Intensive Care Med (2011) 37:224–232
DOI 10.1007/s00134-010-2079-y

REVIEW

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Sonographic diagnosis of pneumothorax

Received: 11 July 2010
Accepted: 9 September 2010
Published online: 20 November 2010

Electronic supplementary material
The online version of this article (doi:10.1007/s00134-010-2079-y) contains supplementary material, which is available to authorized users.

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Abstract *Purpose:* Over the last decade, the use of ultrasound as a technique to look for pneumothorax has rapidly evolved. This review aims to analyze and synthesize current knowledge on lung ultrasound targeted at the diagnosis of pneumothorax. The technique and its usefulness in different scenarios are explained, and its merits over conventional radiology are highlighted. *Methods:* A systematic literature search (1995–2010) was performed, involving PubMed, to describe the more recent scientific evidence on the topic. Moreover, this review is also a synopsis of experts' opinion and personal clinical experience. *Results and conclusions:* Ultrasound diagnosis of pneumothorax relies on the recognition of four sonographic artifact signs: the lung sliding, the B lines, the lung point, and the lung pulse. Combining these few signs, it is possible to accurately rule in or rule out pneumothorax at the bedside in several different clinical scenarios. Sensitivity of a lung ultrasound in the detection of pneumothorax is higher than that of conventional anterior–posterior chest radiography, and similar to that of computerized tomography. A major benefit of a lung ultrasound is that it can be used quickly to diagnose pneumothorax at the bedside in any critical situation, like cardiac arrest and hemodynamically unstable patients. Moreover, it can be used to detect radio-occult pneumothorax and to quantify the extension of the air layer. Advantages in terms of reduced complexity, feasibility at the bedside, and absence of exposure to ionizing radiation make lung ultrasound the method of choice in several common clinical situations.

Keywords Emergency ultrasound · Lung ultrasound · Pneumothorax · Chest sonography

Introduction

For many clinicians, detection of pneumothorax (PNX) by bedside ultrasound is a novel application. Although sonography is an old technique, the idea that ultrasound does not traverse air for many years prevented its application in the assessment of lung disease. Only in the last decade, several studies provided evidence that lung ultrasound (LUS) is useful for the bedside diagnosis of pulmonary consolidations, pulmonary edema, and PNX, in addition to already established applications, such as the diagnosis of pleural effusion and pleural masses [1–6]. Such LUS applications are particularly useful in the emergency setting. Modern LUS developed thanks to improved understanding of the meaning of sonographic artifacts caused by the interaction of the sonographic beam with air, fluids, and tissues. Lung diseases are characterized by a change in the relationships between air and water. Depending on the location and magnitude of such changes, a distinction can be made between three different sonographic syndromes: (1) the pleural syndrome (pleural effusion, PNX, pleural masses), characterized by presence of fluid, air, or abnormal tissue in the pleural space; (2) the interstitial syndrome (pulmonary edema, pulmonary fibrosis, interstitial pneumonia), characterized by slight increase of fluid in the interstitium and reduced air in the alveolar spaces; and (3) the alveolar syndrome (pneumonia, atelectasis, contusion, cancer, infarction), characterized by fluid with complete loss of air in the alveolar spaces, leading to consolidation. Sonographic semiology of lung diseases is based on the recognition of artifacts rather than visualization of real structures. Paradoxically, the role of artifacts as indicators of real clinical conditions is anything but an abstraction. Many pulmonary conditions may be diagnosed or excluded through the recognition and interpretation of artifacts [1–5].

In PNX, air is confined in the pleural space, thus lying between the sonographic probe applied to the thorax wall and the lung. This condition prevents the diffusion of the sonographic beam deep into the parietal pleura and thus the visualization of deep lung structures. Theoretically, this phenomenon would bar any diagnostic application of LUS. However, the recognition of certain dynamic sonographic artifacts makes the use of LUS at the bedside useful for the detection and quantification of PNX. In clinical practice, out of the many modern potential applications of LUS in the bedside evaluation of lung diseases, its use for diagnosing PNX is one of the most effective. Although the sonographic semiology of PNX is not difficult, the relative rarity of this disease compared to other pulmonary conditions impairs the acquisition of appropriate skills. The purpose of this review is to facilitate the acquisition of the technique and provide the reader with the latest scientific evidence of its practical usefulness.

