available. BLUE protocol or a twelve-zone examination is most

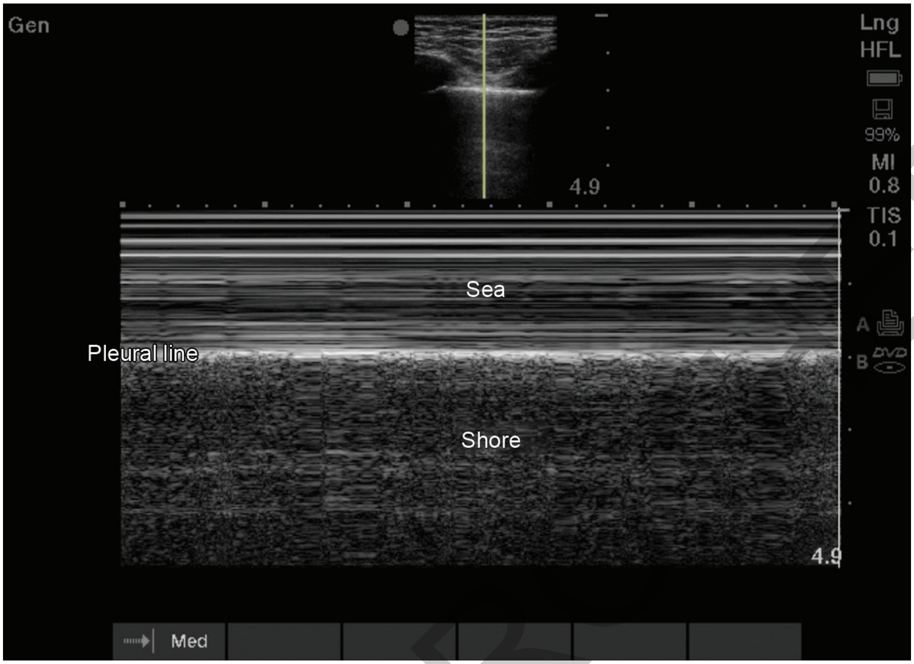


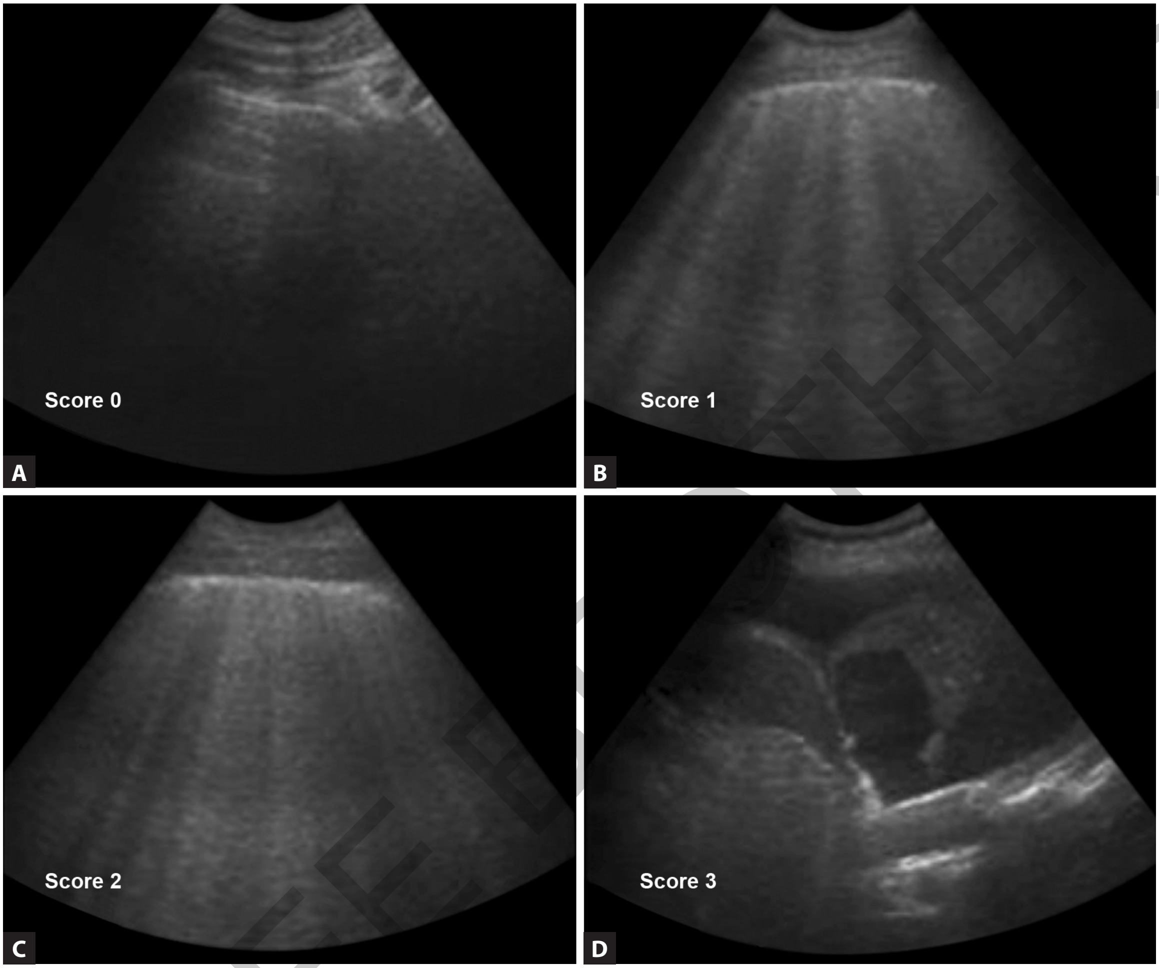
Fig. 7: Seashore sign.

