**Name of Journal: *World Journal of Radiology***

**ESPS Manuscript NO: 21527**

**Manuscript Type: Review**

**Incremental value of thoracic ultrasound in intensive care unit: Indications, uses and application**

Liccardo B *et al*. Thoracic ultrasound in ICU

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**Author contributions:** All authors equally contributed to this paper with conception and design of the study, literature review and analysis, drafting, critical revision, editing, and final approval of the final version.

**Conflict-of-interest** **statement:** No potential conflicts of interest.

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**Received:** July 19, 2015

**Peer-review started:** July 19, 2015

**First decision:** September 30, 2015

**Revised:** January 25, 2016

**Accepted:** February 14, 2016

**Article in press:**

**Published online:**

**Abstract**

Emergency physicians are usually called to care for unstable patients with life-threatening conditions, and to take both rapid and sharp decisions about unclear clinical pictures. The concept of using ultrasound as a real-time bedside clinical tool for the clinician, added to the irreplaceable historical and physical examination, in the emergency setting, is obtaining a growing consensus. B-mode sonography is an old technology proposed for medical applications more than 50 years ago. Its application in the diagnostic procedures of thoracic diseases has always been considered limited by the presence of air contained inside the lung, and by the presence of the bones of the thoracic cage, which prevent the progression of the ultrasound beam. However, the close relationship between air and water in the lung causes a variety of artifacts seen by ultrasound. At the bedside, thoracic ultrasound is based primarily on the analysis of these artifacts. The goals are to improve accuracy and safety in the diagnostic and therapeutic approach of variety of pulmonary pathologic diseases which are predominantly “water-rich” or “air-rich” conditions. The indications, contraindications, advantages, disadvantages, and technique of thoracic ultrasound, and related procedures will be analyzed in the present review.

**Key words:** Thoracic ultrasound; Intensive care unit; Heart failure; Pleural effusion; Pneumothorax; Echocardiography

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**Core tip:** The close relationship between air and water in the lung causes a variety of artifacts seen by ultrasound. At the bedside, thoracic ultrasound is based primarily on the analysis of these artifacts. The goals are to improve accuracy and safety in the diagnostic and therapeutic approach of variety of pulmonary pathologic diseases which are predominantly “water-rich” or “air-rich” conditions. The indications, contraindications, advantages, disadvantages, and technique of thoracic ultrasound, and related procedures will be analyzed in the present review.

Liccardo B, Martone F, Trambaiolo P, Severino S, Cibinel GA, D’Andrea A. Incremental value of thoracic ultrasound in intensive care unit: Indications, uses and application. *World J Radiol* 2016; In press

**INTRODUCTION**

Emergency clinicians are often implied to take care of critically patients with life-threatening settings; more over physicians are called to take both quickly and precisely choices about clinical conditions usually unclear[1-3].

In this contest, the idea of utilized ultrasound as a real-time bedside clinical instrument for the emergency physician, added to the irreplaceable historical and physical examination, in the emergency conditions, is getting an increasing consent.

As a matter of fact, even though bedside portable chest radiography (CR) is relatively inexpensive, available in most hospital, and provides useful information, it has been shown to be inaccurate in many situations and has a few limitations[4]. Over the technical limitations of the tool (movement, and breath holding during the X-ray exposure, cassette placed posteriorly the thorax, *etc*.) that may lead the incorrect assessment of the most frequent pulmonary disease (such as alveolar interstitial syndrome, pulmonary consolidation, and pleural effusion)[5], the time required to achieved a bedside ordinary CR, and to compile a report, may bring to retard the diagnosis, and extended the staying of the patient in the emergency department, contributing to overcrowding of the department. Nevertheless, the CR is not ever helpful for diagnosis of pneumothorax in ill patient staying in intensive care unit (ICU) during non invasive ventilation.

However, chest’s computer tomography (CCT) could be assessed the best tool for the imaging diagnosis of most of the thoracic settings, but it is costly, not usable in the ICU, and exposes ill patient to a strength unsafe transport to the radiology unit[6]. Moreover, CCT set out patient to high dose of radiation, which obviously restricts the possibility to repeat the proceeding, and makes not available the tool for pregnancy, and for pediatric patients[7,8].

Ultrasound is an old technology and its use in the diagnostic proceedings of chest illness has ever been considered restricted by the presence of air contained inside the lung, and by the presence of the bones structure, which prevent the progression of the ultrasound[9-12].

As matter of fact, in the textbook “Harrison, Principles of Internal Medicine” about thoracic ultrasound (TUS) they say[13]:

“Because ultrasound energy is rapidly dissipated in air, ultrasound imaging is not useful for evaluation of the pulmonary parenchyma. However, it is helpful in the detection and localization of pleural abnormalities and is often used as a guide to placement of a needle for sampling of pleural liquid (*i.e.*, for thoracentesis)”.

