# Role of ultrasound in the management of pleural diseases in respiratory intensive care patients

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***Introduction*** Ultrasonography (US) has become an invaluable tool in the management of critically ill patients.

***Objectives*** This study aimed to evaluate the role of US in the diagnosis and treatment of pleural diseases in patients in the respiratory intensive care unit.

***Patients and methods*** This study recruited 55 patients who presented with suspected clinical and/or radiological evidence of pleural disease in whom US and chest radiography were performed. In addition, US-guided interventions were carried out whenever needed and computed tomography scans of the chest where obtained whenever possible.

***Results*** Pleural effusion was the most common pleural disease encountered (54.5%). US correctly predicted the nature of most pleural effusions, whether transudative or exudative (84%). US was significantly more sensitive than chest radiography in the diagnosis of pleural effusion and pleural thickening ($P = 0.00$ and 0.004, respectively) and had significantly better sensitivity for unilateral effusions and for septations compared with computed tomography ($P = 0.004$). There was almost perfect agreement between US results and the final diagnosis in all pleural diseases, with κ values ranging from 0.9 to 0.98. A total of 67 US-guided interventions were carried out, with a success rate of 94%, and only one (1.5%) complication was encountered in the form of partial pneumothorax. US affected the diagnosis and altered the treatment policy, with recorded favorable outcomes. Short-term training programs enable pulmonologists to acquire US examination skills after 30 examinations.

***Conclusion*** US is an efficient and suitable method for evaluating pleural disease in the respiratory intensive care unit, especially pleural effusion. US-guided pleural interventions have been successful and have shown favorable outcomes and minimal complications. Short-term training could enable mastering of US use.
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## Introduction

The benefits of ultrasonography (US) include its portability, low cost, lack of radiation exposure, and ability to provide dynamic and real-time procedural guidance at the bedside [1]. Lung consolidation, atelectasis, and pleural effusions are common in intensive care unit (ICU) patients and are often present at the same time. Portable, supine, and anteroposterior chest radiographs taken in these patients offer limited sensitivity for the diagnosis of pleural effusion [2].

The use of portable US machines has greatly enhanced the evaluation and management of patients with pleural disease [1]. US examination of the pleural space has proven to be of high value for the diagnosis of effusion, distinguishing transudative from exudative pleural fluid, accurately estimating the volume of pleural fluid, and aiding the drainage of pleural effusions with a catheter or by simple thoracocentesis [3–6]. US-guided pleural interventions have been associated with increased success in thoracocentesis even after a failed clinically directed thoracocentesis and lower frequencies of post-thoracocentesis pneumothorax [7,8]. This seems crucial in critically ill patients, especially in those with low lung reserve, who are under oxygen therapy or under positive pressure mechanical ventilation.

In comparison with CT scanning, US is easier to perform and may better distinguish pleural thickening from pleural effusion [3]. In addition, it detects thoracic empyema in its early stages [9]. The US diagnosis of pneumothorax is well established and has been reported to be of value in the acute assessment of patients when an upright chest radiograph is not possible to achieve, most notably in trauma patients and in those in the ICU [10].

US is a valuable and accessible tool for intensivists and pulmonary physicians. With proper training, intensivists and pulmonary physicians can achieve a high level of competence in all aspects of US relevant to their specialty. A machine with good-quality two-dimensional imaging capability must be continuously available in the ICU [11].

This study aimed to evaluate the role of US in the diagnosis and treatment of pleural diseases in respiratory intensive care unit (RICU) patients.

## Patients and methods

This prospective study included consecutive patients who presented with suspected clinical and/or radiological evidence of pleural disease to the RICU of Abbassia Chest Hospital during the period between January 2011 and January 2013. Patients with parenchymal lung diseases with no pleural involvement were excluded.

All patients were subjected to full history taking, thorough clinical examination, chest radiography performed anteroposteriorly for the bedridden and posteroanteriorly for ambulant patients (MUX-10 Mobile Art eco; Shimadzu, Kyoto, Japan), and diagnostic chest US. A CT scan of the chest was performed whenever possible (Asterion 4 Multi Slice; Toshiba, Tokyo, Japan). Chest US-guided interventions were performed whenever needed.

In each patient, laboratory or radiological investigations were selected according to the suspected disease etiology to reach a final diagnosis, as described by Tu *et al.* [12].

