ORIGINAL

Nektaria Xirouchaki
Eleftherios Magkanas
Katerina Vaporidi
Eumorfia Kondili
Maria Plataki
Alexandros Patrianakos
Evaggelia Akoumianaki
Dimitrios Georgopoulos

Lung ultrasound in critically ill patients: comparison with bedside chest radiography

N. Xirouchaki · K. Vaporidi · E. Kondili ·
M. Plataki · E. Akoumianaki ·
D. Georgopoulos (✉)
Department of Intensive Care Medicine,
University Hospital of Heraklion,
University of Crete, Heraklion,
Crete, Greece
e-mail: georgop@med.uoc.gr
Fax: +30-2810-392636

E. Magkanas
Department of Radiology, University
Hospital of Heraklion, University of Crete,
Heraklion, Crete, Greece

A. Patrianakos
Department of Cardiology, University
Hospital of Heraklion, University of Crete,
Heraklion, Crete, Greece

Abstract *Purpose:* To compare the diagnostic performance of lung ultrasound and bedside chest radiography (CXR) for the detection of various pathologic abnormalities in unselected critically ill patients, using thoracic computed tomography (CT) as a gold standard. *Methods:* Forty-two mechanically ventilated patients scheduled for CT were prospectively studied with a modified lung ultrasound protocol. Four pathologic entities were evaluated: consolidation, interstitial syndrome, pneumothorax, and pleural effusion. Each hemithorax was evaluated for the presence or absence of each abnormality. *Results:* Eighty-four hemithoraces were evaluated by the three imaging techniques. The sensitivity, specificity, and diagnostic accuracy of CXR were 38, 89, and 49% for consolidation, 46, 80, and 58% for interstitial syndrome, 0, 99, and 89% for pneumothorax, and 65, 81, and 69% for pleural effusion, respectively. The corresponding values for lung ultrasound were 100, 78, and 95% for consolidation, 94, 93, and 94% for interstitial syndrome, 75, 93, and 92% for pneumothorax, and 100, 100, and 100% for pleural effusion, respectively. The relatively low sensitivity of lung ultrasound for pneumothorax could be due to small number of cases ($n = 8$) and/or sub-optimal methodology. *Conclusions:* In our unselected general ICU population lung ultrasound has a considerably better diagnostic performance than CXR for the diagnosis of common pathologic conditions and may be used as an alternative to thoracic CT.

Keywords Intensive care unit ·
Ultrasonography · Pneumothorax ·
Pleural effusion · Consolidation ·
Interstitial syndrome

Introduction

Traditionally lung imaging in critically ill patients is performed either by bedside chest radiography (CXR) or thoracic computed tomography (CT) [1]. Both techniques have limitations which constrain their usefulness. Although thoracic CT is the gold standard for lung imaging, it is expensive and cannot be performed on a routine basis. In addition the transportation of critically ill patients to the radiology department combined with the radiation exposure carries a measurable risk. On the other hand, limitations of bedside CXR have been well described and lead to poor-quality X-ray films with low sensitivity [2–4]. Indeed it has been shown that even under carefully controlled exposure conditions more than 30% of the X-ray films are considered suboptimal [2, 5]. Finally, there is poor correlation between CXR findings and those of CT [6]. Nevertheless, despite these

limitations bedside CXR remains the daily reference for lung imaging.

Nowadays bedside lung ultrasound is increasingly used in patients managed in intensive care units (ICUs) [7–9]. It has been shown in patients with acute respiratory distress syndrome (ARDS) that compared to bedside CXR, lung ultrasound has a higher diagnostic accuracy for pleural effusion, consolidation, and interstitial syndrome [10]. We wanted to assess the value of lung ultrasound performed by independent investigators in a general population of critically ill patients with a variety of diseases. For this purpose we compared the diagnostic performance of lung ultrasound and bedside chest CXR for the detection of several pathologic abnormalities in unselected critically ill patients, using thoracic CT as a gold standard.

Methods (see also electronic supplementary material, ESM)

The study was conducted in a medical–surgical ICU. The study was approved by the hospital ethics committee and informed consent was obtained from each patient or next of kin.