TABLE 2: Semiquantitative assessment of lung zones.		
Score	***Image***	***Interpretation***
0	A-lines with lung sliding or 1–3 B-lines visible	Normal aeration
1	Greater than 3 B-lines either spaced or coalescent. Subpleural consolidation <50% scan area	Moderate loss of aeration
2	Coalescent B lines, subpleural consolidation >50% of scan area	Severe loss of aeration
3	Tissue-like pattern/ visualization of consolidated lung/hepatization of lung	Complete absence of aeration

used by critical care experts.[3] Each zone is scored from 0 to 3 depending on images obtained in the region **(Table 2 and Figs. 8A to D)**. Total LUS ranges from 0 to 36 and helps in monitoring and guiding the treatment of the patients.

LUNG PATHOLOGIES ON ULTRASOUND

- *Pneumothorax:*
  - Pneumothorax occurs when air accumulates within pleural space due to disruption of the visceral and parietal pleura.
  - *Ultrasound findings in pneumothorax:*
    - *Absence of lung sliding*: The shimmering effect of the pleural line, due to gliding of pleural layers, is absent due to air in the space.
    - *Absent B-lines:* B-lines are vertical lines that arise from the pleura and move with respiration, usually seen in normal lungs. In pneumothorax, these lines are absent.
    - *Presence of the "barcode" or "stratosphere" sign on M-mode:* When M-mode is used on the pleural line, a normal lung will show a "seashore" pattern due to



Figs. 8A to D: (A) Presence of lung sliding with A-lines or fewer than two isolated B-lines; (B) Well-defined B-lines; (C) Multiple coalescent B-lines; (D) Lung consolidation.

movement, while a pneumothorax will display a "barcode" or "stratosphere" pattern, indicating no lung movement **(Fig. 9)**.

- *Lung point sign:* The lung point is the area where the pneumothorax starts and the lung adheres to the pleura again. This is a highly specific sign for pneumothorax. The presence of a lung point is 100% specific for confirming a diagnosis of pneumothorax.
- *Pleural line shift:* In some cases, the pleural line may appear shifted or discontinuous due to air in the pleural space.

- *Pleural effusion:*
  - In various conditions, such as heart failure, infection, malignancy, or inflammation, abnormal accumulation of fluid occurs in the pleural space, known as pleural effusion, which can impair lung expansion.

