Original Article

Chest Sonography in the Diagnosis of Pneumothorax

Jitendra Balesa[1], Vinita Rathi[1], Sunil Kumar[2] and Anupama Tandon[1]

Departments of Radiology and Imaging[1] and Surgery[2], University College of Medical Sciences and Guru Teg Bahadur Hospital, Delhi, India

Abstract

Background. Few studies have assessed the utility of chest ultrasonography in the diagnosis of pneumothorax in India.

Methods. Chest ultrasonography was undertaken in 126 haemodynamically stable patients, followed by a chest radiograph within 30 minutes. If pneumothorax was not seen on the chest radiograph, a non-contrast computed tomography of the thorax was performed within 3 hours. The time taken to make or exclude a diagnosis of pneumothorax, by ultrasonography, was assessed. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of chest ultrasonography was estimated.

Results. For the diagnosis of pneumothorax in any clinical situation, the average time taken on ultrasonography was less than 2 minutes. The sensitivity, specificity, accuracy, PPV and NPV of chest ultrasonography was 89%, 88.5%, 88.9%, 96.7% and 67.6%, respectively.

Conclusions. Chest ultrasonography can be used as a primary imaging modality in the diagnosis of pneumothorax in a vast variety of clinical situations. **[Indian J Chest Dis Allied Sci 2015;57:7-11]**

Key words: Chest ultrasonography, Pneumothorax, CT scan, Bullous emphysema, Radio-occult pneumothorax.

Introduction

Several studies have evaluated the role of chest ultrasonography in specific clinical settings, e.g., post-traumatic pneumothorax[1-11]; pneumothorax in intensive care unit patients[12]; post-intervention pneumothorax[13-15]; as well as a few scattered reports or studies regarding the role of ultrasonography in pneumothorax due to lung diseases[16]; pneumothorax in children[17]; residual pneumothorax after intercostal chest tube drainage[18,19] and spontaneous pneumothorax.[20] Chest ultrasonography for pneumothorax has shown good results in the hand of radiologists[2], surgeons[4], physicians[15], senior residents[7], intensivists[12], trainees of trauma teams[1,10] and even space physicians.[21] However, few studies have systematically evaluated the role of chest ultrasonography in the diagnosis of pneumothorax, combining all above described clinical settings.

In the present study, we assessed the role of chest ultrasonography, in the diagnosis of pnemothorax in haemodynamically stable patients and assessed the average time for the diagnosis of pnemothorax by chest ultrasonography.

Material and Methods

The present study was a prospective-one conducted during the period October 2010 to March 2012. We included 126 haemodynamically stable patients with clinical and/or radiographic suspicion of pneumothorax; and patients with chest tube *in-situ* who required evaluation for residual pneumothorax. Patients with extensive subcutaneous emphysema were excluded from the study.

The study protocol was approved by the Ethical Committee of our institution. A written, informed consent was taken from all patients. After a rapid initial assessment, stabilisation and resuscitation of the patient, real-time chest ultrasonography was performed using either Philips HDI 5000 SonoCT Colour Doppler (Wankhai, Hong Kong); Siemens Sonoline Antares (Erlangen, Germany); Philips HD7 XE Color Doppler Ultrasound (Bothell, WA, USA); Siemens Sonoline Adara (St. Issaquah, USA) ultrasonogrpahy machines. Findings were recorded in a proforma and a video recording was also made on the ultrasonography machine. Both sides of the thorax were evaluated, starting with the unaffected lung, to establish a baseline. A 2–5 MHz convex transducer and a high frequency 7–12 MHz linear array transducer was used. Each side was first examined in the longitudinal plane, from the 3rd intercostal space to the diaphragm through the anterior and lateral chest wall; followed by examination through the intercostal spaces transversely, from the sternum to mid-axillary line. Finally, M–Mode and Power Doppler scanning was carried out.