### Chest ultrasonographic examination

All patients underwent chest sonographic examinations with an US machine (Sonoline G6OS, Ultrasound Imaging System; Siemens, Mountain View, California, USA) as described by Mathis *et al.* [13] under completely aseptic conditions. For every patient, the two hemithoraces (right and left) were examined by US.

#### *Examination steps*

(1) Patients were instructed to sit erect whenever possible. In comatose patients, the back of the bed was elevated to 45° and the patients were turned to the oblique position. US transmission gel was used on clean, dry skin.
(2) The examination was performed initially using a convex C 3.2 MHz transducer, scanning both sides of the chest, starting from the costophrenic angle upward, dorsal to ventral. The transducer was placed intercostally with a perpendicular orientation. The patients' arms were raised and crossed behind their heads to extend the intercostal spaces and facilitate access. Thereafter, a linear L 7.5 MHz transducer was used to obtain additional information in the same manner.
(3) Two-dimensional format US imaging was used; Doppler was used whenever needed. Split images were used to compare both sides. US images were collected for each patient and real-time videos were recorded for selected patients.

At the end of each chest US examination we achieved the following:

(1) We clarified the nature of unknown pleural densities.
(2) We detected pleural effusion, estimated its volume, and classified the different sonographic patterns.
(3) We differentiated subpulmonary effusion from subphrenic fluid accumulation and diaphragmatic paralysis in radiographically elevated hemidiaphragms.
(4) We localized pleural tumors or pleural thickening and measured their size. Pleural thickening appeared in US images with different densities, ranging from hypoechoic to echoic. 'Color Doppler sign' was used to differentiate between thickenings and effusions.
(5) We assessed the invasion of tumors into the pleura and chest wall and guided transthoracic needle biopsy of the pleura.
(6) We recognized pneumothorax: pneumothorax was diagnosed with a combination of the two key sonographic signs (lung sliding and B lines), and whenever possible 'lung point' sign was used as described by Mathis *et al.* [13].
(7) We recorded complications resulting from US-aided interventions.
(8) We compared US findings with radiographic and CT findings when available.

### Classification of sonographic patterns in pleural effusions

(1) Pleural effusions were classified as follows:
   (a) anechoic pattern: no echogenic density within the effusion;
   (b) complex nonseptated pattern: with some visible bright spots as echogenic density within the effusion;
   (c) complex septated pattern: with prominent fibrinous septation within the effusion; and
   (d) homogenously echogenic pattern: with echogenic spot densities evenly distributed within the effusion [13].
(2) The volume of pleural effusion was classified as follows: minimal if the echo-free space was seen within the costophrenic angle; small if the space was greater than the costophrenic angle but still within a one-probe range; moderate if the space was greater than a one-probe range but within a two-probe range; and large or massive if the space was bigger than a two-probe range [13].

### Chest ultrasonography-guided interventions

*Diagnostic thoracocentesis*

US scanning was performed to confirm the presence of fluid and to select and mark the best puncture site. The puncture was then made during real-time scanning while visualizing the needle during penetration. A 22 G needle attached to a syringe was generally used for diagnostic aspiration. Occasionally, larger needles (20 or 18 G) were used in highly viscous pleural fluid. The procedure was carried out under local anesthesia induced with 2% lidocaine administered through a 4 cm injection.

*Catheter drainage of pleural collection*

The best puncture site was marked as stated previously. A Flexima (10 Fr) pigtail catheter was used to drain the pleural fluid, especially loculated pleural fluid. The catheter was then attached to a closed urinal bag or an underwater seal in cases of hydropneumothorax. The procedure was carried out under local anesthesia induced with 2% lidocaine administered through a 10 cm injection. Daily output was recorded to follow-up patient progress. Occasionally, transcatheter infusion of fibrinolytics was performed to facilitate drainage of septated and loculated pleural fluid collections. A volume of 250 000 IU of streptokinase diluted in 50 ml saline was injected twice daily. The catheter was then clamped for 45 min before reopening it.

*Pleural biopsy of pleural thickening or tumor*

US scanning was performed to confirm the presence of pleural thickening or a pleural mass and to select the best puncture site. The puncture was then made during real-time scanning while visualizing the needle during penetration. Either fine-needle aspiration using a 16–20 G needle attached to a syringe was performed or a biopsy sample was obtained using an Abrams needle or an Egemen semiautomatic biopsy needle (16 G). The procedure was carried out under local anesthesia induced with by injection (10 cm) of 2% lidocaine.