Forty-two mechanically ventilated patients were prospectively studied. Patients were enrolled in the study when a thoracic CT scan with iodine contrast material was ordered by the primary physician not involved in the study. No other selection criteria were applied. Prior to CT scan a bedside CXR was obtained and lung ultrasound was performed. Ventilator settings were kept unchanged throughout the study. Four pathologic entities were evaluated by each imaging method: (1) consolidation, (2) interstitial syndrome, (3) pneumothorax, and (4) pleural effusion. For data analysis each hemithorax was divided into six regions (see below), three in upper fields (anterior, posterior, lateral) and three in lower fields (anterior, posterior, lateral).

Chest radiography

Anterior CXR was performed using portable X-ray equipment (Siemens polymobile, Erlangen, Germany). The evaluation of CXR was performed by an expert radiologist, unaware of the lung ultrasound and CT findings. Consolidation, interstitial syndrome, pneumothorax, and pleural effusion were defined using the terminology of the Nomenclature Committee of the Fleischner Society [11]. The anatomic landmarks used for the location of regions were lung apex, mid-axillary line, hilar line, external limit of the rib cage, mediastinal border, and diaphragm, as previously described [10].

Multiple detector computed tomography (MDCT)

MDCT was performed with a Siemens Somatom Sensation (16 slices, Erlangen, Germany). Scans were obtained in the supine position from the apex of the thorax to the lung bases. Assessment included thin MDCT high resolution computed tomography (MDCT-HRCT) and spiral MDCT scans. MDCT-HRCT scans were used to reveal diffuse lung parenchymal involvement as ground glass opacities, septal or non-septal lines, and fibrotic changes (architectural distortion). MDCT scans were evaluated for mediastinal and pleural pathology and lung lesions (atelectasis, alveolar consolidation, and parenchymal bands) as described by the Nomenclature Committee of the Fleischner Society [11]. To facilitate comparison between methods, interstitial syndrome was defined as the presence of ground glass opacities, septal or non-septal lines, or fibrotic changes. Similarly consolidation was defined as the presence of atelectasis, alveolar consolidation, or parenchymal bands. Lung regions were located using the same anatomical landmarks as with X-ray. Two individual radiologists, unaware of the lung ultrasound and CXR findings, studied the MDCT-HRCT and MDCT images together and decisions were reached by consensus.

Lung ultrasound

Visualization of the lungs was performed using a microconvex 5–9 MHz transducer appropriate for transthoracic examination (HITACHI EUB 8500). Access to standardized images (seashore sign, stratosphere sign) was possible. Ultrasonography was evaluated by a single operator (N.X.), who was unaware of the CT and CXR findings. Lungs were divided into 12 regions as previously described [10]. The anterior surface of each lung was defined by clavicle, parasternal, anterior axillary line, and diaphragm and was divided into two areas, upper and lower. The lateral surface was defined by the anterior and posterior axillary lines and divided into an upper and lower area. Finally, the posterior lung surface was defined by the posterior axillary and the paravertebral lines and divided into an upper and lower area. The apex was scanned from the supraclavicular space. Patients were studied in the supine position. The lateral position was used for posterior lung surface examination. This, however, represents a major limitation of regional analysis (see below). The normal lung generates lung sliding and A-lines (repetition lines parallel to the pleural line) [8, 9]. Consolidation [isoechoic tissue-like structure (i.e., liver), caused by loss of lung aeration] and interstitial syndrome (multiple B-lines in a specific lung area) were defined as previously described [12–14]. Power Doppler was used to differentiate tissue-like structures (e.g., echoic pleural effusion) from consolidation [15]. The shred sign, specific for consolidation, was not used [8]. Pneumothorax was

diagnosed when the A-line sign (only A-lines visible) was associated with the stratosphere sign (complete abolition of lung sliding). Local lung sliding or B-lines exclude the diagnosis [16, 17]. The lung point sign, specific for pneumothorax, was additionally used [18]. Pleural effusion was determined as a hypoechoic or echoic structure, containing isoechoic particles or septations in inflammatory pleural diseases. In addition to power Doppler [7–9], the quad and sinusoid signs, which indicate pleural effusion regardless of its echogenicity, were used [7–9].

Data analysis

Each lung region was evaluated and characterized as positive or negative for each abnormality. A hemithorax was characterized as positive for an abnormality if it presented at least one positive region, and negative if all regions were negative. The results of CXR and lung ultrasound were compared with the corresponding CT scan results. Sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy were calculated using standard formulas.