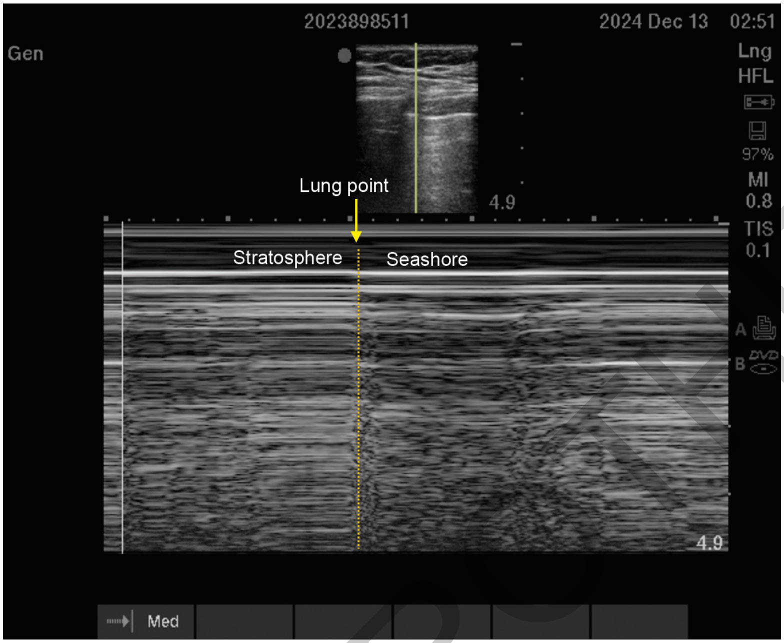
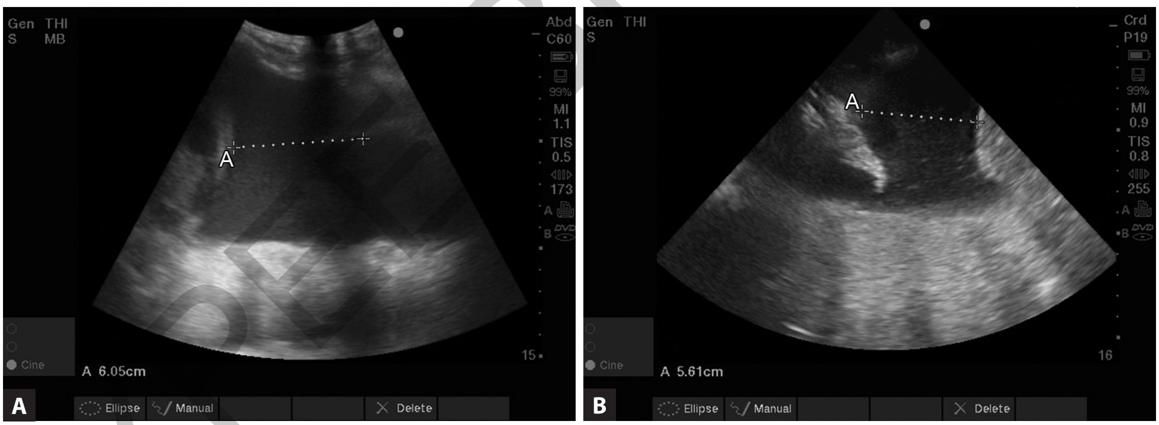
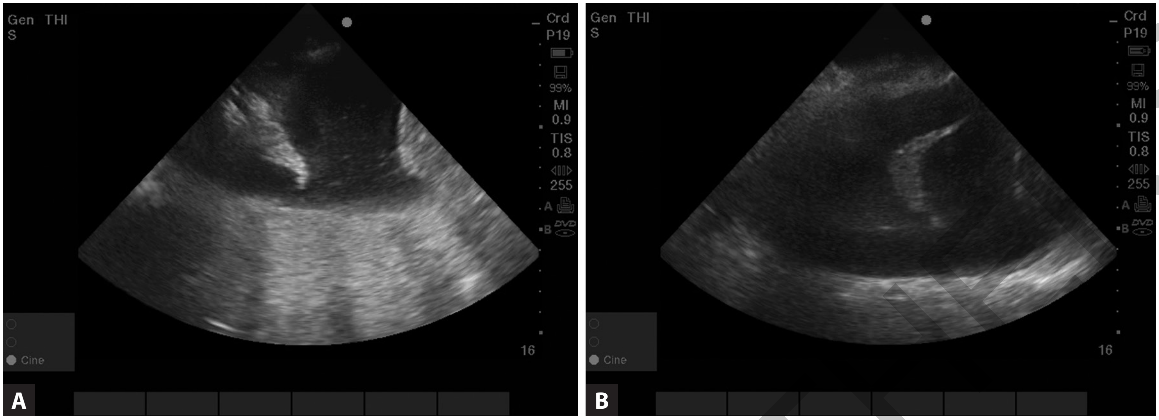


Fig. 9: Lung point (pneumothorax).