Methods

We searched for relevant English-language original articles, reviews, editorials, and letters by using PubMed (1995–July 2010), based on keywords in title, abstract, and MeSH terms. We used the following search terms: “lung ultrasound”, “chest ultrasound”, “chest sonography”, “thoracic ultrasound”, “thoracic sonography”. This review not only summarizes scientific evidence based on data from original studies, but also reports experts’ opinion drawn from published editorials and letters, presentations, and open discussions that were held during the recent international conferences on intensive care medicine (http://www.startpromotion.net/2010_SMART/) and emergency ultrasound (http://www.winfocus.org/world/; http://www.efsumb.org/intro/home.asp) and debate during the First International Consensus Conference on Pleural and Lung Ultrasound (http://www.winfocus.org/world/plus). Finally, opinions and beliefs coming from the personal clinical experience of the author are also reported.

Technical equipment

Sonographic diagnosis of PNX can be performed by using basic technology and any probe. This is a general rule for LUS, but in particular it is well suited for the evaluation of PNX, whose diagnosis relies on the recognition of very simple signs. The linear high frequency probe (5–12 MHz) is well suited for the analysis of the pleural line, which is superficial and easily visualized even in obese and large patients. Convex and micro-convex probes, working at lower frequencies (2–5 MHz), are more indicated to evaluate under-pleural artifacts. The conventional B-mode imaging is adequate. The color Doppler and M-mode technologies are helpful only occasionally. For real-time emergency application, the only fundamental prerequisites are: (1) that the unit should be easily portable from bed to bed and (2) a minimum required image quality. Most of the old and modern mobile units have these qualities.

The technique

Except for rare occasions discussed later, in PNX air in the pleural space tends to accumulate in the least-dependent part of the chest [7, 8]. This area can be easily located through the observation of the patient and the consideration of where any amount of air confined in the pleural space should be placed according to anti-gravity laws [8]. When the patient lies in the supine position, the area of interest corresponds to the anterior and inferior part of the chest on both sides of the thorax, approximately the third–fourth intercostal space between the parasternal and the mid-clavicle lines (Fig. 1) [8, 9]. This location is easy to scan in almost all in-hospital patients, regardless of the clinical condition, patient habits, and respiratory movements. The probe should be gently placed in the intercostal acoustic window of the located area. In an adult, the focus should be set superficial, aligning it to the height of the pleural line, generally 0.5 cm below the rib surface. The initial plane should be longitudinal, with the long axis of the probe parallel to the long axis of the patient’s body. This plane allows visualization of at least two ribs and the corresponding intercostal space (Fig. 2). Beginning the procedure through this plane is important, as it also allows inexperienced physicians to identify immediately the main target, i.e., the parietal pleura [10]. The latter appears as a

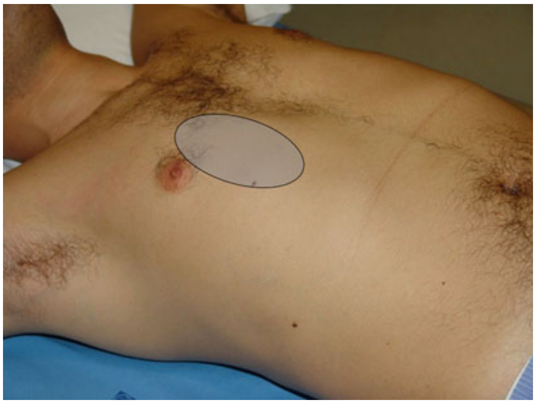

Fig. 1 The anterior–inferior chest area (*grey area*) in the supine patient, corresponding to the third–fourth intercostal space between the parasternal and the mid-clavicle lines. Sonographic evaluation for pneumothorax should always begin from this area

