Pulmonary ultrasound in the intensive care unit

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Abstract

Pulmonary ultrasonography (PUSG) is a new diagnostic tool for pleuropulmonary disease in the critically ill patient. Images obtained in this study result from the interaction between the ultrasound shaft with the pleura, the pulmonary parenchyma and the air/liquid interface. These images are classified as horizontal and vertical. Their correct identification and interpretation requires a learning curve. Currently, PUSG is an excellent alternative to evaluate pulmonary condition of hospitalized patients in the intensive care unit (ICU). Sensitivity and specificity are high for pneumothorax, alveolar-interstitial syndrome and pleural effusion diagnosis. PUSG practiced in the ICU is one of the most promising diagnostic procedures in intensive care medicine, and the practice and indications of this tool will surely extend in the coming years. The objective of this study is to make known the general principles of PUSG and their use in the critically ill patient, based on cases of hospitalized patients in the ICU of the Medica Sur Clinical Foundation that were studied with PUSG.

Key words: pulmonary ultrasonography, seashore sign, pneumothorax, alveolar-interstitial syndrome.

Ultrasonography (USG) is a diagnostic procedure used daily in clinical practice. In emergency rooms, intensive care medicine and anesthesiology, it is useful to establish the diagnosis (ultrasound FAST) and to guide invasive procedures such as placement of central catheters, drainage of collections (abscesses, ascites, pleural effusion, etc.), regional blocks of plexus and nerves. This has positioned the USG as an indispensable tool for intensivist because it has the advantages of being noninvasive, cost-effective and practiced at the patient’s bedside.1

USG assessment of the chest can be performed with the patient in the sitting or decubitus position. In most studies a high-frequency linear transducer (5-7.5 MHz) is recommended for assessment of the chest wall, whereas for the study of the lung and pleura, it is recommended to use a lower frequency in the range of 3.5 MHz. It has recently been described that the new USG convex transducer with high frequency (10-13 MHz) has better resolution.2,3

Pulmonary evaluation by imaging studies in seriously ill patients is done routinely by simple chest x-ray and computed tomography (CT). Pulmonary USG (PUSG) has not been traditionally considered due to the misconception that artifacts are observed due to the presence of air, limiting its use to drain pleural collections and sometimes for punctures directed at peripheral tumors.

Fundamentals of PUSG

Based on the ultrasonographic principle that air reflects sound waves, PUSG was not considered as a useful diagnostic tool. It was not until 1986 when Rantanen described the utility of ultrasound for pleural pulmonary evaluation of horses, which led Werneck et al. to introduce it into clinical practice. In this publication, the pleural pulmonary image of eight patients with pneumothorax was described, which he compared with 20 healthy subjects and concluded that in patients with pneumothorax normal pleural mobility disappeared.4,5

Normal PUSG Imaging

The image shown in PUSG is the result of the interaction between air and interstitial lung tissue with ultrasound beam. In the image, obtained artifacts were observed with different levels of intensity.
and echogenicity in gray scale, both in real time as in the M-mode (motion time), which are horizontal and vertical, with proper identification being essential for proper interpretation of the normal anatomic/structural elements.

The first step for PUSG evaluation is to define the interface between the chest wall and lungs through the identification of the pleural line. To locate this line, the ribs are identified, which emit a hypoechoic and acoustic shadow in real time. The pleural line is a hyperchogenic image, well delimited between two ribs and represents the parietal and visceral pleura. Under normal conditions the pleural line has an undulating movement that follows the respiratory movements (“gliding” sign) and represents shifting of the visceral pleura over the parietal. The three key elements for identifying the pleural line are hyperechoic line below the ribs, undulating movement that follows respiration, and presence of horizontal and vertical artifacts underneath that give different images.

Horizontal Artifacts

The main horizontal artifacts are “A lines” characterized by being short horizontals, hyperchogenic and that appear cyclically with a pattern similar to the distance from the transducer to the pleural line and represent the reverberation of sound over it (Figure 1).