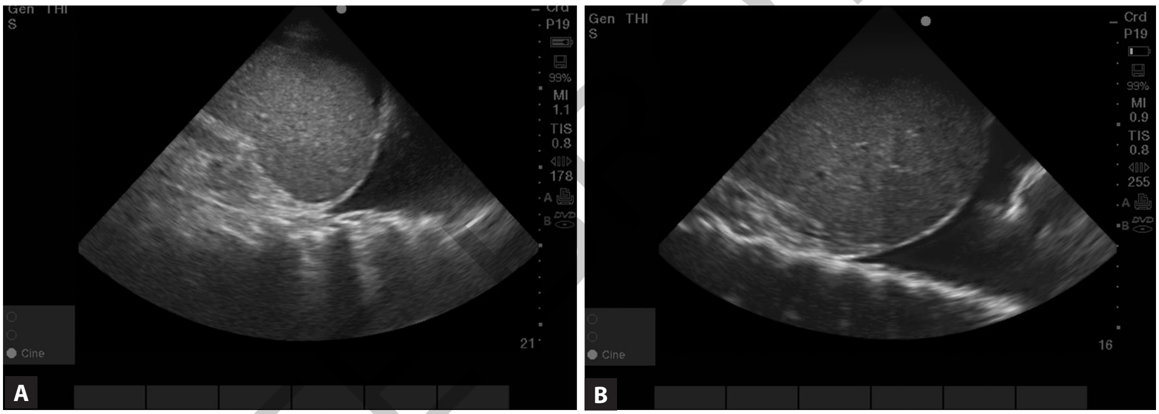


Figs. 10A and B: Fluid appears as a dark (anechoic) or less echogenic (hypoechoic) area in the pleural space.

- *Ultrasound findings in pleural effusion* ***(Figs. 10 to 14)****:*
  - *Anechoic or hypoechoic area:* Fluid appears as a dark (anechoic) or less echogenic (hypoechoic) area in the pleural space **(Figs. 10A and B)**.
  - *Floating lung or lung flapping or jellyfish sign:* The lung may appear to "float" or move within the fluid, resembling the movement of a jellyfish with respiration **(Figs. 11A and B)**.
  - *Spine sign:* The thoracic spine becomes visible above the diaphragm due to the presence of fluid, which acts as an acoustic window **(Figs. 12A and B)**.



Figs. 11A and B: Jelly fish sign.



Figs. 12A and B: Pleural effusion spine sign.