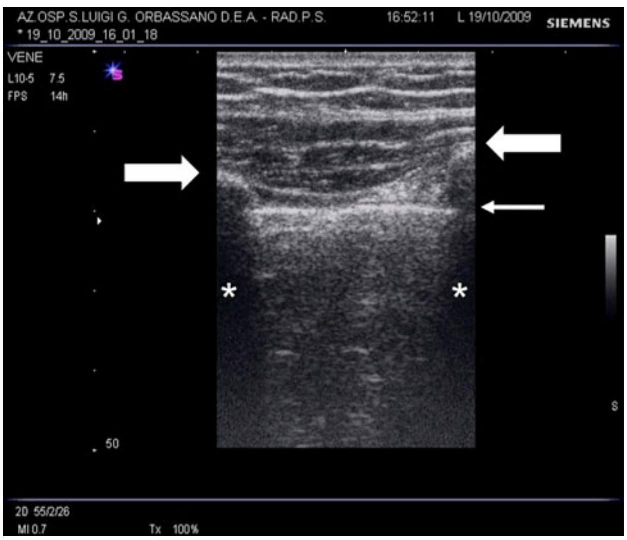

Fig. 2 Longitudinal lung ultrasound scan of the anterior chest, allowing visualization of two adjacent ribs (*large white arrows*), two rib shadows (*white asterisks*), and the parietal pleura between and under the ribs (*thin white arrow*). This plane allows a safe detection of the echogenic pleural line

thin echogenic horizontal line located between and below two adjacent ribs (Fig. 2). Without a simultaneous visualization of ribs and pleura, the sonographer may mistake the echogenic costal surface for the pleural line. Once the pleural line corresponding to the parietal pleura has been detected, the probe can be slightly rotated to correspond to the long axis to the intercostal space. This is known as the oblique plane, which allows the visualization of a larger extension of the pleural line. Sometimes, it is necessary to scan more intercostal spaces by moving the probe laterally and inferiorly, in order to evaluate the extension of PNX or to confirm the diagnosis (Fig. 3).

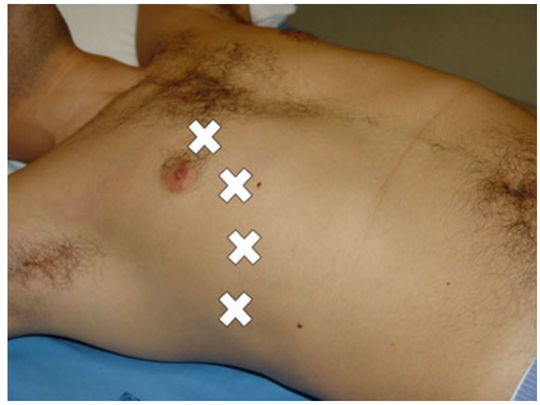

Fig. 3 The probe is moved progressively toward the lateral chest, checking for lung sliding at different locations (*white crosses*). When lung sliding is absent in the anterior chest, this procedure is useful to look for the area where the lung adheres again to the parietal pleura. The point on the chest wall where lung sliding intermittently appears during respiration is the lung point. Detection of the lung point is useful to confirm pneumothorax and evaluate its extension

Sonographic signs of PNX

Sonographic semiology of PNX may appear complex, as it relies on recognition or exclusion of several ultrasound dynamic artifacts. This complexity is only apparent, because even brief training and a few supervised experiences allowed safe and reproducible recognition of these signs on video clips by pre-hospital physicians and by non-physician heath care providers using portable devices on a porcine model [11, 12]. The most important issue to be learned is how to combine different signs in different settings, in order to achieve the highest accuracy of the method. This is related to the exact knowledge of the sensitivity and specificity of each independent sign in different clinical situations.