Vertical Artifacts

Vertical artifacts are B, Z and E lines. “B lines,” better known for their morphology as “comet tail” are generated by ultrasound resonance originating in a rigid structure surrounded by air, such as the interalveolar septum. B lines have the following USG characteristics: 1) verticals and well-defined triangulars, 2) a vertex that originates in the pleural line and base that directs itself to the pulmonary parenchyma, 3) extend up to the end of the image (longitude up to 17 cm) 4) cross and erase A lines, 5) synchronous movement with pleural displacement. Under normal conditions the “comet tails” are sole or multiple artifacts, up to three in number with a distance of 7 mm between each of them. Occasionally, B lines <1 cm in length can be observed, which have no significance. The simultaneous presence of multiple B lines with a 3-5 mm distance between each are called “rockets.” They are more clearly identified in the anterolateral region and are associated with interstitial pulmonary disease or congestion (equivalent to Kerley B lines) (Figure 1).

“Z lines” are vertical artifacts that resemble B lines and have no pathological significance. They can occasionally be seen in the pneumothorax. They have the following characteristics: 1) they originate in the pleural line and have a depth of 2-5 cm, 2) they do not erase A lines, 3) they are short in the sense that they do not extend up to the limit of the image, and 4) they do not follow pleural movement (Figure 1).

“E lines” (E, for emphysema) are secondary to subcutaneous emphysema. They are characterized by being vertical lines that adopt the morphology of a laser beam (fine hyperchogenic image). They originate above the pleural line, and its starting point is the thoracic wall.

Beach Sign

Pulmonary movement is clearly observed in M-mode, which shows the difference between the pattern that resembles waves located above the pleural line (continuous, undulating and hyperchogenic) and a granular pattern (below) resembling sand; hence, the term “beach” sign. This image is highly useful to rule out various entities as described in the second part of this study (Figure 2A).

PUSG Patterns in the Seriously Ill

The most often described USG patterns in the literature are those which present themselves in pneumothorax, alveolar-interstitial (A-I) syndrome, and pleural effusion.

Pneumothorax

The prevalence of pneumothorax in the ICU is 6% and is usually secondary to barotrauma and dynamic hyperinflation. Clinical and simple chest x-rays are the diagnostic modalities used universally for its diagnosis, but it underestimates in up to 30-40% of cases, especially in emergency situations and in polytraumatized patients. The majority of undiagnosed patients will develop tension pneumothorax, especially those on mechanical ventilation. The concept of occult pneumothorax describes the cases of pneumothorax without clinical or radiographic manifestations and for which a CAT scan of the chest is the gold standard for diagnosis. However, there are drawbacks to performing a CAT scan, such as

![Figure 1. Pulmonary ultrasound (PUSG) showing pleural line (PL), A line, Z line, B line.](image-url)
the need for transfer of the patient (usually unstable, with many lines, dependent on vasopressors and inotropes and mechanical ventilation) to the imaging service. Along with the high costs of CAT, USG offers an excellent diagnostic alternative in serious disease.11-15

USG images of pneumothorax are as follows;16,17

- Loss of undulating movement (lung sliding) of the pleural line, which is in relation to the non-displacement of the two pleural leaves due to the presence of air. This dynamic sign is accentuated in M-mode in which the loss of the pleural dynamics and the air give an image of horizontal lines superimposed on what is called the “stratosphere” sign. Loss of pleural undulating movement is not pathognomonic of pneumothorax and has a specificity of 96.5%. Its absence, in addition to the pneumothorax, has been described in pleural fibrosis, pachypleuritis, pulmonary condensation and adult respiratory insufficiency syndrome (ARIS), considerations which should be taken into account when performing an ultrasound study (Figure 2B).18-20

- Another pneumothorax dynamic sign modification of the USG pattern associated with respiratory movements (inspiration-expiration) is related to pleural and parenchymal displacement and preferentially presents itself when the pneumothorax is anterior and is not under tension. The image observed is a changing pattern of pleural displacement, A lines and B lines with “beach” sign in M-mode during inspiration due to loss of undulating movement of the B lines and beach sign, which is substituted by the “stratosphere sign,” during expiration. This image is called “lung point sign” (Figure 3).21,22

- “A lines” are part of the normal USG pattern, but can also be seen in pneumothorax. A lines are generated by the static barrier air imposes on the ultrasonic beam. The presence of A lines in pneumothorax are called “A line” sign.22

- Another USG sign seen in pneumothorax are “O lines” (not A or B lines), which are characterized by the presence of a pleural line that has no movement and has absence of A and B lines. In these cases the movement of the transducer may show some A lines.22

- In some cases “Z lines” may be present with the following characteristics: originate in the pleural line, are vertical, do not erase the A lines, are well-defined, from 2 to 5 cm in length, and are independent of pleural displacement.