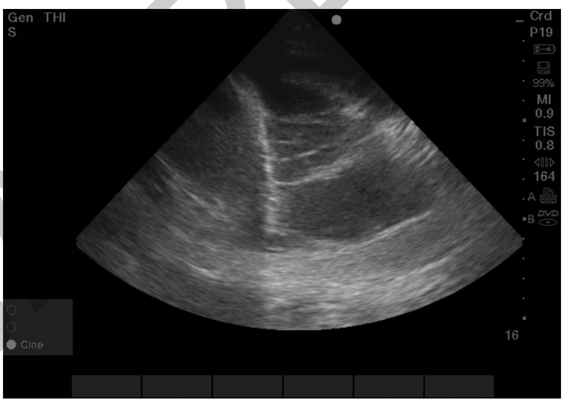
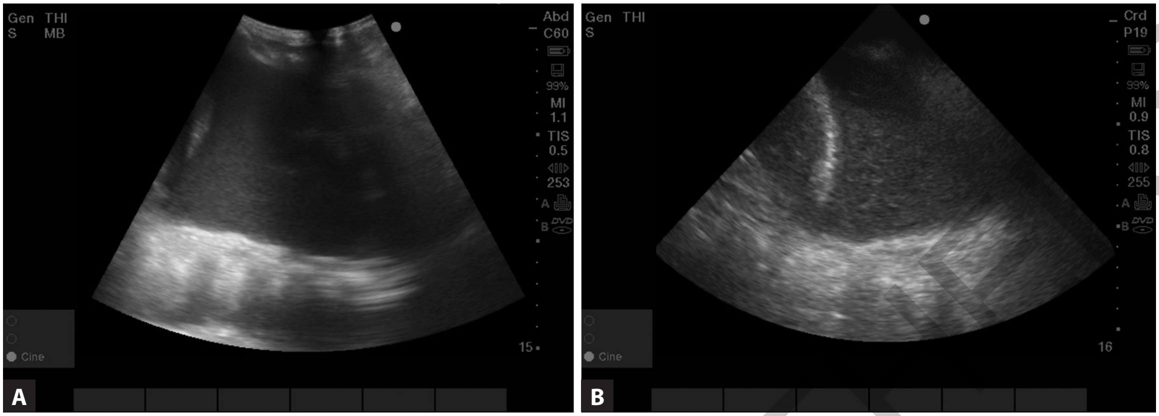


Fig. 13: Septated pleural effusion.

- *Sinusoid sign:* On M-mode, the pleural fluid between the parietal and visceral pleura shows a sinusoidal pattern, confirming the presence of free fluid.
- *Mirror image artifact:* This occurs when the liver or spleen appears to extend above the diaphragm, a sign of fluid in the pleural space reflecting sound waves.
- *Diaphragm flattening or inversion:* The diaphragm may appear flattened or inverted due to pressure from a large effusion.



Figs. 14A and B: *Hematocrit sign:* Exudative pleural effusion: spontaneous ECHO contrast (SEC).

    - *Atelectatic lung:* Echogenic lung tissue may be visualized as compressed or consolidated within the effusion, indicating atelectasis.
    - *Pleural thickening and septated pleural effusion:* In some cases, thickening of the pleura and septated pleural effusion are observed, which may suggest an exudative effusion or underlying pleural pathology **(Fig. 13)**.
    - *Hematocrit sign:* Separation of fluid and cellular contents of effusion is seen in hemothorax or exudative pleural effusion. An anechoic shadow of fluid and heterogeneously hypoechoic shadow of the cellular component is visible on LUS (**Figs. 14A and B**).
- *Pneumonia:*
  - Pneumonia is defined as an infection within the lung parenchyma that leads to consolidation, visible as a hypoechoic or echogenic area within the lung tissue.
  - Pneumonia disrupts normal aeration, resulting in a "hepatization" appearance, where the affected lung area resembles the echotexture of the liver.
  - *Ultrasound findings in pneumonia:*
    - *Dynamic air bronchograms:* Moving, bright spots within the consolidated area, representing air within bronchi.
    - *Pleural line abnormalities:* The pleural line overlying the consolidated area may be thickened or irregular.
    - *B-lines:* Vertical, hyperechoic lines that radiate from the pleural line and extend deep into the lung, often seen surrounding the consolidation.
    - *Shred sign:* The irregular or shredded border of the consolidated lung, indicating alveolar involvement **(Fig. 15)**.
    - *Lung consolidation:* The infected lung tissue appears as a solid area, often with hyperechoic punctate areas that represent trapped air **(Fig. 16)**.
- *Cardiogenic pulmonary edema:*
  - In cardiogenic pulmonary edema, fluid accumulates in the lungs due to increased pressure in the pulmonary capillaries, typically resulting from left-sided heart failure.
  - When the heart's left ventricle cannot effectively pump blood forward, pressure builds up backward in the left atrium and

Fig. 15: Shred sign.