Lung sliding

The first important dynamic sign to be checked is the "lung sliding". It is a slight and bright horizontal movement of the pleural line which can be checked in a few seconds and is more evident during active and passive respiration [10]. The resolution of the sonograph does not allow distinction between the two pleural layers, and the sliding is an indirect sign indicating the presence of the visceral pleura adhering to the parietal pleura. When air separates the two pleural layers, the movement disappears and cannot be detected by LUS. In this case, the parietal pleura is still visualized but does not move. Separate detection of lung sliding on the anterior–inferior areas of the two hemithoraces in the supine patient confidently allows exclusion of PNX in the critically ill with a negative predictive value of 100% [1, 10]. The color Doppler technology may be of some help when the sliding is doubtful because a blush of color under the pleural line is detected only when the lung is moving with respiration and adheres to the parietal pleura [13, 14]. The M mode is useful only in order to objectify the motion of the pleura on a printable image [1]. However, the absence of lung sliding does not necessarily confirm PNX, since several other conditions, like massive atelectasis, main-stem intubation, pulmonary contusion, ARDS, and pleural adhesions, may cause motionless pleural line [15]. These conditions are particularly frequent in critically ill patients, i.e., those most in need of an early sonographic diagnosis. For these reasons, when LUS is applied in emergency and critical situations, the specificity of absent lung sliding in predicting PNX is reduced, ranging from 91% in the general population to 78% in ICU patients and 60% in ARDS patients [1, 10, 16]. In a recent study on critically ill patients, the positive predictive value of absent lung sliding was as low as 22% [17]. Safe rule-in of PNX by LUS must necessarily rely on other sonographic signs. Particularly main-stem intubation does not present a significant problem because the non-ventilated lung shows other sonographic signs that allow prompt distinction from PNX.

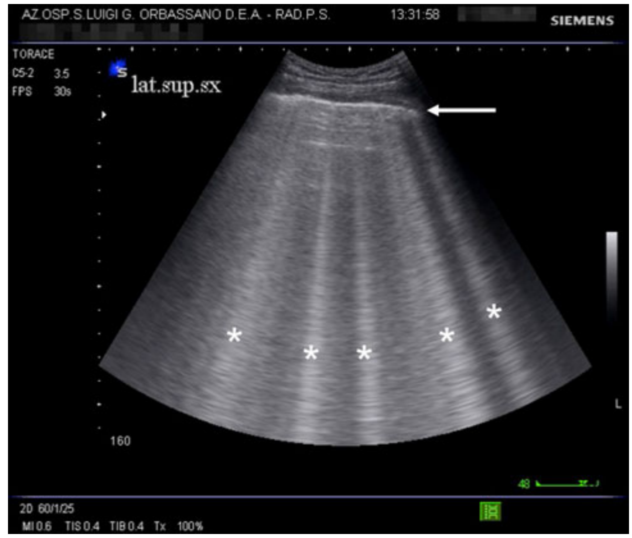

Fig. 4 Lung ultrasound scan showing multiple B lines (*white asterisks*). Features of B lines are that they arise from the pleural line (*white arrow*) and spread vertically like echogenic rays, reaching the lower edge of the screen without fading. Further, they move synchronously with the respiratory movements

B lines

In an ultrasound evaluation of the lung, the area deep to the pleural line is considered as the artifact zone. Air in the alveolar spaces does not allow visualization of real structures, while it gives an under-pleural finely sparkling typical uniform background pattern. Often, some well-defined horizontal or vertical linear echogenic artifact can be visualized. Among the vertical artifacts, the “B lines” are particularly important for the diagnosis of PNX. B lines arise from the pleural line, spread vertically like echogenic rays, reach the lower edge of the screen without fading, and move synchronously with the respiratory movements (Fig. 4) [18–21]. These artifacts are the result of multiple reflection of the ultrasound beam between two elements with opposite acoustic impedance, such as the alveolar air and the fluid of interlobular septa. The number and diffusion of B lines rise when the fluid content increases in the diseased lung [22–24]. Often, B lines are also visualized in the normal lung, even if isolated in some specific areas of the chest [25]. In the LUS diagnosis of several lung conditions, B lines are the main sonographic sign to be checked. In PNX, their significance is indirect, because visualization of even one isolated B line represents a safe demonstration of the adherence of the visceral pleura to the parietal pleura [1]. Visualization of B lines rules out PNX with a true negative rate of 100% [26]. Obviously, the absence of B lines is not a powerful indicator of PNX.