Results (see also ESM for additional results, figures and videos)

Patient characteristics and admission diagnosis are shown in Table 1. The indications for thoracic CT scanning included diagnosis of pulmonary embolism (8 patients), ARDS assessment (13 patients), multiple trauma (12 patients), lung cancer (3 patients), evaluation after major thoracic surgery (2 patients), diagnosis of lung fibrosis (2 patients), diagnosis of lung abscess (1 patient), and mediastinitis (1 patient). Three trauma patients had normal lungs. In these patients a CT scan was performed to exclude aortic dissection. These three patients were included in the final statistical analysis.

A total of 504 lung regions (12 in each patient) and 84 hemithoraces (2 in each patient) were evaluated by the three imaging techniques. Because changing the position

Table 1 Patients characteristics

Age (years)	57.1 ± 21.5
Sex (male/female)	34:8
APACHE II	16.5 ± 6.5
Admission diagnosis	
Sepsis/MODS	18
Trauma	11
Acute exacerbation of COPD	7
Cardiogenic pulmonary edema	2
Postoperative acute respiratory failure	4

MODS multiple organ dysfunction syndrome, *COPD* chronic obstructive pulmonary disease

of the patient from supine to lateral during a lung ultrasound examination may alter the results (a major limitation of the followed protocol) only the detailed hemithorax analysis is presented (see ESM for detailed region analysis). Sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy of lung ultrasound and CXR for each pathologic entity and for each hemithorax are shown in Table 2. Overall lung ultrasound performed better than bedside CXR, exhibiting considerably higher sensitivity, positive and negative predictive values, and diagnostic accuracy for all pathologies examined. CXR had a slightly higher specificity than lung ultrasound for consolidation and pneumothorax.

Lung ultrasound had four false positive results for consolidation. In all of them the consolidation was considered to be small in size and located in one region.

Lung ultrasound had two false positive and three false negative results for interstitial syndrome, all in patients with chest trauma. The two false positive results were associated with consolidation in CT. Two of the three false negative results occurred in patients with pneumothorax.

There were eight cases of pneumothorax and lung ultrasound identified six of them, whereas five tests were false positive. The two pneumothoraces missed by lung ultrasound were small, located in the apex, and did not require any intervention. In all cases of false positive results the pneumothoraces were considered to be small in size. Analysis of these five false positive cases revealed that three occurred in patients with subcutaneous emphysema due to chest trauma (in one patient a chest tube was previously inserted), and two in patients with severe COPD and overinflation (i.e., presence of intrinsic positive end-expiratory pressure).

Region analysis (see ESM for detailed analysis) showed that the lung ultrasound false positive results were mainly observed in regions located adjunct to regions positive for the same pathology identified by both lung ultrasound and CT scan. Lung ultrasound false negative results for pleural effusion were exclusively observed in the upper posterior field, indicating that this regional discrepancy was due to posture. In the majority of cases where lung ultrasound had false negative results for interstitial syndrome, this pathology was identified in adjunct regions. In 23 out of 504 regions CT identified both consolidation and interstitial syndrome, whereas lung ultrasound identified only one pathology.

Discussion

The main finding of this study is that in a mixed surgical–medical ICU population of mechanically ventilated critically ill patients, lung ultrasound identifies the most common pathologic abnormalities of the respiratory system encountered in these patients with high diagnostic

Table 2 Sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy of CXR and lung ultrasound (LU) compared to CT scan for each abnormality and for each hemithorax

Pathology	LU/CXR	CT +	CT −	Sensitivity (%)[a]	Specificity (%)[b]	PPV (%)[c]	NPV (%)[d]	DA (%)[e]
Consolidation	LU +	66	4	100	78	94	100	95
	LU −	0	14					
	CXR +	25	2	38	89	93	28	49
	CXR −	41	16					
Pneumothorax	LU +	6	5	75	93	55	97	92
	LU −	2	71					
	CXR +	0	1	0	99	0	90	89
	CXR −	8	75					
Pleural effusion	LU +	63	0	100	100	100	100	100
	LU −	0	21					
	CXR +	41	4	65	81	91	44	69
	CXR −	22	17					
Interstitial syndrome	LU +	51	2	94	93	96	90	94
	LU −	3	28					
	CXR +	25	6	46	80	81	45	58
	CXR −	29	24					

Each hemithorax was characterized as positive (+) or negative (−) for the abnormality by the presence or absence of a single positive region, respectively