*Ultrasonography-guided intercostal tube readjustment*

US was also used to readjust already placed nonfunctioning intercostal tubes.

### The training program

One of the objectives of this study was to design, implement, and evaluate a training program for one of the researchers (I.A.) on the use of US for the diagnosis and treatment of pleural disease. The following order of training was implemented:

(i) a brief academic background concentrating on US management of pleural disease given by the radiology consultant;
(ii) attendance of at least 15 cases of US examinations and/or interventions in pleural disease patients performed by the radiology consultant;
(iii) performance of examination and/or intervention in at least 15 cases of pleural diseases under the supervision of the radiology consultant;
(iv) performance of examination and/or intervention of at least 15 cases of pleural disease single-handedly, which were re-examined by a radiology consultant later on.

*Evaluation of the training program*

Efficacy and efficiency of the training program was evaluated using the evaluation checklist presented in Table 1. A score percentage was given by the radiology consultant on each item. The learning curve of the research candidate was assessed as regards the number of supervised examinations needed to obtain competency in the US examination.

All patients underwent chest radiography and US evaluation. US assessment included examination of both chest sides (hemithoraces). Thus, 110 sides were evaluated by US. In contrast, only 43 patients underwent both US examination and CT scanning and thus 86 sides were evaluated by US. Sensitivities and specificities were calculated for 110 sides and 86 sides while comparing US with radiography and US with CT scanning, respectively. It is to be noted that some patients may have more than one pleural pathology – for example, pleural mass with pleural effusion.

**Table 1 Checklist evaluation of the training program**

| Checklist | Trainee finding | Consultant score percentage and comments |
|---|---|---|
| Patient position | | |
| Probe selection | | |
| Probe manipulation | | |
| Technical limitations | | |
| Image quality | | |
| Anatomic landmarks | | |
| Pleural effusion echogenicity | | |
| Pleural effusion volume | | |
| Miscellaneous findings | | |
| Lung overview | | |
| Dynamic findings | | |
| Machine control | | |
| Identifying safe puncture sites | | |
| Placement of drainage catheter | | |
| Pleural biopsy | | |
| Anesthesia | | |
| Final diagnosis | | |
| Complications | | |
| Total score | | |

### Statistics

Data were analyzed using the SPSS statistical package, version 15.0 for windows (SPSS Inc., Chicago, Illinois, USA). Statistical measures were expressed as means and SDs for quantitative variables and as percentages for qualitative variables. Cross-table statistics with Pearson's correlation coefficients was used to assess the correlation between two qualitative variables. Differences in sensitivity and specificity between the different imaging modalities tested were evaluated using McNemar's test statistic. The $\chi^2$-test for unpaired data was used to test differences for statistical significance. The κ statistic with linear weighting was used. The linear weighted κ-value measures the relative concordance between US result and the final diagnosis. κ-values less than 0 represent less than chance agreement, 0.01–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and 0.80–0.99 almost perfect agreement. For all comparisons, *P*-values less than 0.05 were taken to indicate statistically significant differences. The final diagnosis was considered the reference standard to compare the results of all imaging modalities.

## Results

### Study population characteristics

Fifty-five patients were recruited during the study period. Thirty-nine were male (71%) and 16 were female (29%). Their ages ranged from 19 to 81 years, with a mean of 49.5 ± 18.3 years.

At the time of examination, 25 patients were mechanically ventilated (45%), 24 were on oxygen therapy [20 on nasal prong (36%), two on venturi mask (4%), and two on a face mask (4%)], and six were on room air (11%).

As regards the patients' temperatures at the time of examination, the highest recorded temperature was 40°C and the lowest recorded temperature was 35°C. The mean temperature was 37.2 ± 0.93°C. Twenty-six patients were normothermic (47%), 17 patients were feverish (31%), and 12 patients were hypothermic (22%).

### Final diagnosis and ultrasonographic findings

The characteristics of the different pleural pathologies as detected by US are illustrated in Table 2. Pleural effusions were the most common pleural pathology encountered.

There was almost perfect agreement between US results and the final diagnosis, with κ values 0.98 for pleural effusion, 0.95 for pleural thickening, 0.92 for pneumothorax, and 0.9 for pleuroparenchymal masses.

### Pleural effusion

Sixty pleural effusions were recorded on final diagnosis. US detected 59 effusions (98.3%). Table 3 describes the characteristics of pleural effusions with regard to site, loculation, volume, and echogenicity as seen on chest US.