But thanks, firstly to the pioneering work of a French intensivist Daniel Lichtenstein, and after to others, they understated that ultrasound applied on chest and lung generate sonographic artifacts, and that those artifacts patterns are correlated with clinical, and radiologic diagnosis in ICU.

Lichtenstein, in fact, proposed the basis and utility of TUS formulated in few basic principles. Firstly, the intimate relationship between air and water in the lung causes a variety of artifacts seen by ultrasound. Because air and, consequently the lung, cannot be visualized by sonography, thoracic ultrasound, TUS is based primarily on the valuations of these artifacts. Secondly, air and water have opposing gravitational dynamics. Consequently, a variety of pathologic conditions (pleural effusions, consolidations) is predominantly “water-rich”. These pathologies are generally found in the posterior aspects of a supine patient. On the other hand, there are several “air-rich” conditions (pneumothorax) and, as a result, are predominantly found in the anterior aspects of a supine patient (Table 1)[14].

This review focus on potential clinical application of TUS.

**ULTRASOUND MACHINE REQUIREMENTS**

Ultrasound machines should be lightweight, battery-powered, hand-carried, compact, and simply to move, permitting the valuation of many patient straight bedside. Moreover, ultrasound instruments should be provided with an hard disk and a USB door saving and unloading images and clips, and a paper recorder[15-17].

Moreover, ultrasound machines is used for many patients, probes can be carrier for resistant germs that could be present in the ICU. As matter of fact, ultrasound instruments and probes should be treated with frequently decontamination proceedings[18].

**PROBES**

The ultrasound equipment suitable for TUS imaging must been provided with 3.5-MHz, 5-MHz, 7.5-MHz, or 10-MHz convex, linear, and sector transducers; each probe has its inherent advantages and disadvantages.

A convex or linear transducer, better than a sector scanner, has a large vision of the range; for this reason is preferred for the initial valuation and for the screening. The curved array convex probe (3.5-MHz) has the profit of allowing view of deeper lesions, rapid assessment of the lateral thoracic cavity for signs of pleural fluid in the supine patient. However, due to its large footprint, only a small portion of the intercostal space is accessible. Furthermore, the low frequency does not allow for detailed assessment of the most important zone in thoracic ultrasound, such as pleural line. The high-frequency linear array probe (5-MHz or 7.5-MHz) give best resolutions of close structures, allows for detailed examination of the pleura and provides rapid assessment of superficial lesions interesting the chest wall and pleura, such as pneumothorax. Its large footprint, however, hinders access to larger areas of lung tissue because of the interference of the ribs. Furthermore, the high-frequency sacrifices depth-of-penetration, preventing assessment of deeper structures such as atelectasis, consolidation, and large pleural effusions. For injuries with a short ultrasound view or a really limited intercostal space, anyway, a sector probe is in general choosed, moreover cardiac probe allows simultaneous examination of heart and lung.

**SCANNING PROCEDURE**

Each TUS study should started obtaining patient’s history and a clinical evaluation.

Commonly, TUS may be performed by two different approaches: a systematic approach, or a focused approach that starts on the area of chest distress[19].

During TUS systematic examination, patients is valuated in a seated laying from anterior lateral, posterior, and supraclavicular approach, to scan both posterior and anterior areas of the thorax; by this approach patient should stay with both arms lifted over the head[20].

On the other hand, in ICU a methodical procedure is not always possible, because is a proceeding that needs time, and frequently patients clinical condition are really severe. Current reviews have pointed out the simpler procedures feasible on patients independent from their position and from respiration, looking for sonographic signs easier to been acquired.

In both approaches, thoracic cage can be divided in different zones[10,11,21,22].

In the chest we can distinguish three different wall: the anterior, the lateral and the posterior wall; more of the diagnostic proceedings of TUS interest the anterior, and lateral parts of the chest cage. The anterior wall is delimitated from the sternum to the anterior axillary row, while the lateral wall is delimitated from the anterior to the posterior axillary row, and the posterior wall is delimitated from the paravertebral row, the scapularis row and the posterior axillary row[11,22-24].

Thoracic parts are obviously the same on both areas, but the presence of the heart on the left side, reduces the helpful scansion on the left side.

The real limitation of ultrasound is when TUS needs to be applied to the posterior zone of the chest of bedridden patient, immobilized patient, intubated patient, or unconsciousness patient. In these conditions, little probes may be useful, because can be placed between the patient, and bed. Infants, and small children, to obtain better images, can be evaluated by placing the babies in supine or in oblique position. The transducer can slide behind the patients back, and aim up roughly perpendicular to the chest wall[14,25].

Lower portions of the chest may be evaluated from an abdominal sight. The right lung can be seen passing across the liver, while the left lung can be seen by passing across the spleen, in both conditions diaphragm will be crossed and visualized[19].