Lung pulse

In addition to horizontal lung sliding, other movements of the pleural line can be visualized by LUS. Occasionally, in the absence of lung sliding, a vertical movement of the pleural line synchronous to the cardiac rhythm can be detected. It is called the “lung pulse”, and can be caused by the transmission of the heart beats through a consolidated motionless lung, as well as by apnea subsequent to pharmacological paralysis or simply by breath holding in the absence of disease [15, 27]. This sign is very useful to differentiate PNX from other conditions characterized by the absence of horizontal pleural motion. In a study on patients with cardiac activity but absent lung sliding due to massive atelectasis and main-stem intubation, lung pulse was a common finding which allowed diagnosis with 93% sensitivity [15]. On the contrary, PNX is characterized by the absence of both lung sliding and lung pulse at LUS because the intrapleural air layer does not allow transmission of both horizontal and vertical movements to the parietal pleura. Thus, visualization of lung pulse rules out PNX.

Lung point

Contrary to the signs mentioned so far, the lung point allows confirmation of PNX with 100% specificity [16].

When a sonographic pattern suggestive of PNX (i.e., absent lung sliding and absent B lines) is detected in the anterior–inferior chest area of the supine patients, diagnostic confirmation can be achieved by gradually moving the probe toward the lateral–inferior chest areas (Fig. 3). This maneuver is targeted at the detection of a point on the chest wall where a respiratory pattern (i.e., lung sliding and/or B lines) is visualized again and intermittently replaces the motionless pleura. This point is named the "lung point". This is where the lung adheres again to the parietal pleura, and corresponds to the lateral edge of the intrapleural air layer, as demonstrated through comparison with CT images (Fig. 5) [28–30]. Thus, the more lateral the lung point is on the chest wall, the greater is the extension of the air layer. The presence of a lung point is 100% specific for ruling in PNX [16]. Unfortunately, the sensitivity of this sign is low because in the case of PNX with complete retraction of the lung, no lung point can be visualized. Again, as for lung sliding, sensitivity of lung point depends on the setting where LUS is applied. In the case of cardiac arrest or hemodynamic instability due to PNX, searching for the lung point is useless because most likely the lung has completely collapsed. On the contrary, in the stable patient and especially in the case of radio-occult PNX, sensitivity of the lung point is higher: when the lung point is detected, PNX can be confidentially diagnosed. On occasions, PNX extension can be assessed.

Clinical usefulness

The usefulness of LUS in the diagnosis of PNX depends on the correct combination of the four above-mentioned sonographic signs. Figure 6 shows a flowchart explaining the correct sequence to rule in or rule out the diagnosis of PNX by LUS. However, the positive and negative predictive values of each sign vary according to the clinical scenario. The step-by-step process presented in Fig. 6 may slightly change depending on the hemodynamic status of the patient, the type of PNX, and the relative setting. In our opinion, LUS may be most useful in the diagnosis of PNX in cardiac arrest/unstable patients, in the diagnosis of radio-occult PNX, in the evaluation of the extension of PNX in stable patients, and in the diagnosis of PNX in remote areas.

Cardiac arrest/unstable patient

In the extreme emergency where other image tests are not applicable, LUS is strikingly useful. Sonography can