Forty-two effusions were exudative (70%), 14 effusions were transudative (23.3%), and four effusions were undetermined (6.7%). The chest US prediction of the nature of the pleural effusion (transudative or exudative) was in agreement with the true nature of the effusion in 84% of the pleural effusions that were chemically analyzed.

### Comparison between chest ultrasonography and chest radiography findings

The results of the comparison between chest US and chest radiography findings as regards the different pleural pathologies are shown in Table 4. US was more statistically significantly sensitive and specific in the detection of pleural effusion

**Table 2 Characteristics of different pleural pathologies as detected by ultrasonography**

| Pleural pathology | Final diagnosis (100%)[a] | US finding[a] (%) |
|---|---|---|
| Pleural effusions | 60 | 59 (98.3) |
| Pleural thickening | 24 | 22 (92) |
| Pneumothorax | 14 | 13 (92) |
| Pleuroparenchymal masses | 6 | 5 (83.5) |

[a]Number of hemithoraces (sides); US, ultrasonography.

**Table 3 Characteristics of pleural effusion as detected by ultrasonography**

| Characteristics | Final diagnosis [*n* (%)][a] | Detected by US [*n* (%)][a] |
|---|---|---|
| Number | | |
| Total | 60 (100) | 59 (98.3) |
| Site | | |
| Unilateral | 36 (60) | 36 (60) |
| Bilateral | 24 (40) (12 patients) | 23 (36.6) (12 patients) |
| Loculation | | |
| Free | 46 (76.7) | 45 (75) |
| Encysted | 14 (23.3) | 14 (23.3) |
| Volume | | |
| Minimal | 10 (16.7) | 10 (16.7) |
| Small | 18 (30) | 17 (28.3) |
| Moderate | 23 (38.3) | 23 (38.3) |
| Massive | 9 (15) | 9 (15) |
| Echogenicity pattern | | |
| Anechoic | 33 (55) | 32 (53.3) |
| Complex nonseptated | 16 (26.7) | 16 (26.7) |
| Complex septated | 9 (15) | 9 (15) |
| Homogenously echogenic | 2 (3.3) | 2 (3.3) |

[a]Number of hemithoraces (sides); US, ultrasonography.

**Table 4 Comparison between chest US and chest radiography findings as regards different pleural pathologies**

| Pleural pathology | Sensitivity | | | Specificity | | | PPV | | | NPV | | | Accuracy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | US [*n* (%)] | CXR [*n* (%)] | *P* | US [*n* (%)] | CXR [*n* (%)] | *P* | US [*n* (%)] | CXR [*n* (%)] | *P* | US [*n* (%)] | CXR [*n* (%)] | *P* | US [*n* (%)] | CXR [*n* (%)] | *P* |
| PE | 0.98 (98) | 0.72 (72) | 0.000* | 1 (100) | 0.82 (82) | 0.004* | 1 (100) | 0.83 (83) | 0.001* | 0.98 (98) | 0.71 (71) | 0.000* | 0.99 (99) | 0.76 (76) | 0.000* |
| PT | 0.92 (92) | 0.54 (54) | 0.004* | 1 (100) | 0.99 (99) | 1 | 1 (100) | 0.93 (93) | 0.389 | 0.98 (98) | 0.89 (89) | 0.020* | 0.98 (98) | 0.89 (89) | 0.020* |
| PNX | 0.93 (93) | 0.71 (71) | 0.25 | 0.99 (99) | 1 (100) | 1 | 0.93 (93) | 1 (100) | 1 | 0.99 (99) | 0.96 (96) | 0.369 | 0.98 (98) | 0.96 (96) | 0.625 |
| PPM | 0.83 (83) | 1 (100) | 1 | 1 (100) | 0.95 (95) | 0.063 | 1 (100) | 0.55 (55) | 0.119 | 0.99 (99) | 1 (100) | 1 | 0.99 (99) | 0.97 (97) | 0.219 |

CXR, chest radiography; NPV, negative predictive value; PE, pleural effusion; PNX, pneumothorax; PPM, pleuroparenchymal masses; PPV, positive predictive value; PT, pleural thickening; US, ultrasonography; *Test parameters were based on 110 sides.

compared with chest radiography. A sensitivity of 0.92 for US examination against 0.54 for chest radiography in the detection of pleural thickening ($P < 0.05$) was noted. US had a more statistically significant negative predictive value and accuracy in the detection of pleural effusions and thickening compared with chest radiography. No statistically significant difference was seen between the sensitivity and specificity of chest US and chest radiography in the detection of pneumothorax and pleuropulmonary masses.