By moving the probe in an upper or downer way, the pleura is represent under the ribs, moving during inspiration and expiration, synchronized with breathing motions.

The probe is shift in transverse, or longitudinal way to better see the lung using the intercostal spaces like an ultrasound windows, preventing the ribs. Both the longitudinal and the convex probes allows the visualization of couple ribs and the pleural row between this two bones. This proceeding is the first and most significant passage of chest evaluation, because it permit an easier and a more accurate valuation of the pleural row. When the pleural line has been seen, placing and turning the probe in the intercostal space,transverse scan can be obtained to a best visualization of the pleura and its artifacts[11,12].

A completely TUS evaluation included the scansion of both emidiaphragms, normal zone included, to compared normal with pathological areas.

**ULTRASOUND NORMAL APPEARANCE AND TERMINOLOGY**

Normal lung parenchyma is not visualized because it is composed primarily of air, which scatters, and impedes the transmission of sound waves. The dramatic difference in the acoustic characteristics of smooth tissues and the lung makes the chest surface a particularly strong reflector of ultrasound waves, and is responsible for creating a number of reverberation artifacts that lend valuable information about the lung’s current pathophysiology.

Ultrasound picture of the thoracic cage typically displays smooth-tissue echogenicity with multiple layers of fascia, sub-cutaneous, and muscle of different thickness depending of patient constitution.

The transducer can be positioned both perpendicular to the ribs, and transverse, over the intercostal spaces.

The longitudinal approach, perpendicular to the ribs, consent a view of the lower and the upper ribs and, a little more profound, the pleural line (Figure 1), while the oblique approach, with the probe placed in the intercostals space, consent the view of a bigger part of the pleural line, not hidden by the rib shadows[25].

Leaning the transducer on each intercostal space, in longitudinal approach, three fundamental structure can be highlight: the pleural line, the thoracic cage, and the pulmonary artifact.

The depth should be adjusted to the patient size, to the patient habitus, and depending on the structure we would seen: in fact, to visualize the pleural line in obese, or in muscled patients, or in very thick ribcages, higher depths are needed, while in children or very thin patients, littler depth are required. Depth should also be correct by the objective of our valuation: if we are searching for pneumothorax, for a better visualization of the pleural line, and to assess the sliding, the depth should be shorter; while if we need to value a pleural effusion, the depth should be higher. Typically the focus should be placed at the pleural row level, for a better visualization of artifacts.

Different portions of the thoracic cage may be highlight through TUS, but the more significant structures visualized by TUS are the margins of the ribs. They seems as a line with uninterrupted echogenicity, like the physiological pleural row, but without any movements; moreover the margin of the normal ribs produces an acoustic shadow that masked in part the structures above, except for the cartilage zone of the ribs that consent the transmission of the ultrasound beam, showing the pleura underling and its sliding. TUS may be also used in the diagnosis of chest wall pathologies (such as fractures after resuscitation cardio-pulmonary, or trauma), but this is not in the scope of our review.

The second structure to highlight is the pleural row; it seems as a thin echogenic row, under the ribs. This row represents the visceral and parietal layers, seen together. Typically, the pleural lines are smooth and thick (less than 2 mm of thickness); between two rows there is the pleural space (less than 0.3/0.4 mm). The near ribs, the upper and the lower, with the pleural line below them, delineate a typically ultrasound sign named “Bat sign”, better shown by convex probe, due to its curvilinear shape (both the near ribs are the wings of the bat and, the pleural line under them is the backside of the bat). The recognition of this sign is important, since it simply consent the finding of the pleural row (Figure 2).

The pleural row moving through respiration, and its movement is synchronized with respiration[3]. This movements is named lung sliding or gliding[25], and its recognitions is a significant passage in chest evaluation, since is a sign of physiologic moving of pleura.

Moreover, the heart beats caused another movement called the lung puls, that is the moving of the pleural row synchronous with the cardiac beam. Is a vertical movement that is easier to see on the left hemithorax, and is produced by the transmission of heart rhythm.

The presence of intrapleural air (like in pneumothorax) avoids the transmission of any kind of moving (both vertical and horizontal) to the parietal pleura. As matter of fact, visualizing the lung pulse, is it possible toexclude pneumothorax.

Moreover the M-mode can be used to document lung sliding, recordings a mark named seashore sign (Figure 3)[26]. In this kind of picture, below the pleural line of the phisiological lung, is it possible to see the pulmonary artifact made of a steady background pattern, finely sparkling, and with several linear artifacts. On the setting, sparkling artifact are created when the ultrasound beam is no uniformly mirrored back to the transuder by the microspheric surfaces of air that are trapped in the alveoli[9,10].

Moreover, linear artifacts can be distinguished in two different kinds, vertical and horizontal.