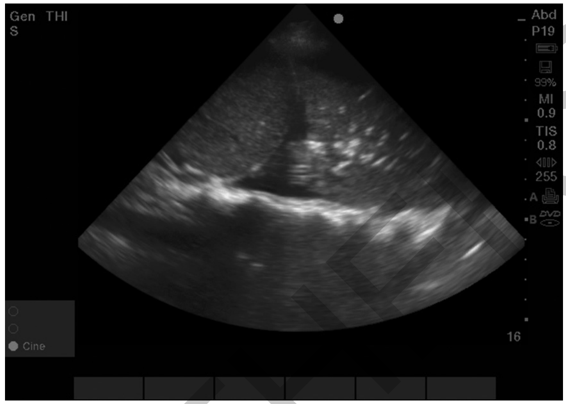


Fig. 16: Consolidation.

pulmonary veins, forcing fluid out of the capillaries and into the alveolar spaces and lung interstitium.

- *Ultrasound findings in cardiogenic pulmonary edema include:*
  - *Multiple B-lines:* Vertical, hyperechoic lines arising from the pleural line and extending deep into the lung field, resembling "comet tails." In cardiogenic pulmonary edema, multiple B-lines appear diffusely across lung fields, indicating interstitial fluid.
  - *Thickened pleural line:* The pleural line may appear thickened due to fluid accumulation in the interstitial spaces.
  - *Subpleural consolidations:* Small and patchy hypoechoic areas near the pleural surface, representing areas of lung tissue collapse or micro-consolidations due to fluid overload.
  - *Pleural effusion:* Often present as a secondary finding, typically in the dependent areas of the lung, and appears as an anechoic or hypoechoic area between the lung and chest wall.
  - *"White lung" appearance:* When B-lines are numerous and close together, they can create a near-continuous bright or "white" appearance on USG, indicating significant interstitial edema.
  - *Absence of lung sliding:* In severe cases, reduced or absent lung sliding may be seen due to the stiffness of fluid-filled lungs.

▪ *Acute respiratory distress syndrome (ARDS):*

- ARDS is a severe, inflammatory lung condition characterized by acute onset of widespread alveolar damage and respiratory failure.
- ARDS shows specific signs due to the severe, diffuse alveolar, and interstitial damage it causes. These USG findings help to differentiate ARDS from other causes of respiratory distress, such as cardiogenic pulmonary edema.
- *Ultrasound findings in ARDS include:*
  - *Multiple B-lines (comet tails) in patchy distribution:* Unlike cardiogenic pulmonary edema, B-lines in ARDS are often unevenly distributed, with both spared and affected areas. This pattern reflects the heterogeneous involvement of the lung.
  - *Thickened and irregular pleural line:* The pleural line in ARDS often appears thickened and irregular, indicating damage to the alveolar-capillary barrier.

- *Subpleural consolidations:* Small, hypoechoic areas beneath the pleura, reflecting areas of alveolar collapse or consolidation.
- *Lung sliding:* Lung sliding may be diminished in areas of severe consolidation or atelectasis but is generally preserved in other regions.
- *"Spared areas":* Unlike cardiogenic edema, ARDS often has areas of normal lung interspersed with diseased lung, creating a patchy pattern on USG.
- *Larger consolidations and air bronchograms:* More extensive consolidations with air bronchograms (air-filled bronchi within consolidated areas) may be visible, especially in the dependent regions of the lung.
- *Pleural effusion:* Less common in ARDS than in cardiogenic edema, but small effusions may be present, particularly if associated with fluid overload from treatment.

- *Chronic obstructive pulmonary disease (COPD):*
  - COPD primarily reflects hyperinflation and air trapping rather than specific structural changes, given that COPD affects the lung's ability to expand and contract normally.
  - *Ultrasound findings in COPD include:*
    - *Prominent A-lines:* Horizontal, repetitive lines below the pleural line, representing normal air artifacts due to hyperinflation and trapped air. A-lines are the dominant artifact in COPD and indicate a lack of significant lung interstitial involvement.
    - *Reduced or absent B-lines:* B-lines (vertical artifacts) are generally absent in stable COPD, as they suggest interstitial fluid, which is not a feature of COPD unless there is coexisting heart failure or infection.
    - *Thickened and irregular pleural line:* Chronic inflammation and structural remodeling in COPD can cause pleural irregularities, seen as a thickened and sometimes interrupted pleural line on USG.
    - *Decreased lung sliding:* Lung sliding, a shimmer-like movement of the pleura during respiration, may be reduced or subtle in severe COPD due to air trapping, which restricts lung movement against the chest wall.
    - *Diaphragmatic flattening and limited motion:* COPD often leads to diaphragmatic flattening and reduced diaphragmatic excursion, which can be visualized on USG. Limited diaphragm movement is associated with hyperinflation and air trapping, particularly in severe cases.
    - *Bullae or large air spaces:* In advanced COPD, large air-filled spaces (bullae) may be present, which can appear as areas without normal lung sliding and without artifacts (anechoic regions).