Both static as well as dynamic sonographic signs were evaluated in all the patients. Static sonographic

[Received: August 8, 2013; accepted after revision: August 01, 2014]

Correspondence and reprint requests: Dr Vinita Rathi, Professor, Department of Radiology and Imaging, University College of Medical Sciences and Guru Teg Bahadur Hospital, Shahdara, Delhi-110 095, India; E-mail: vineetarathi@yahoo.com

signs include Comet–tail artifacts from the pleural line (Figure 1A) or B–lines (Figure 1B) and augmented horizontal reverberation artifacts / A–lines (Figure 2). Dynamic sonographic signs include lung sliding / Gliding sign, "Seashore sign" (Figure 3A) and "Stratosphere sign" (Figure 3B) on M–mode; and "Power slide" on Power Doppler. A sonographic diagnosis of "Pneumothorax" or "No Pneumothorax" was made.

Chest radiograph was obtained in supine or erect position within 30 minutes of performing chest ultrasonography. The initial chest radiograph was not seen by the radiologists performing the chest ultrasonography. In 68 of the 126 patients in whom the diagnosis of pneumothorax made on chest ultrasonography was confirmed on the chest radiograph, computed tomography (CT) of the chest was not performed to avoid exposure to radiation. In the remaining 58 cases out of 126, a non-contrast CT of the chest was done within 3 hours of conduct of chest ultrasonography, using Somatom Plus 4 Volume Zoom Multislice CT (Siemens, Erlangen, Germany) or Somatom Definition AS 64 Slice CT (Siemens, Erlangen, Germany). Axial scans with a slice thickness of 3 mm or less were acquired at appropriate KVp and mAs. Scanning was done from the thoracic inlet to the domes of diaphragm and images were viewed in both lung and mediastinal windows. The maximum thickness of pneumothorax was recorded on axial CT images.

Statistical Analysis

The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and overall accuracy of chest ultrasonography were calculated considering chest radiograph (n=68) and computed tomography (n=58) as 'gold standard'. The performance of chest ultrasonography in the detection of pneumothorax was compared to the "gold standard" using a Kappa agreement test. A Kappa value greater than 0.60 indicates good agreement with the gold standard.

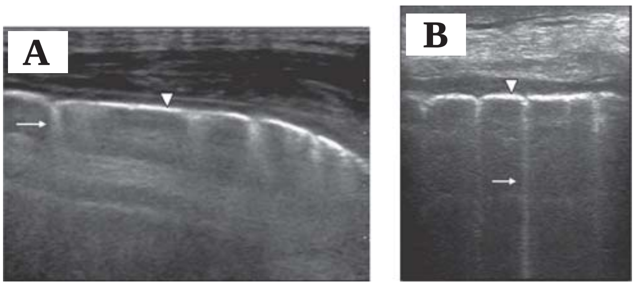

Figure 1. (A) Comet-tail artifacts: Short, ill-defined, hyperechoic vertical artifacts (arrow) extending from and below the pleural line (arrowhead) and moving with it, on respiration; and (B) B-Lines: Comet-tail artifacts extending to the edge of the ultrasound screen are called B–lines. Presence of comet tail artifacts, B-lines excludes pneumothorax.