The horizontal artifacts are hyperechogenic row showed at standard intervals from the pleural row, as repetition, and are called A-lines (Figure 4). When mached with physiological lung sliding, these reverberation artifacts represent a sign of the physiological presence of air in the alveoli[21,25].

A-lines occur when sound waves pass through the superficial soft tissues, and cross the pleural line encountering air, or tissue that is almost completely composed of air, as in normal lung. These waves are reflected strongly by this tissue/air interface, and bounce back and forth, between the transducer, and lung surface; each volley of sound waves returns to the transducer after a longer period of time, and is thus represented as a bright horizontal line deeper and deeper on the display screen. As this is a classic reverberation artefact, the distance from the skin to the pleural row equals the distance from the pleural row to the first A-line, the first A-line to the second A-line, and so forth.

The vertical artifacts are echogenic beams that come from the pleural row, arriving to the opposite way of the screen in the absence of interruptions and with synchronous movements with lung slidingand respiratory frequency. They are well-defined, laser-like, hyperechoic, and they erases A-lines[26].

In the normal lung vertical artifacts are generally not more than 2-3 per chest parts per emithorax, preferentially at the bases of the lung[11,23,27]; they are named B-lines, or comet tails, (Figure 5)[12,28,29].

The B-linesimage are connected with a little water-rich structure, under the resolution of the sonographic beam enclosed by air, and when this structure is been stricken by ultrasound beam generates this kind of artifacts.

**PULMONARY INVOLVEMENT IN CARDIAC DISEASES**

When we have a clinical setting characterized by damaged lung with an enhanced of free-water[30], vertical artifacts growing up from the pleura and continuing to the opposite way of the dislpay[31],as already said, are named B-lines The quantity of the *comet tails* is related with the increased free-water and the lung aeration leak[32].

It is important to don’t forget, as mentioned above, that some B-lines (one or two) may be view ordinarily in bottom dependent lung regions, such as normally aerated lung bases[23].

It has been demonstrated that many B-lines (nearest then 7 mm) are determinated by thickened interlobular septa featuring interstitial edema. On the opposite site, multiple B-lines (nearest then 3 mm or fewer) are produced by alveolar edema. As matter of fact, the amount of B-lines rises with the grade of leak of aeration.

Moreover, the usefulness of TUS is to assess lung reareation after antimicrobial therapy[33] or after non invasive ventilation.

The cardio-pulmonary system is so complex and interrelated, that an integrated method (lung ultrasound assessment additional to echocardiography) is fundamental to the assessment of pulmonary involvement in acute and chronic cardiac failure[34].

As a matter of fact, the evidence of many, diffuse, and in both the emithorax of comete-tailscorrelated with left ventricular dysfunction or valvular disease is most suggestive of cardiac pulmonary cause of the pulmonary edema[35-37].

On the other hand, the evidence of B-lines, related with normal systolic and diastolic function, suggest a non-cardiogenic cause of the congestion, but a lung disease, such as pneumonia, acute respiratory distress syndrome, acute lung injury, or particularly in chronic setting, pulmonary fibrosis.

On the opposite side, focal multiplex comet tails can be present in physiologic lungs, or in different pathologic such as pleural distress, lung disease, focal pneumonia, pulmonary neoplasia lung contusion, or lung infarction.

This highlight the significance of integrate results obtain trough TUS, echocardiography with patients’ anamnesis, clinical setting, and all instrumental information we can find[38].

**PLEURAL EFFUSION**

Ultrasound imaging is the better tool for the diagnose of pleural effusion, the easiest and the more specific instrument; moreover is very useful to differentiate the nature of pleural fluid[39,40].

Pleural effusion is really easy to find out by ultrasound as an echo-free zone (black area). As matter of fact, pleural effusion plays as an acoustic window, and when pleural effusion is enough abundant to compress the lung, it will appear as consolidated, and moving inside the pleural effusion (Figure 6).

Pleural effusion should be searched in declivous pulmonary zone.

The first passage is to discriminate pleural effusion’s nature: if is a transudate or an exudate.

Transudates appear as anaechoic, with an echo-free pattern, even if sometimes cured transudate pleural effusion that characterized congestive heart disease may be echogenic[41].

On the other hand, exudates appear often echoic, with small moving dots that represent the presence of cells (like macrophages, erythrocytes, or leukocytes), or little spots (such as protein, or fibrin). Inflammatory pleural illnesses produce a characteristic effusion that holds fibrous strings and septations with encapsulated liquid (loculated that could be mobile or immobile) (Figure 7)[42].

In the valuation of pleural effusion, the second passage is to quantify its size. Various formulas have been used for the valuation of volume of the pleural effusion, and lung ultrasound method has been suggested for its quantification.