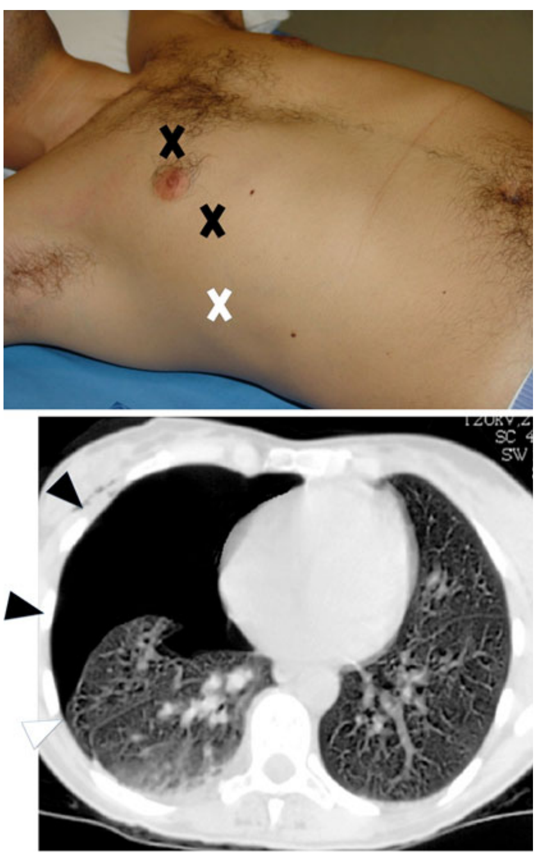

Fig. 5 *Upper panel* progression of the sonographic probe towards the lateral chest (*white crosses*) to check for the lung point (*black cross*) in the supine patient. *Lower panel* the points checked on the chest wall by lung ultrasound correspond to CT scan image (*white and black triangles*) and predict the extension of pneumothorax on the chest wall

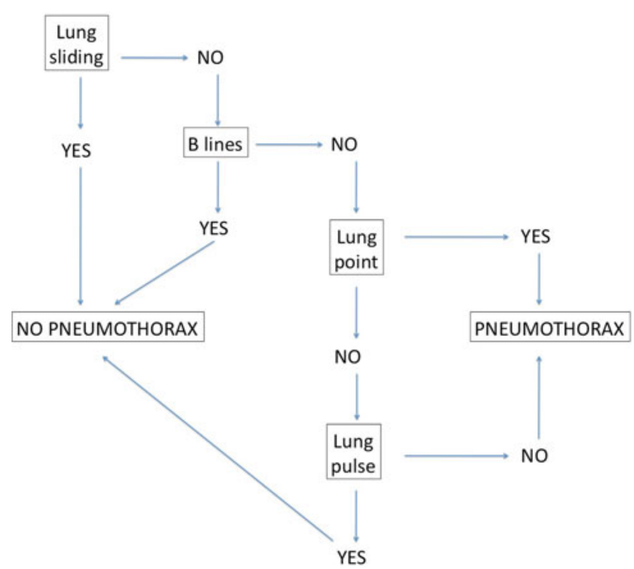

Fig. 6 Flow chart suggesting the correct sequence and how to combine the four sonographic signs to rule out or rule in pneumothorax

drive resuscitation maneuvers, improving diagnostic accuracy and increasing the physician's confidence in deciding aggressive life-saving therapeutic procedures [31–34]. Emergency ultrasound helps the prompt diagnosis of cardiac tamponade, hypovolemia, pulmonary embolism, and PNX [31, 34]. The more critical the clinical scenario where sonography is applied, the more diagnosis should rely on simple signs. Thus, diagnosis of PNX during cardiac arrest in hemodynamically unstable patients relies on lung sliding, B lines, and lung pulse, and these signs can be checked only in one location per side on the anterior chest wall. There is no need to search for the lung point by moving the probe toward the lateral chest: if PNX is the primary cause of the clinical storm, the lung is totally collapsed. In our opinion, a sonographic pattern without detectable lung sliding, absent B lines, and absent lung pulse in the anterior chest of unstable patients should induce the physician to place a chest tube immediately [31].