### Comparison between chest ultrasonography and chest computed tomography findings

The results of the comparison between chest US and chest CT findings with regard to different pleural pathologies are shown in Table 5. There were no statistically significant differences between the sensitivity and specificity of chest US and chest CT in the detection of different pleural pathologies. Further, the results of the comparison between chest US and chest CT as regards pleural effusion characteristics (site, loculation, and volume) are shown in Table 6. Chest US is statistically significantly better than chest CT in the detection of unilateral effusions and septated effusions.

### Empyema

Eighteen empyemic sides were detected among 16 patients. Two of the patients had bilateral empyema. Eight patients had their empyema drained with US-guided interventions (50%). Four patients underwent therapeutic drainage (25%) and six drainage catheters were inserted in the remaining four (25%) patients. Drainage in the other eight (50%) patients was carried out using non-US-guided methods. This study showed that empyema drainage using US-guided interventions in ICU patients was significantly correlated with favorable outcome (cure or transfer from the ICU; Table 7).

### Correlation between patient temperature and ultrasonography finding

The relation between US findings and the body temperature of the patients was studied. There was a significant relation between being feverish and obtaining an US image suggestive of empyema (complex and echoic effusions; Table 8).

### Role of ultrasonography in the management of pleural diseases

The role of US in the diagnosis, treatment, and guided interventions of pleural diseases is illustrated in Figs 1–3.

**Table 5 Comparison between chest US and chest CT findings as regards different pleural pathologies[a]**

| Pleural pathology | Sensitivity | | | Specificity | | | PPV | | | NPV | | | Accuracy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | US [*n* (%)] | CT [*n* (%)] | *P* | US [*n* (%)] | CT [*n* (%)] | *P* | US [*n* (%)] | CT [*n* (%)] | *P* | US [*n* (%)] | CT [*n* (%)] | *P* | US [*n* (%)] | CT [*n* (%)] | *P* |
| PE | 0.98 (98) | 0.9 (90) | 0.219 | 1 (100) | 1 (100) | 1 | 1 (100) | 1 (100) | 1 | 0.97 (97) | 0.88 (88) | 0.204 | 0.99 (99) | 0.94 (94) | 0.219 |
| PT | 0.9 (90) | 0.95 (95) | 1 | 1 (100) | 1 (100) | 1 | 1 (100) | 1 (100) | 1 | 0.97 (97) | 0.98 (98) | 1 | 0.98 (98) | 0.99 (99) | 1 |
| PNX | 0.92 (92) | 0.92 (92) | 1 | 0.99 (99) | 1 (100) | 1 | 0.93 (93) | 1 (100) | 1 | 0.99 (99) | 0.99 (99) | 1 | 0.98 (98) | 0.99 (99) | 1 |
| PPM | 0.8 (80) | 1 (100) | 1 | 1 (100) | 1 (100) | 1 | 1 (100) | 1 (100) | 1 | 0.99 (99) | 1 (100) | 1 | 0.99 (99) | 1 (100) | 1 |

CT, computed tomography; NPV, negative predictive value; PE, pleural effusion; PNX, pneumothorax; PPM, pleuroparenchymal masses; PPV, positive predictive value; PT, pleural thickening; US, ultrasonography; [a]Test parameters were based on 86 sides.

**Table 6 Comparison between pleural effusion characteristics in US and CT**

| Findings | No. (side) | Detection | | Ultrasound | CT scan | *P*-value |
|---|---|---|---|---|---|---|
| Site | 30 | Unilateral | Detected | 30 | 25 | 0.020* |
| | | | Not detected | 0 | 5 | |
| | 20 | Bilateral | Detected | 19 | 20 | 0.305 |
| | | | Not detected | 1 | 0 | |
| Loculation | 14 | Detected | | 14 | 13 | 0.309 |
| | | Not detected | | 0 | 1 | |
| Septation | 9 | Detected | | 8 | 2 | 0.004* |
| | | Not detected | | 1 | 7 | |
| Volume | 8 | Minimal | Detected | 8 | 6 | 0.131 |
| | | | Not detected | 0 | 2 | |
| | 15 | Small | Detected | 14 | 13 | 0.543 |
| | | | Not detected | 1 | 2 | |
| | 19 | Moderate | Detected | 19 | 18 | 0.311 |
| | | | Not detected | 0 | 1 | |
| | 8 | Large | Detected | 8 | 8 | 1 |
| | | | Not detected | 0 | 0 | |

CT, computed tomography; US, ultrasonography; *The differences were based on samples of 86 sides.