- The presence of B lines (comet tails) rules out the diagnosis of pneumothorax because it causes loss of the acoustic impedance between the air and water of the subpleural interlobular septum. For this reason, when faced with suspicion of pneumothorax, the operator must be cautious in its detection.23

PUSG has a sensitivity of 100%, specificity of 91% and positive predictive value (PPV) of 87% for the diagnosis of pneumothorax. The “A line” sign has a sensitivity and negative predictive value (NPV) of 100%, specificity of 60% and PPV of 42%. The pulmonary point sign has a sensitivity of 66% with a specificity of 100%. The absence of B lines has a sensitivity and specificity of 97% for diagnosis of pneumothorax. Unlike these findings, the simple chest x-ray obtained at the bedside has a sensitivity of 36%. PUSG is positioned as an excellent alternative for the diagnosis of pneumothorax in the very ill patient, in the emergency service, and even during transfer of the patient because it detects small and incipient pneumothoraces that cannot be diagnosed clinically or with simple chest x-ray. It must be taken into account that apical, mediastinal and posterior pneumothorax are difficult to visualize due to their anatomic location.24,25

**Figure 2.** (A) PUSG in M-mode where pleural line (PL) and beach sign (SP) are shown. Note the granular USG pattern. (B) Stratosphere sign (SE). Superior image, loss of PL and absence of B lines is observed. Simultaneous inferior image in M-mode where horizontal lines are seen exclusively (characteristic of the “stratosphere” sign), loss of PL and SP.
Pleural Effusion

USG image of pleural effusion is characterized by loss of pleural movement and air fluid level in which characteristically there is an anechoic image present that delineates the collapsed lung due to the effect of the fluid accumulated in the pleural cavity. This follows the effect of the illness and the respiratory movements and determines the image of the “curtain” sign that presents itself in real time as well as in M-mode (Figure 4).26

Alveolar-Interstitial Syndrome

In intensive care medicine there are a large number of entities characterized by having alveolar-interstitial involvement. Some that stand out are ARIS, pneumonia, pulmonary edema, and interstitial diseases. Their USG pattern is well defined and, in general terms, are called A-I syndrome, which is characterized by the following:27,28

- Loss of pleural motion
- Loss of the pleural line in pulmonary condensation
- The characteristic USG image is that of the presence of multiple B lines, usually more than three per field, which are called rockets. The distance between each of these is from 5-7 mm. When they are very thin they are called laser lines (Figure 5).
- B lines and the pattern that they adopt are due to the marked difference in the acoustic impedance between air and water because of the thickening of the interlobular septum due to edema or fibrosis. The number of B lines is directly proportional to the A-I involvement.
- Comet tails are more frequent when the interstitial lesion is due to fibrosis.

ARIS

Routine evaluation of ICU patients is done with chest x-ray, but it has significant limitations for integral assessment of pulmonary involvement. CAT scan has become the gold standard for evaluation of disease extension, the proportion of collapse or alveolar condensation in relation to the healthy lung, and the effectiveness of the alveolar recruitment maneuvers. Its main limitation in the severely ill patient is the need to transfer the patient to the imaging department, which limits its application in daily
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In conclusion, based on our experience and scientific evidence we can say that the current PUSG in the ICU is a non-invasive procedure with high sensitivity, specificity and predictive value, as well as being cost-effective and accessible at any hospital. It requires a simple learning curve and, for this reason, will certainly be positioned as an excellent tool for integral diagnostic approach and daily monitoring of seriously ill patients.

References


Figure 6. USG image of acute respiratory insufficiency syndrome (ARIS) where multiple B lines are seen that emerge from the PL, PE and pulmonary collapse (PC).