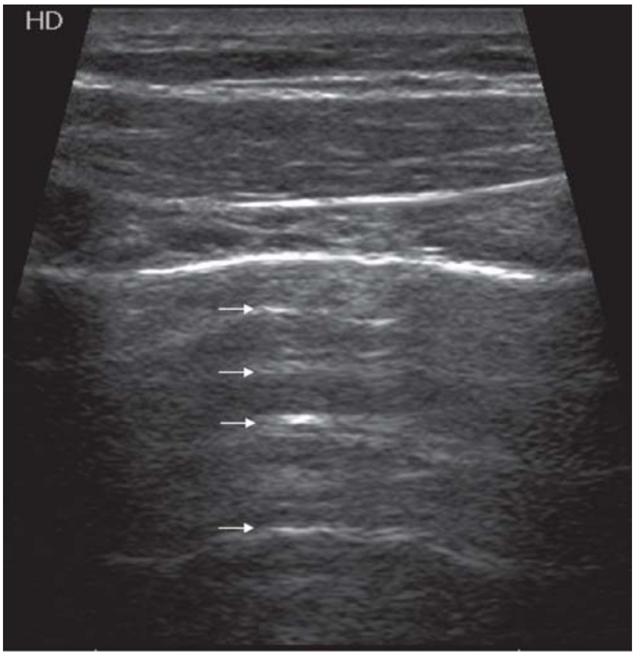

Figure 2. Horizontal reverberation artifacts/A-lines: Parallel horizontal hyperechoic lines (arrows), which show immobility during breathing movements, suggest a diagnosis of pneumothorax.

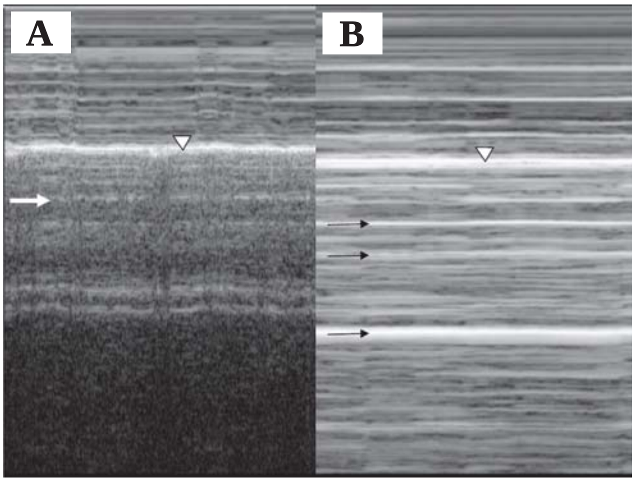

Figure 3. (A) Seashore sign: M-mode showing a granular pattern (arrow) below the pleural line (arrow-head). This appearance of a sandy beach represents lung sliding and indicates absence of pneumothorax; and (B) Stratosphere sign: M-mode showing a linear hyperechoic laminar pattern also called "frozen echoes" (arrow), below the pleural line (arrow-head). This indicates absence of lung sliding, i.e. presence of pneumothorax.

Results

The age range was 2 months to 88 years; 126 cases studied, included 97 males. Chest pain (n=123; 97.6%) and dyspnoea (n=94; 74.6%) were the most common complaints. The duration of complaints ranged from 1 hour to 1 month. On examination, evidence of chest trauma was seen in 75 (59.5%) cases. Mild subcutaneous emphysema was seen in 26 (20.6%) cases. Significant general physical examination findings were tachypnoea (n=66; 52.4%), fever (n=22; 17.4%), pallor (n=16; 12.6%), tachycardia (n=7; 5.5%) and lymphadenopathy (n=5; 3.9%). Decreased breath sounds were found on chest auscultation in 60 (47.6 %) cases.

Chest radiograph was done in the erect position in 100 cases and in the supine position in 26 cases.

According to our "gold standard" (i.e., chest radiograph in 68 cases and CT of the thorax in 58 cases), pneumothorax was present in 100/126 (79.4%) cases; 58 had pneumothorax on the right side, 40 had pneumothorax on the left side and 2 had bilateral pneumothorax. The causes of pneumothorax were: post–intercostal drain (ICD) residual pneumothorax (36%), trauma (35%), chronic obstructive airways disease (12%), spontaneous pneumothorax (8%), tuberculosis (5%), pyopneumothorax (2%), and post–intervention e.g., lung fine needle aspiration cytology (FNAC) or aspiration of pleural fluid (2%) (*see* Table).

Pneumothorax was diagnosed by chest ultrasonography in 89/100 confirmed cases of pneumothorax (true-positive). Chest ultrasonography was able to diagnose all the 35 cases in whom therapeutic intervention was needed for the management of pneumothorax. In 6 of the 8 children, pneumothorax was diagnosed correctly by chest ultrasonography.