In supine setting, an inter-pleural space at the lung base, of about 50 mm (between lung and posterior chest cage) is suggesting of a pleural effusion of about 500 mL[43].

Quantification of the inter-pleural space can be done at either end-expiration or end-inspiration phase, without any difference. All studies accord that ultrasound valuation of the inter-pleural distance is not precise enough to quantify little (< 500 mL) and big (> 1000 mL) pleural effusions[44-46].

Valuation of pleural effusion needs care on the left side to the spleen, while on the right side on the liver, and on both sides on the diaphragm, in particular when pleural puncture is considered. Thoracentesis and biopsy of the pleura sometimes have been necessary for diagnosis of some disease[47-49] and TUS is required to increase the safety of this procedures performed at bedside[50,51].

TUS permit the secure chest drainage of little and/or loculated pleural effusions; moreover TUS allows to highlight pleural adherences that may complicate thoracocentesis. TUS may also decrease the risk of intra-fissural or intra-parenchymal placing of pleural tubes[20,33].

**PNEUMOTHORAX**

Pneumothorax (PNT) is defined by the presence of air, or any different kind of gas, in the pleural space, between visceral and parietal pleural layers; accordingly of this interposition, lung slidingis stopped, because ultrasounds can’t pass across the air present in the pleural space, due to the lung disease. Moreover B-lines are no more visualizable, while only horizontal A-lines can be seen[23].

Different studies have recently underline that bedside TUS is more specific than CR for the diagnosis of PNT in critically ill patient[21,52-54]. In fact bedside CR may underdiagnose up to 30% of conditions[55].

As matter of fact, radiographically “occult” PNT may quickly develop to tension PNT, in particular in patients who received mechanical ventilation (both invasive and non invasive), in which missed, or delayed diagnosis may be fatal.

Failure of lung slidingis the first passage to diagnose PNT.

In general, PNT should be searched firstly at the least gravitationally dependent zone.

The presence of lung slidingpermits to likely rule out PNT; in fact its negative predictive value is about 100%[55].

Moreover in the PNT, the absence of lung slidingcan be also assessed by M-mode, which displays a characteristic setting, called “stratosphere sign”, that is a picture opposite to the physiological seashore sign(Figure 8).

Anyway, the absence of lung sliding does not ever imply PNT. Different other conditions can cause the absence of lung sliding*,* like severe pulmonary fibrosis, pleural adherences, massive atelectasis, bullous emphysema, advanced chronic obstructive pulmonary disease, presence of thoracic tube, high-frequency ventilation, *etc*. Moreover, the absence of B-lines is another state needed for a thoracic ultrasound diagnosis of PNT: in fact, the presence of B-line allows prompt to ruling out the diagnosis of PNT[31].

As matter of fact, the only pathognomonic lung ultrasound sign of PNT is the called “lung point”, that permits to confirm PNT diagnosis (specificity of 100%, and sensitivity of 65%). Lung point is the exact zone of the thoracic wall, where the normal lung sliding displaced the PNT characteristics setting. It represents the area where visceral and parietal pleura layers recover one with the other. Also M-mode done at the lung point, demonstrates an evident shift from one setting to the other (normal seashore signchanged in the stratosphere sign characteristic of the PNT pattern) (Figure 9)[7,38,56].

**DIAPHRAGMATIC FUNCTION**

The diaphragm is the most important respiratory brawn[57,58].

Ultrasound assessment of the diaphragm has not long ago become to grown up in the ICU as characteristic necessity for valuation of diaphragmatic role gain in different clinical settings. In fact, pathological diaphragmatic movement is seen in different situations like in patients in critical conditions who are using mechanical ventilation (invasive and non invasive)[59], after cardiac, or abdominal surgery[57], and also in phrenic nerve injury, or neuromuscular diseases.

Since diaphragmatic movement performs a fundamental part in spontaneous respiration, valuation of the diaphragm motion seems necessary.

In the ICU patients, ultrasound can assess physiological and pathological motion in different kind of clinical settings. The study of the diaphragm using ultrasound is made using a 3.5-MHz, 5-MHz transducer, placing the transuder under the left or right costal margin in the mid-clavicular row, or in the left or right anterior axillary row and directing medially, cranial and caudal; as consequence the ultrasound beam will arrived perpendicularly the third back of the hemi-diaphragm.

The 2-dimensional mode is firstly employed to get the better approach while the M-mode is made to show the movement of the anatomical formations over the selected plane[60].

Preferentially, patients are examinated over the long axis of the intercostal spaces, the hole right hemidiaphragm is seen by ultrasound; in fact the liver allowed a perfect transmission of the beam, filling the dome entirely, while the left acoustic window is littler because the spleen fills only half of the corresponding hemidiaphragm[20].