Radio-occult PNX

Several studies showed that LUS is more sensitive than supine chest radiography and similar to CT in the detection of traumatic and postprocedure iatrogenic PNX [18, 28–30, 35–39]. Bedside chest radiography misses a substantial proportion of cases independently of the extension of PNX [40]. Cases missed by conventional radiology are defined as radio-occult PNX [41, 42]. Compared to LUS, the sensitivity of upright posterior–anterior chest radiography has not been fully investigated, but our feeling is that even optimal radiologic examinations may be less sensitive than sonography in the detection of small PNX. Detection of small radio-occult PNX is not devoid of clinical significance, as it may quickly progress to cause hemodynamic instability. In trauma patients to be submitted to invasive ventilation and those who need aerial transportation, physicians should carefully rule out the possibility of even the smaller PNX. In these cases, the high sensitivity of LUS in diagnosing PNX is of great help. Moreover, even if the radio-occult small PNX in a stable patient is not usually drained, prognosis, follow-up, and observation criteria in the emergency department change when PNX is diagnosed.

Evaluation of PNX extension

This assessment is particularly important in some conditions. The treatment guidelines of three important scientific societies state that in primary spontaneous PNX the percentage of lung collapse is a major criterion to decide treatment [43–45]. There are no published guidelines for the treatment of traumatic and iatrogenic postprocedure PNX, but there is a consensus among experts that the volume of PNX is one determinant to decide chest tube drainage versus conservative treatment [46]. When CT scan images are available, quantification of the volume of PNX is highly accurate. Often, in clinical practice, methods to evaluate the percentage of lung collapse must rely on chest radiography reading, the accuracy of which is low [47]. The guidelines on the treatment of primary spontaneous PNX distinguish between large and small PNX based on the measurement of the visible gap between the parietal and visceral pleura at upright posterior–anterior chest radiography (Table 1). As mentioned above, the location of the lung point in the supine patient allows one to predict the extension of PNX. Even if there is not a strict correlation between the extension on the chest wall and the volume of the intrapleural air, it is reasonable to speculate that the extension of PNX allows semiquantification of the volume, accurately discriminating between large and small PNX, i.e., sizes under or over 11–15% of the thorax volume [28, 30]. This is enough to drive treatment decision making in most cases of PNX, both primary spontaneous and iatrogenic. Moreover, when a CT scan is not available, LUS is the obvious substitute for the diagnosis of PNX and also for the evaluation of its extension.

Remote areas

LUS can be performed at the bedside using simple mobile or even portable machines. Compared to the costly and complex radiologic process, detection of PNX by LUS does not depend on sophisticated technology and is easily applied. These features make ultrasound most suitable in remote or extreme environments, where radiographic evaluation is delayed or impossible, such as during sport events on the sea or high mountains, military conflicts, rural medicine, and space explorations [48, 49]. We should not

Table 1 Guidelines' definition of "large" pneumothorax by upright posterior–anterior chest radiography reading and corresponding recommended treatment

Guideline	Definition of large pneumothorax	Recommended treatment
ACCP [43]	More than 3 cm apical interpleural distance	Intercostal catheter drainage
BTS [44]	Presence of a visible rim of 2 cm between lung and chest wall	Aspiration
BSP [45]	Pleural gap along the entire length of the lateral chest wall	Aspiration or small bore catheter thoracostomy drainage

ACCP American College of Chest Physicians; *BTS* British Thoracic Society; *BSP* Belgian Society of Pulmonology