Table. Clinical spectrum of pneumothorax cases (n=100)

	No. (%)
Post Intercostal drainage residual pneumothorax	36 (36)
Post traumatic	35 (35)
Chronic obstructive airway disease	12 (12)
Primary spontaneous pneumothorax	8 (8)
Tuberculosis	5 (5)
Pyopneumothorax	2 (2)
Post-intervention (e.g., lung biopsy, pleural aspiration)	2 (2)
Total	**100**

There were 23 true-negative, 3 false-positive and 11 false-negative cases on chest ultrasonography. A false-positive diagnosis of pneumothorax was made on chest ultrasonography in 2 cases with bullous emphysema (Figure 4) and in 1 case with pleural thickening. All 11 false-negative cases diagnosed on chest ultrasonography had a pneumothorax of width <1 cm on axial CT section (Figure 5). Kappa agreement test indicated that ultrasonography had a strong agreement with the 'gold standard' (kappa=0.70, $p<0.05$). Twenty-one of the 32 (65.6%) cases of pneumothorax missed on the chest radiograph but diagnosed on chest CT, were correctly diagnosed on ultrasonography. Pneumothorax >1.0 cm in thickness on CT scan, was diagnosed on sonography in all cases. "Lung sliding", i.e., to-and-fro movement of pleural line with respiration, was the most useful sign in the

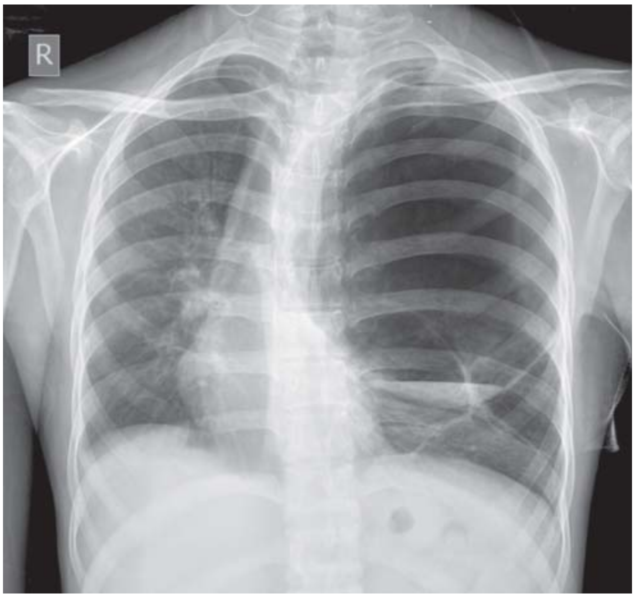

Figure 4. Chest radiograph (postero-anterior view) showing a large infected bulla in the left lung which mimicked pneumothorax on ultrasonography.

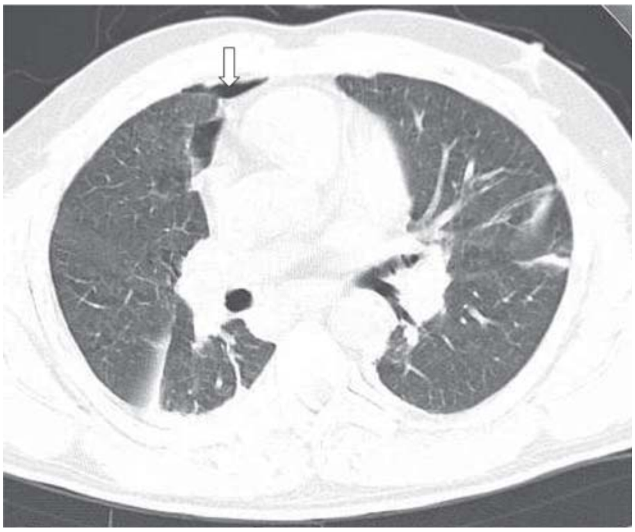

Figure 5. Small anterior pneumothorax (arrowhead) on axial computed tomography (3 mm section) which was missed on chest sonography.

detection or exclusion of pneumothorax. It was absent in all cases diagnosed to have pneumothorax.