TP true positive, *TN* true negative, *FP* false positive, *FN* false negative

[a] Sensitivity = [TP/(TP + FN)] × 100

[b] Specificity = [TN/(TN + FP)] × 100

[c] Positive predictive value (PPV) = [TP/(TP + FP)] × 100

[d] Negative predictive value (NPV) = [TN/(TN + FN)] × 100

[e] Diagnostic accuracy (DA) = [(TP + TN)/(TP + TN + FP + FN)] × 100

accuracy. It is important to note that patients were enrolled in the study when a thoracic CT scan was ordered by the primary physician and no other selection criteria were applied. Therefore, the lung ultrasound performance was tested in unselected critically ill patients with a variety of conditions that might interfere with the imaging technique (i.e., obesity, chest trauma, tissue edema).

We evaluated four common abnormalities (pneumothorax, pleural effusions, consolidation, and interstitial syndrome) that have important implications in patient management and decision making. In order to accurately characterize the diagnostic performance of the three imaging methods 12 lung regions were analyzed in each patient. Nevertheless, in the decision-making process the presence of a certain pathology in a hemithorax is more important than its exact localization. In addition posture may affect the location of the findings making the clinical significance of analysis of relatively small lung regions questionable. For this reason we compared findings of all imaging modalities in each hemithorax. We believe that this analysis is clinically more relevant than the analysis of each separate region and at the same time minimizes the effects of posture (i.e., gravity) and the problem of overlapping between adjunct regions on the diagnostic performance of the various imaging techniques.

Interstitial syndrome

This disorder is of prime importance for diagnosing acute respiratory failure [8], acute circulatory failure [14], and control of hemodialysis [19] among others. In our study lung ultrasound had a sensitivity and diagnostic accuracy of 94%, comparable to those reported in patients with ARDS or respiratory failure [8]. In two cases lung ultrasound identified interstitial syndrome, whereas CT did not recognize such an abnormality (false positive cases). The difference in time between the two imaging techniques might be the cause of these two false positive cases. Thoracic CT was performed after lung ultrasound, within a time frame that for logistic reasons was between 1 and 4 h. Studies have shown that this interval is sufficient to modify the appearance of interstitial syndrome on CT, because this pathology is very sensitive to treatment [19, 20]. Lung ultrasound had three false negative results. In two cases (polytrauma patients) a concomitant pneumothorax was present which interfered with the ability of lung ultrasound to evaluate the affected lung regions. Nevertheless, lung ultrasound was much more sensitive and specific than bedside CXR in identifying interstitial syndrome.

Consolidation

The sensitivity of lung ultrasound for the detection of consolidation in critically ill patients has been reported to be in the region of 90% [8, 13, 19, 20]. In our study lung ultrasound had a sensitivity of 100% and a diagnostic accuracy of 95% in identifying this abnormality. Similar to its diagnostic performance in interstitial syndrome, CXR had a much lower sensitivity (38%) and diagnostic

accuracy (49%). The lung ultrasound had four false positive cases, resulting in a specificity of 78%, lower than that reported in the literature [13]. In all cases the consolidation was considered to be small in size and located in one region. It is likely that the time interval between lung ultrasound and CT (up to 4 h in some cases) as well as the mobilization and transportation of the patient to the radiology department contributes to this discrepancy (i.e., small consolidations may be resolved, particularly in mechanically ventilated patients). The non-use of the shred sign, specific for consolidation, might also contribute to low specificity [8].

In region analysis we observed that in most cases the discrepancy between lung ultrasound and CT was attributed to overlapping of adjunct regions in lung ultrasound examination. Specifically, in these cases when lung ultrasound identified a consolidation in the lower lateral region, both lung ultrasound and CT identified a consolidation in the lower posterior region. These underline the importance of hemithorax analysis in order to evaluate the diagnostic performance of lung ultrasound.

Pleural effusion

Lung ultrasound has long been used for identification of pleural effusions having a sensitivity above 90% [21, 22]. In our study the sensitivity and specificity were 100% in hemithorax analysis. Region analysis showed that all regions with false positive results ($n = 44$, usually lower lateral) were adjunct to regions (usually lower posterior) where both tests identified a pleural effusion. CXR performed very poorly (sensitivity 65%, diagnostic accuracy 69%) indicating that this technique is useless in diagnosis and evaluation of pleural effusion.