Left and right hemidiaphragms respiratory motion should always be evaluated; physiological inspiratory diaphragmatic motion is caudal, because the diaphragm go toward the transducer, while physiological expiratory movement is cephalic, as the diaphragm shift apart from the transducer. As consequence of this movements, in the M-mode we can measured: diaphragmatic shift (displacement, cm), velocity of diaphragmatic contraction (slope, cm/s), inspiratory time (Tinsp, s) and lenght of the cycle (Ttot, s) (Figure 10*)*.

In mechanically ventilated patients, the assessment of diaphragmatic movement occasionally could need to shortly disengage the patient from the ventilator to best asses spontaneous breathing stresses. A lot of ICU patients may also be affected by pulmonary consolidation, atelectasis, or pleural effusions, which allow a better valuation of the hemidiaphragms. The values of diaphragmatic movement in healthful subjects were indicate to be 1.8 ± 0.3, 7.0 ± 0.6 and 2.9 ± 0.6 cm for men, and 1.6 ± 0.3, 5.7 ± 1.0, and 2.6 ± 0.5 cm for women, respectively during rest, deep breathing and volunteer sniffing[61].

The excurtion of the diaphragm dome valuated using M-mode ultrasound is useful for predicting extubation outcomes[62].

Diaphragm thickening during inspiration represents diaphragm shortening and is analogous to the “ejection fraction” of the heart.

**INTEGRATED CARDIO-PULMONARY ULTRASOUND - THE BLUE PROTOCOL**

Acute respiratory distress is a really severe setting. The correction and immediate reorganization of acute respiratory failure, are two fundamental steps for the correct management patients in critical conditions in ICU and to avoid initial mistakes and their deleterious consequences.

A study published in 2008 by Lichtenstein *et al*[63] assess the utility of TUS in patients allowed to the ICU with respiratory distress.

It deduced that TUS can help the physician to make a easiest diagnosis in patients with acute respiratory distress; Lichtenstein called this protocol the BLUE protocol (meaning Bedside Lung Ultrasound in Emergency).

This observational study was conducted performing ultrasonography on 260 consecutive dyspnoetic patients whose access to the ICU for acute respiratory distress; the conclusion of the ultrasound evaluation at the first presentation of the dyspnoetic patient to the ICU, were match with the last diagnosis at the resignation. Unclear diagnoses and uncommon patterns (frequency less than 2%) were excluded from their study. Three fundamental elements were evaluated: artifacts (A-lines or B-lines), lung sliding, and alveolar consolidation and/or pleural effusion; all this items were combined with venous analysis, and at the end were clustered to value ultrasound outline (Table 2).

In the BLUE protocol*,* the first step is to check anterior lung sliding. Its presence rules out the diagnosis of PNT.

The A’ profile (A-profile with absence of lung sliding) and lung point showed PNT (81% sensitivity and 100% specificity), while if lung point is not present, additional diagnosis modalities are necessary.

The second step is looking for anterior B-lines.

The B profile (presence of anterior lung sliding with lung comet tails) indicated the presence of acute pulmonary edema (97% sensitivity and 95% specificity).

The B’ profile (B profile with absence of lung sliding), A/B profile (anterior prevailing B-lines on one side, and prevailingA-lines on the other), and C profile (identifies anterior alveolar consolidations) suggest the presence of pneumonia (89% sensitivity and 94% specificity).

The A profile (characterized by anterior lung sliding with A-lines) suggest an investigation for depth venous thrombosis, and if is show, pulmonary embolism is assessed (81% sensitivity and 99% specificity). If the depth venous thrombosis is absent, PLAPS (posterior and/or lateral alveolar and/or pleural syndrome) is valued. The setting combining A-profile, free veins, and PLAPS is named A-V-PLAPS-profile and is a characteristic setting suggesting pneumonia.

An A-profile with the absence of DVT or PLAPS (called the “nude profile”) whit lung sliding preserved is probably to be an exacerbation of COPD or severe asthma (89% sensitivity and 97% specificity).

The application of these settings would have present the right diagnoses in about 90.5% of conditions.

The procedure used a convex or a sector probe (or any type of probe you have!).

Obviously, to give better results, BLUE protocol must initiate just after the physical examination and must be integrated into the clinical approach; moreover cardiac analysis, through by echocardiography, completes this approach.

A recent multicenter study enrolling 1.005 patients assay the thesis that an integrated method implementing TUS with clinical examination would have superior diagnostic precision than a standard valuation in discriminating acute decompensated heart failure from non-cardiogenic dyspnea in the ICU. The TUS-implemented method had a prominently superior precision (sensitivity, 97%; specificity, 97.4%) in differentiating heart distress from non-cardiac pattern of acute dyspnea than the early clinical examination (sensitivity, 85.3%; specificity, 90%), CR sole (sensitivity, 69.5%; specificity, 82.1%), and natriuretic peptides (sensitivity, 85%; specificity, 61.7%)[64].