The average time taken for ultrasonographic examination of both lungs and evaluation of all sonographic signs was 4 minutes, in the present study. The time taken for diagnosing the presence or absence of pneumothorax by sonography (usually possible by one or more sonographic signs) ranged from 1 minute to 18 minutes. The average time taken by sonography for diagnosing presence or absence of pneumothorax in any clinical scenario, including children, in our study of 126 cases, was 1 minute 53 seconds. There were 5 cases in which more than or equal to 5 minutes were required for the ultrasonographic diagnosis of presence or absence of pneumothorax. In 3 out of these 5 cases, presence of subcutaneous emphysema produced a delay in the detection of pleural line, leading to an increase in the time required; 1 had localised pneumothorax and the other had a small pneumothorax in only one intercostal space, on sonography.

Discussion

The sensitivity of chest ultrasonography in our study (89%) was comparable to (86.2%)[1] and (91.4%)[11] observed in other studies which had included post-trauma pneumothorax cases. The sensitivity of chest ultrasonography in our study was less than the figure of 100% reported in some other studies.[2,13,15] These studies had included only adult patients who had undergone transthoracic sonography-guided lung biopsy[15]; only adult patients who had undergone transbronchial biopsy or ultrasound-guided chest tube placement,[13] and adult blunt thoracic trauma victims.[2] On the other hand, our study included a wide spectrum of cases including those with trauma; history of intervention; various lung diseases (e.g., tuberculosis, chronic obstructive airway disease, bullous lung disease, etc); patients with intercostal chest tube *in-situ*; cases with primary spontaneous pneumothorax and even children. This vast spectrum studied may be a contributory factor, for the sensitivity of ultra-sonography in our study being less than 100%.

Only 4 out of a total of 53 cases had pneumothorax, in the report by Reissig *et al*[13]; and there is no mention of the size of pneumothorax detected in their 4 cases. Sartori *et al*[15] (n=285) had detected only 8 patients with pneumothorax by ultrasonography of which only one patient had a small pneumothorax on thoracic CT. The prevalence of pneumothorax in their study[15] was only 2.8%, while in our study pneumothorax was present in 79.4% cases. Also, in our study ultrasonography made a true positive diagnosis of small pneumothoraces (<1.0 cm in size) in 13 out of 24 cases. In the study reported by Sartori *et al*[15], despite the large number of patients enrolled, the low number of cases of pneumothorax detected may make their estimate of sensitivity of ultrasonography as 100% questionable.

In another study,[7] 21/204 cases had pneumothorax but only 2 patients had minimal pneumothorax. However, in our study, 24 patients had a small pneumothorax (<1.0 cm thickness on axial CT images) and all 11 cases in which the diagnosis of pneumothorax was missed by sonography (false-negative) had a small pneumothorax (i.e., present in only 2–5 CT-axial sections of 3 mm each). The sensitivity of 89% reported in the present study was lower than the 95% reported by Nandipati *et al*.[7] However, a missed pneumothorax of less than 1.0 cm had no clinical consequences in our study.

Chest ultrasonography yielded false-positive results in 3 of our patients: due to bullous emphysema in 2 and pleural thickening in 1. It has been observed that in a patient with bullous emphysema showing absence of lung sliding was responsible for one false-positive result.[2] Rowan *et al*[3] also stated that presence of pleural adhesions or any condition in which the pleural surfaces do not slide against each other at respiration, are other potential pitfalls responsible for false-positive cases on ultrasonography. In another study,[1] 2 of the 3 false-positive cases were due to pleural adhesions (confirmed by CT) and one due to acute respiratory distress syndrome.