Pneumothorax

The bedside diagnosis of pneumothorax is extremely important in ICU patients. It is known that supine CXR is not sensitive for diagnosis of pneumothorax [17, 23]. Indeed in our study bedside CXR did not identify any of the eight pneumothoraces. Lung ultrasound has been successfully used for identification of pneumothorax in a variety of patients [8, 16, 23–26]. These studies report a sensitivity of 81–100%. In our study lung ultrasound identified six out of the eight pneumothoraces, having a relatively low sensitivity (75%). However, both pneumothoraces missed by lung ultrasound were small and none required drainage, a finding similar to Brook et al. [24] in the emergency department. The small number of cases and/or suboptimal methodology could explain the relatively low sensitivity. In our study five tests were false positive, resulting in a specificity of 93%. In all these false cases the pneumothoraces were considered to be small in size and not contributing to the patients' clinical picture. These false positive cases occurred in three patients with clinical subcutaneous emphysema due to chest trauma (in spite of subcutaneous air, which was minimal, we were able to analyze the pleural line) and in two patients with severe COPD and overinflation. Because in our study lung point was not mandatory for the diagnosis of pneumothorax and not recognized in these cases we cannot exclude suboptimal methodology being responsible for the false positive results. Finally operator bias due to the underlying diagnoses of chest trauma and severe COPD (diagnoses associated with increased risk of pneumothorax) might contribute to the discrepancy. Nevertheless, because lung ultrasound did not miss any clinically significant pneumothorax, our data indicate that this technique is a reliable tool for bedside diagnosis of this abnormality.

This study has some limitations. Firstly, a relatively small number of patients ($n = 42$) were studied. However, the fact that the performance of lung ultrasound was evaluated separately on each hemithorax, increased the cases (from 42 to 84), partly overcoming this limitation. Nevertheless, the small number of pneumothoraces ($n = 8$) may partly influence the results concerning this pathology. Secondly, the time interval between lung ultrasound and CT could not be controlled, and was up to 4 h in some cases. This might contribute in an unknown extent to the observed discrepancy between methods. Thirdly, lung ultrasound accessibility was difficult in some patients due to tissue edema (overload), polytrauma (major surgery, pre-existing chest tube, subcutaneous emphysema) and obesity. Nevertheless, the patients studied represent the typical population of critically ill patients. Fourthly, patients were positioned laterally for ultrasound examination, and this might change the localization of some abnormalities (i.e., pleural effusions). The use of the microconvex probe facilitates semiposterior analyses with minimal or no patient mobilization. Lung ultrasound examination could benefit from this advantage, simplifying the methodological approach and avoiding region per region analysis which, as we showed, imposes several problems. Fifthly, the only selection criterion we used for study enrollment was the decision of the primary physician to perform thoracic CT scan with iodine contrast material. Thus, the population studied was considered to be preselected as having some kind of respiratory system pathology. Notwithstanding that the number of patients with normal respiratory system on CT was small ($n = 3$), there were no lung ultrasound false positive findings in these patients.

Although in our study an ultrasonographic protocol was followed that permitted the operator to approach the lung in an organized fashion, our data of region analysis indicate that the majority of the patients can be satisfactorily examined in the supine position (because imaging of the latter lung regions provides an acceptable view of posterior regions). However, the decision to not examine

the dorsal regions should be individualized. Some patients in whom paravertebral pathology or very small pleural effusion is suspected, need the posterior approach, made easy using a short microconvex probe.

In conclusion, in a general ICU population lung ultrasound has a considerably better diagnostic performance than bedside CXR for the diagnosis of most common pathologies. Lung ultrasound has a diagnostic accuracy of 92–100% in identifying pneumothorax, consolidation, interstitial syndrome, and pleural effusion, and may therefore be considered as an alternative to CT for these patients.