- *Pulmonary embolism (PE):*
  - PE refers to the obstruction of pulmonary arteries by a blood clot, which can lead to signs of lung infarction or associated complications rather than direct visualization of the embolism itself, as USG cannot directly visualize clots in the pulmonary arteries.
  - However, certain indirect USG findings may suggest PE, especially when combined with clinical suspicion and other imaging modalities, such as echocardiography and Doppler USG for deep vein thrombosis (DVT).
  - *Ultrasound findings in PE include:*
    - *Wedge-shaped and pleural-based consolidations:* Hypoechoic, triangular

areas adjacent to the pleura, often in the lung periphery. These may represent pulmonary infarcts caused by emboli obstructing blood flow.

- *Absence of B-lines:* In affected areas, there is often a lack of B-lines (which indicate interstitial fluid), as PE typically leads to infarction rather than interstitial fluid accumulation.
- *Peripheral hypoechoic lesions:* Small, round, or wedge-shaped hypoechoic lesions with or without air bronchograms may be seen in the lung periphery, indicating infarction.
- *Pleural effusion:* A small, unilateral pleural effusion may be present, often on the side of the embolism, due to local inflammation or infarction.
- *Right ventricular dysfunction on cardiac USG:* A common finding associated with PE, visible on echocardiography, includes right ventricular dilation and dysfunction, indicating increased pulmonary pressure and strain due to embolic obstruction.

LIMITATIONS

Lung ultrasound is a highly operator-dependent technique. Since LUS is mainly interpretation of artifacts, the images obtained are influenced by the selection of probe, depth, and gain settings. Careful interpretation of scans is thus required to prevent false negatives and false positives in the diagnosis and monitoring of patients. There are certain conditions when LUS fails to be of help **(Table 3)**.

TABLE 3: Limitations of LUS.

Condition	*Reason*
Subcutaneous emphysema	Ultrasound waves are unable to pass through air interfaces, LUS fails to come to aid in patients with subcutaneous emphysema
Heavy body habitus	Obese and heavily built patients may have obscured lung window due to increased depth of viscera
Asthma/COPD/ pulmonary embolism	Imaging same as in normal lung. Diagnosis is not possible by LUS alone

(COPD: chronic obstructive pulmonary disease; LUS: lung ultrasound)

CONCERNS

For practical purposes, routine and frequent use of USG for monitoring and guiding the management is considered safe for the patients. Animal models have shown incidences of pulmonary capillary hemorrhage, raising concerns of safety of its use in monitoring the progress of diseases. Such incidences, however, have not been replicated in human subjects.

CONCLUSION

Lung ultrasound has rapidly gained acceptance in emergency departments, semi-ICUs, ICUs, and even wards for bedside assessment of patients. It can aid in diagnosing etiology behind hypoxemia in up to 90% cases.[4]

A thorough training though is essential before one starts using USG machine for routine lung scans in their settings. Rocca et al.[5], have rightly pointed out that beginners in LUS are able to identify A-lines, B-lines, consolidation, and pleural effusion, a further experience enables one to recognize sliding signs, lung pulse, lung point, interpretation of air bronchograms, and quantification of pleural effusions. Advanced and expert LUS users are able to compute LUS scores and use them to guide management and ventilation strategies. The number of scans needed or the duration of experience required to reach to that level has not yet been defined. Nevertheless, LUS continues to be an important tool in our everyday practice.

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PULSE

Emergency Ultrasound Guide

Salient Features

- Emphasizes the proactive use of ultrasound to address life-threatening conditions before they become severe
- Focuses on rapid identification of emergency conditions
- Guides the use of ultrasound for critical interventions
- Enhances bedside diagnostic capabilities
- Empowers physicians to make informed, real-time decisions at the patient's bedside to improve overall care.

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