In the present study, intercostal chest tube was inserted for treatment in 35 cases of pneumothorax, confirmed by "gold standard." All these 35 cases were detected by chest ultrasonography. This suggests that sonography is able to detect all the cases with clinically significant pneumothorax, i.e. those in whom therapeutic intervention is required.

Chest ultrasonography was performed in 39 cases with intercostal drainage tube (ICD) *in-situ*, to detect residual pneumothorax, if any. Chest ultrasonography detected 30 out of 39 cases with residual pneumothorax. In the present study, the PPV of sonography in the detection of residual pneumothorax was 100%, which was similar to the figure reported in another study.[19] Since sonography detected 21/32 patients with pneumothorax that was not evident on the chest radiograph, and was also able to identify all cases having a pneumothorax of >1.0 cm thickness on CT, it has the potential to replace serial chest radiographs in monitoring of the patients with pneumothorax; and thereby, avoid exposure to ionising radiation.

As chest ultrasonography correctly identified pneumothorax in 6 of the 8 children it can be advocated as the initial quick imaging modality, that does not involve the use of ionising radiation, in a child with suspected pneumothorax.

In our study, as in another study,[22] chest radiography was used as the "gold standard", when it showed obvious pneumothorax, and CT whenever it proved necessary. A single gold standard (traditionally considered to be CT) was not used, to avoid unnecessary irradiation of young patients.

Chest ultrasonography was used for the first time in the evaluation of pneumothorax at our institution; and prior to this study we did not have any practical experience with ultrasonographic signs for the diagnosis of pneumothorax. Zhang *et al*[1] mentioned that they had received formal training of 28 hours on emergency bedside ultrasound before conducting their study. The average time taken by sonography for diagnosing presence or absence of pneumothorax in our study was 1 minute 53 seconds. This was comparable to the average time taken of 2.3±2.9 min[1] and ≤2 min[6] reported in other studies.

In this study we had used 4 ultrasound machines as per availability and the results using all these 4 machines were comparable. Our experience is similar to that reported by Volpicelli *et al*[20] who had stated that ultrasonographic diagnosis of pneumothorax does not need sophisticated, top-quality equipment.

Conclusions

Chest ultrasonography can be used as a primary imaging modality for the diagnosis of pneumothorax in a vast array of clinical settings, as it has a high sensitivity and specificity. It is especially useful in children and for the follow-up of residual pneumothorax in patients with intercostal chest tube drainage. Unlike chest radiographs and CT it also avoids the risk of exposure to ionising radiation. Chest ultrasonography requires a short learning experience and can make a rapid and confident diagnosis of presence or absence of pneumothorax in less than 2 minutes, so it should be combined with "Focussed Assessment with Sonography for Trauma (FAST)" as "Extended FAST (E–FAST)".[3,7]

However, cases with a large bulla in the lung or with pleural thickening can be misdiagnosed as pneumothorax on ultrasonography. Thus, chest ultrasonography cannot replace CT, which will continue to remain the "gold standard" in the diagnosis of pneumothorax, especially in the detection of small pneumothoraces.