References

1. Rubinowitz AN, Siegel MD, Tocino I (2007) Thoracic imaging in the ICU. Crit Care Clin 23:539–573
2. Henschke CI, Yankelevitz DF, Wand A, Davis SD, Shiau M (1996) Accuracy and efficacy of chest radiography in the intensive care unit. Radiol Clin North Am 34:21–31
3. Henschke CI, Yankelevitz DF, Wand A, Davis SD, Shiau M (1997) Chest radiography in the ICU. Clin Imaging 21:90–103
4. Lichtenstein D, Peyrouset O (2006) Is lung ultrasound superior to CT? The example of a CT occult necrotizing pneumonia. Intensive Care Med 32:334–335
5. Yu CJ, Yang PC, Chang DB, Luh KT (1992) Diagnostic and therapeutic use of chest sonography: value in critically ill patients. AJR Am J Roentgenol 159:695–701
6. Rouby JJ, Puybasset L, Cluzel P, Richecoeur J, Lu Q, Grenier P (2000) Regional distribution of gas and tissue in acute respiratory distress syndrome. II. Physiological correlations and definition of an ARDS severity score: CT Scan ARDS Study Group. Intensive Care Med 26:1046–1056
7. Bouhemad B, Zhang M, Lu Q, Rouby JJ (2007) Clinical review: bedside lung ultrasound in critical care practice. Crit Care 11:205
8. Lichtenstein DA, Meziere GA (2008) Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 134:117–125
9. Lichtenstein DA (2009) Ultrasound examination of the lungs in the intensive care unit. Pediatr Crit Care Med 10:693–698
10. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ (2004) Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 100:9–15
11. Austin JH, Muller NL, Friedman PJ, Hansell DM, Naidich DP, Remy-Jardin M, Webb WR, Zerhouni EA (1996) Glossary of terms for CT of the lungs: recommendations of the Nomenclature Committee of the Fleischner Society. Radiology 200:327–331
12. Yang PC, Luh KT, Chang DB, Yu CJ, Kuo SH, Wu HD (1992) Ultrasonographic evaluation of pulmonary consolidation. Am Rev Respir Dis 146:757–762
13. Lichtenstein DA, Lascols N, Meziere G, Gepner A (2004) Ultrasound diagnosis of alveolar consolidation in the critically ill. Intensive Care Med 30:276–281
14. Lichtenstein DA, Meziere GA, Lagoueyte JF, Biderman P, Goldstein I, Gepner A (2009) A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. Chest 136:1014–1020
15. Yang PC (1996) Color Doppler ultrasound of pulmonary consolidation. Eur J Ultrasound 3:169–178
16. Volpicelli G (2011) Sonographic diagnosis of pneumothorax. Intensive Care Med 37:224–232
17. Lichtenstein DA, Meziere G, Lascols N, Biderman P, Courret JP, Gepner A, Goldstein I, Tenoudji-Cohen M (2005) Ultrasound diagnosis of occult pneumothorax. Crit Care Med 33:1231–1238
18. Lichtenstein D, Meziere G, Biderman P, Gepner A (2000) The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Med 26:1434–1440
19. Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJ, Liteplo A (2009) Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis. Time course for resolution. Chest 135:1433–1439
20. Kato S, Nakamoto T, Iizuka M (1996) Early diagnosis and estimation of pulmonary congestion and edema in patients with left-sided heart diseases from histogram of pulmonary CT number. Chest 109:1439–1445
21. Joyner CR Jr, Herman RJ, Reid JM (1967) Reflected ultrasound in the detection and localization of pleural effusion. JAMA 200:399–402
22. Remerand F, Dellamonica J, Mao Z, Ferrari F, Bouhemad B, Jianxin Y, Arbelot C, Lu Q, Ichai C, Rouby JJ (2010) Multiplane ultrasound approach to quantify pleural effusion at the bedside. Intensive Care Med 36:656–664
23. Soldati G, Testa A, Sher S, Pignataro G, La Sala M, Silveri NG (2008) Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. Chest 133:204–211
24. Brook OR, Beck-Razi N, Abadi S, Filatov J, Ilivitzki A, Litmanovich D, Gaitini D (2009) Sonographic detection of pneumothorax by radiology residents as part of extended focused assessment with sonography for trauma. J Ultrasound Med 28:749–755
25. Sartori S, Tombesi P, Trevisani L, Nielsen I, Tassinari D, Abbasciano V (2007) Accuracy of transthoracic sonography in detection of pneumothorax after sonographically guided lung biopsy: prospective comparison with chest radiography. AJR Am J Roentgenol 188:37–41
26. Galbois A, Ait-Oufella H, Baudel JL, Kofman T, Bottero J, Viennot S, Rabate C, Jabbouri S, Bouzeman A, Guidet B, Offenstadt G, Maury E (2010) Pleural ultrasound compared to chest radiographic detection of pneumothorax resolution after drainage. Chest 138:648–655