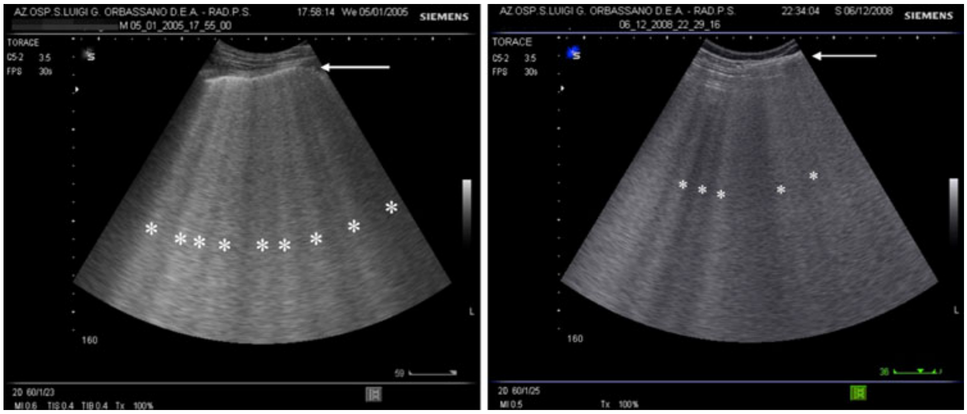

Fig. 7 *Left panel* ultrasound lung scan showing regular respiratory pattern. Visualization of B lines (*asterisks*) predicts the adherence of the two pleural layers (*white arrow*), thus ruling out pneumothorax with a true negative rate of 100%. *Right panel* ultrasound lung scan in a trauma patient with thoracic subcutaneous emphysema. The subcutaneous air hinds the pleural line, but the regular pattern, thus excluding pneumothorax, may be misdiagnosed by visualization of the horizontal respiratory motion of the muscolar layers (*white arrow*) mimicking the lung sliding, and some vertical echogenic artifacts similar to the B lines, known as E lines (*asterisks*)

forget that the expensive health care typical of developed countries covers only a small part of the world population. Very often, in hospitals in poor countries, sonography is the only available imaging diagnostic technology.

Pitfalls and special features

The following paragraphs allude to conditions in which the sonographer could be misled when LUS is applied to detect signs of PNX.

Subcutaneous emphysema

Subcutaneous emphysema is common in trauma patients and postprocedure PNX. Parietal subcutaneous emphysema may hinder the diagnosis of PNX as it may lead to a false view of pleural motion and vertical artifacts similar to B lines [50]. Often, the "false pleural sliding" is the movement during respiration of the echogenic muscular layers of the chest wall, while the "false B lines" are linear artifacts known as "E lines" (Fig. 7) [18]. These artifacts are similar to the B lines because they are vertical and appear as echogenic lines that spread vertically like rays, reaching the lower edge of the screen without fading. Compared to B lines, the important difference is that they do not arise from the pleural line [18]. To avoid misdiagnosis, the sonographer should be sure to visualize the pleural line between and under two ribs and to observe the same depth of the pleural line on both sides of the chest [31]. In postprocedure and trauma patients, monolateral absence of the pleural line and visualization of E lines allow sonographic diagnosis of subcutaneous emphysema. In the post-traumatic situation, even if air between the chest wall and the parietal pleura prevents the direct sonographic diagnosis of PNX, subcutaneous emphysema typically correlates with PNX and thus clinical decision making is not difficult.

Double lung point

The principle that the more lateral the lung point is in the supine patient the more the PNX is extended is always acceptable when the air layer moves freely in the pleural space. However, on occasions, that air is trapped between two areas where the visceral and parietal pleura for some reason adhere. In this case the laterality of the lung point fails to indicate the real extension of the PNX, while two lung points surrounding the air bubble may be visualized [51]. Between the two lung points, an area of lung without pleural sliding will be visualized (Online Resource 1). Location of the most lateral lung point could be misleading in the assessment of the extension of PNX, suggesting a large PNX volume and therefore a useless therapeutic drainage. Moreover, presence of regular sliding along the parasternal chest area (i.e., the least-dependent chest region in the supine patient) could lead to miss the diagnosis of PNX. A double lung point can be detected in PNX secondary to trauma when pulmonary contusions can cause pleural adhesion or, less frequently, even in spontaneous PNX of young adults [51, 52].

Conclusions

LUS is a very accurate bedside method in the diagnosis of PNX. Its application allows prompt diagnosis in many emergency situations. Moreover, LUS can also be useful for a semiquantification of the volume of PNX, thus driving treatment in stable patients. The diagnosis relies on the combination of four sonographic artifact signs that can be easily identified by an experienced physician at the bedside. The flaws of bedside conventional radiological technique and the invasiveness, complexity, and cost of CT technology make LUS a primary choice for the diagnosis of PNX in many clinical scenarios.

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