**LIMITATIONS OF THE TECHNIQUE**

TUS has many advantages (Table 3), and also some limitations that may be distinguished in physician, patient and disease limitation.

About physician limitation, thoracic ultrasound is restricted by inter-observer variability and needs time to be acquired. Moreover, TUS valuation and the right valuation of the following images, requires training direct to getting the expertise and abilities. Due to the strong consequence of TUS on patient management, any emergency clinician and intensivist should be formed[19].

About patient limitations in ICU, patients who are under mechanical ventilation, as a consequence of the presence between the heart and the thoracic wall of the inflated lung, the sonographic imaging could be non adequate; other elements that can limit imaging acquisition are related to surgical injury and chest dressings that can alter or preclude the transmission of ultrasound beams to the lung, moreover also obesity and COPD can worsen the quality of the images[7].

Also, absence of patient compliance, and the difficulty to move patients into the best position make several studies technically non adequate[65].

About disease limitations, lung disease can be shown by TUS only if the location of pulmonary disease is peripheral and grow up to the pleura; secondly if air is not present in the pleural space, subcutaneous air, and if the lesion is not covered under a bones. This physical limitation are especially significant when ruling out consolidations (especially for tumors) that can be placed in a medially position or bordered by normally aerated lung. In fact, is significant to underline that centrally placed lesions tipically avoid to ultrasound examination, and this is the most important limitiation of TUS [25].

**CONCLUSION**

TUS permit accurate, bedside, fast, and easier valuation of the more important acute respiratory distress (Tables 4 and 5)[19,26,66].

TUS is fast, non-invasive, not expensive, reliable, flexibility, bedside availability, and repeatable, does not employ radiation, and contrast medium; for all these reason TUS may be used on every patients, independently from their age, during pregnancy, with renal failure, or allergic setting. Finally, movable ultrasound machine also permit ultrasound examination in any moment and in any site, thanks to its transportability, and the possibility to execute moving imaging[20].

TUS represents a new and useful item for the emergency physician to be used at all steps of the diagnosis and for the management of the critically ill patient; moreover TUS is really important for the differential diagnosis of the patient who access to the ICU, to differentiate different setting like dyspnea[38], pulmonary consolidation, pleural effusion, alveolar-interstitial syndrome, and pneumothorax that could have similar clinical presentations.

TUS done by clinician in charge of ICUs looks to be one of the more hopeful skills for respiratory monitoring, for therapeutic monitoring, and for avoid any kind of delay on the management of critically patient.

For all this reason TUS is rapidly expanding in our departments[7] and is fast becoming an essential part of the emergency patient assessment and of the armamentarium in the ICU[19,67].

**ACKNOWLEDGEMENTS**

The authors are grateful to Dr. Ilario de Sio and Lucia Morelli for their cooperation for the figures section.

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**P- Reviewer:** [Chello](http://www.wjgnet.com/esps/Admin/Manuscript/MsReviewerResultList.aspx?SId=505382) M, [den Uil](http://www.wjgnet.com/esps/Admin/Manuscript/MsReviewerResultList.aspx?SId=227470) CA, [Ferrer-Hita](http://www.wjgnet.com/esps/Admin/Manuscript/MsReviewerResultList.aspx?SId=2576989) JJ, [Lazzeri](http://www.wjgnet.com/esps/Admin/Manuscript/MsReviewerResultList.aspx?SId=2639698) C **S- Editor:** Gong XM

 **L- Editor:** **E- Editor:**

**Table 1 Appearance of different clinical settings**

|  |
| --- |
| **Appearance of different clinical settings** |
| **Clinical setting** | **Artifacts** |
| Normal lung | Almost air |
| Pneumothorax | Full of air  |
| Interstitial syndrome | Air and minimal fluid |
| Pleural effusion | Full of fluid |
| Lung consolidation | Fluid and air (more fluid, tissue-like) |

**Table 2 BLUE protocol, profiles**

|  |  |  |
| --- | --- | --- |
| **Profile** | **Characteristic items** | **Diagnosis** |
| A’ profile | Abolished lung sliding and presence of lung point | Pneumothorax  |
| B profile | Anterior lung sliding with presence of lung comet tails | Acute pulmonary edema  |
| B’ profile | Lung comet tails with abolished anterior lung sliding  | Pneumonia  |
| A/B profile | Anterior predominant B lines on one side, and predominant A lines on the other side | Pneumonia |
| C profile | Anterior alveolar consolidations | Pneumonia |
| A profile | Anterior lung sliding with A lines, and the presence of DVT | Pulmonary embolism  |
| A-V-PLAPS-profile | Anterior lung sliding with A lines, PLAPS, absence of DVT | Pneumonia |
| Nude profile | Anterior lung sliding with A lines, absence of without DVT or PLAPS  | Severe asthma or exacerbated COPD  |

DVT: Depth venous thrombosis; PLAPS: Posterior and/or lateral alveolar and/or pleural syndrome; COPD: Chronic obstructive pulmonary disease.