References

1. Zhang M, Liu ZH, Yang JX, Gan JX, Xu SW, You XD, *et al*. Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. *Crit Care* 2006;10:112.
2. Rowan KR, Kirkpatrick AW, Liu D, Forkheim KE, Mayo JR, Nicolaou S. Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT: initial experience. *Radiology* 2002;225:210–4.
3. Kirkpatrick AW, Sirois M, Laupland KB, Liu D, Rowan K, Ball CG, *et al*. Hand–held thoracic sonography for detecting post traumatic pneumothorax: the extended focussed assessment with sonography for trauma (E-FAST). *J Trauma* 2004;57:288–95.
4. Knudtson JL, Dort JM, Helmer SD, Smith RS. Surgeon performed ultrasound for pneumothorax in the trauma suite. *J Trauma* 2004;56:527–30.
5. Dulchavsky SA, Schwarz KL, Kirkpatrick AW, Billica RD, Williams DR, Diebel LN, *et al*. Prospective evaluation of thoracic ultrasound in the detection of pneumothorax. *J Trauma* 2001;50:201–5.
6. Soldati G, Testa A, Pignataro G, Portale G, Biasucci DG, Leone A, *et al*. The Ultrasonographic deep sulcus sign in traumatic pneumothorax. *Ultrasound Med Biol* 2006;32: 1157–63.
7. Nandipati KC, Allamaneni S, Kakarla R, Wong A, Richards N, Satterfield J, *et al*. Extended focused assessment with sonography for trauma (EFAST) in the diagnosis of pneumothorax: experience at a community based level I trauma center. *Injury* 2010;41:862–5.
8. Gillman LM, Ball CG, Panebianco N, Kadi AA, Kirkpatrick AW. Clinician performed resuscitative ultrasonography for the initial evaluation and resuscitation of trauma. *Scand J Trauma Resusc Emerg Med* 2009;17:34.
9. Stone MB. Ultrasound diagnosis of traumatic pneumothorax. *J Emerg Trauma Shock* 2008;1:19–20.
10. Soldati G, Testa A, Sher S, Pignataro G, La Sala M, Silveri NG. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. *Chest* 2008;133:204–11.
11. Donmez H, Tokmak TT, Yildirim A, Buyukoglan H, Ozturk M, Yasar Ayaz U, *et al*. Should bedside sonography be used first to diagnose pneumothorax secondary to blunt trauma? *J Clin Ultrasound* 2012;40:142–6.
12. Lichtenstein D, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. *Chest* 1995;108:1345–8.
13. Reissig A, Kroegel C. Accuracy of transthoracic sonography in excluding post interventional pneumothorax and hydropneumothorax comparison to chest radiography. *Eur J Radiol* 2005;53:463–70.
14. Targhetta R, Buergeois JM, Chavagneux R, Balmes P. Diagnosis of pneumothorax by ultrasound immediately after ultrasonically guided aspiration biopsy. *Chest* 1992;101:855–6.
15. Sartori S, Tombesi P, Trevisani L, Nielsen I, Tassinari D, Abbasciano V. Accuracy of transthoracic sonography in detection of pneumothorax after sonographically guided lung biopsy: prospective comparison with chest radiography. *AJR Am J Roentgenol* 2007;188:37–41.
16. Slater A, Goodwin M, Anderson KE, Gleeson FV. COPD can mimic the appearance of pneumothorax on thoracic ultrasound. *Chest* 2006;129:545–50.
17. Liu DM, Forkheim K, Rowan K, Mawson JB, Kirkpatrick A, Nicolaou S. Utilization of ultrasound for the detection of pneumothorax in the neonatal special-care nursery. *Pediatr Radiol* 2003;33:880–3.
18. Saucier S, Motyka C, Killu K. Ultrasonography versus chest radiography after chest tube removal for the detection of pneumothorax. *AACN Adv Crit Care* 2010;21:34–8.
19. Galbois A, Ait-Oufella H, Baudel JL, Kofman T, Bottero J, Viennot S, *et al*. Pleural ultrasound compared with chest radiographic detection of pneumothorax resolution after drainage. *Chest* 2010;138:648–55.
20. Volpicelli G, Audino B. The double lung point: an unusual sonographic sign of juvenile spontaneous pneumothorax. *Am J Emerg Med* 2011;29:355. e1–e2.
21. Kirkpatrick AW, Nicolaou S, Rowan K, Liu D, Cunningham J, Sargsyan AE, *et al*. Thoracic sonography for pneumothorax: the clinical evaluation of an operational space medicine spin-off. *Acta Astronautica* 2005;56:831–8.
22. Lichtenstein D, Mezière G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive Care Med* 2000;26:1434–40.