**Table 3 Thoracic ultrasound advantages**

|  |
| --- |
| **Thoracic ultrasound advantages** |
| Rapid diagnosis |
| No limitation with setting, patient position, and clinical conditions |
| Differential diagnosis (chest pain, pulmonary edema, exacerbation of chronic obstructive pulmonary disease, subpulmonary effusion, subphrenic fluid accumulation, tumors, *etc*.) |
| Diagnosis presence and nature of pleural effusions |
| Guide invasive procedures (thoracentesis, chest tube placement, biopsy, *etc*.) |
| Diagnosis diaphragm paralysis |
| Diagnosis localized pleural tumors or pleural thickening, assess the invasion of the pleura and chest wall |
| Diagnosis pneumothorax, drainage or verify lung expanded |
| Few limitation in ventilated patient |

**Table 4 Acute respiratory disorders**

|  |  |
| --- | --- |
| **Pleural effusion** | Pleural effusion is an echo-free zone (dark zone), than cause lung consolidation, and floating in the pleural effusionTUS allows to distinguish the nature of the fluid:* Transudate: Anaechoic, and echo-free pattern
* Exudate: Echogenic, with small moving dots (leukocytes, erythrocytes, fibrin, protein particles, *etc*.), fibrous strings, and mobile, or immobile septations with encapsulated liquid

TUS allows also to quantify volume of pleural effusionUS may guide thoracentesis, and biopsy of the parietal pleura |
| **Pneumothorax** | The interposition of gas between visceral and parietal pleural layers, abolish lung sliding, and B-lines; only horizontal A-lines can be seen. Stratosphere sign is the characteristic pattern of the abolition of lung sliding valuated by M-mode. The lung point is the precise area of the chest wall, where visceral and parietal pleura regain contact with each other, where the regular reappearance of the lung sliding replaces the pneumothorax pattern |
| **Diaphragmatic function** | The diaphragm study can be made by placing the probe below costal margin and using the M-mode to display the motion of the anatomical structures; normal inspiratory diaphragmatic movement is caudal, while normal expiratory trace is cranial. In the M-mode, the diaphragmatic excursion, the speed of diaphragmatic contraction, the inspiratory time, and the duration of the cycle can be measured |

TUS: Thoracic ultrasound.

**Table 5 Comparative table of different acute respiratory disorders**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **A-Lines** | **B-Lines** | **Lung sliding** | **Pulse** | **Particular characteristics** |
| **Normal** | Present | Rare | Present | Present |  |
| **Pneumothorax** | Present | Never | Absent | Absent | Lung point |
| **Pleural effusion** | Absent | Absent | Absent | Absent | Presence of B-lines in case of concomitant interstitial syndrome, or pneumonia |
| **Interstitial syndrome** | Absent | Multiple | Present | Present | B-lines crowded, and confluent (white lung) |

\*

\*

**Figure 1** **Longitudinal approach with longitudinal probe; allow to see upper and lower ribs (\*) with their shadow’s cone, and pleural line (arrow).**

**Figure 2** **Bat sign with convex probe, make of two adjacent ribs with the pleural line between [upper and lower ribs are the wings of the bat\* and, pleural line that is the back of the bat (arrow)].** Under the pleural line is also possible to see two A-lines.

**Figure 3** **M-mode and seashore sign, helps to document lung sliding on a picture.**

**Figure 4** **A-Lines.** A: A-lines whit convex probe; B: A-lines whit sector probe. Arrow shows the pleural line, \* shows A-lines.

**Figure 5** **B-lines.** \*show B-lines.

**Figure 6** **Pleural effusion.** Pleural effusion is an echo-free (dark zone\*), and determinate the compression of the lung that appear consolidated, and floating in the pleural effusion (arrow).

**Figure 7** **Loculated pleural effusion, appear as a dark zone (\*) contains immobile septations (arrow) with encapsulated liquid.**

**Figure 8** **Stratosphere sign.** Pointing M-mode in the zone characterized by the abolition of lung sliding it shows a characteristic pattern, the stratosphere sign, opposed to the normal seashore sign (by courtesy of Dr. Ilario De Sio).

**Figure 9** **Lung point (arrow)**. Is the precise area of the chest wall, where the regular reappearance of the lung sliding replaces the pneumothorax pattern and it corresponds to the point where visceral and parietal pleura regain contact with each other (by courtesy of Dr. Lucia Morelli).

**Figure 10** **M-mode, diaphragmatic excursion (see the text) (by courtesy of Dr. Lucia Morelli).**