**Table 7 Outcome of empyema patients**

| Method | Outcome | | |
|---|---|---|---|
| | Death | Cure | Transfer |
| Non-US-guided methods | 4 | 1 | 3 |
| US-guided methods | 0 | 4 | 4 |

Pearson's correlation coefficient: 0.59; US, ultrasonography; *P*-value: 0.05.

**Table 8 US images in feverish patients**

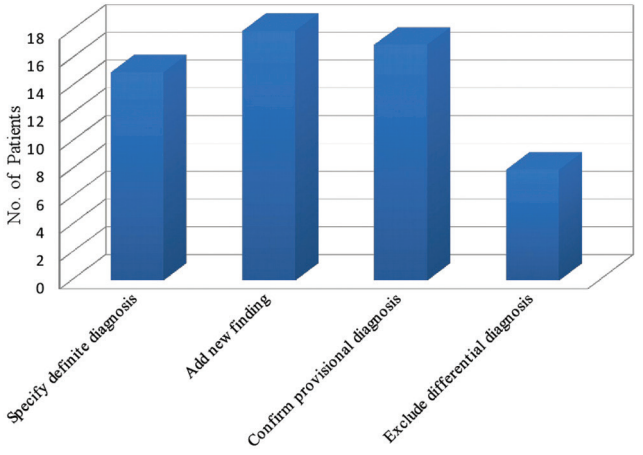
| Fever | US finding | |
|---|---|---|
| | Complex effusion | Other finding |
| Feverish | 12 | 5 |
| Normo/hypothermic | 13 | 25 |

Pearson's correlation coefficient: (0.33); US, ultrasonography; *P*-value: 0.01.

US reached a definite diagnosis, added new findings, confirmed a provisional diagnosis, and excluded differential diagnosis in 27.2, 30.9, 32.7, and 14.5% of cases, respectively. In some patients, US changed the diagnosis in more than one aspect (Fig. 1).

US findings impacted medical treatment and led to US-guided therapeutic interventions, determination of treatment choice, modification of treatment choice, and follow-up of treatment progress in 10.9, 30.9, 16.3, 1.8, and 1.8% of cases, respectively. US had no effect on treatment in 47.2% of cases (Fig. 2).

**Fig. 1**



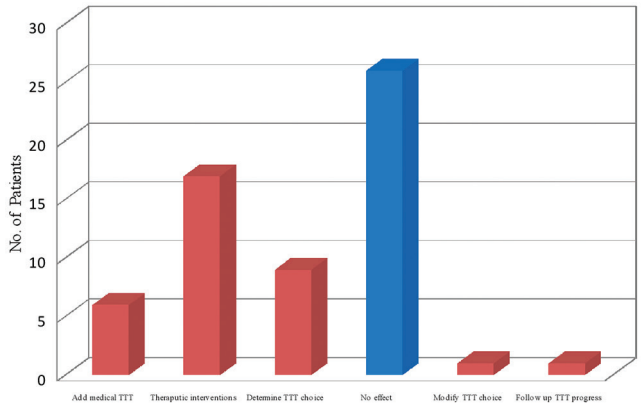

Effect of US examination and/or intervention on the diagnosis. US, ultrasound.

A total of 67 US-guided interventions were carried out. Diagnostic thoracocentesis, catheter drainage, therapeutic drainage, fine-needle aspiration, and pleural biopsy were performed in 58, 13.5, 15, 6, and 3% of cases, respectively. Other interventions such as mechanical septolysis, medical fibrinolysis, and thoracostomy tube position adjustment were also performed in one case each (1.5%; Fig. 3).

The success rate of all interventions was 94%. Failed diagnostic thoracocentesis due to extremely thick gelatinous effusions and a very thick chest wall occurred in two and one case, respectively. Failure of catheter drainage due to technical reasons occurred in one case.

US-guided interventions in patients, with or without oxygen therapy and encountered complications are listed in Table 9. Only one complication was encountered during the 67 interventions (1.5%). A partial pneumothorax occurred after therapeutic drainage of a pleural effusion of a mechanically ventilated patient, which was managed accordingly without compromising the patient's condition.

**Fig. 2**




Effect of ultrasound examination and/or intervention on the treatment.

**Table 9 Ultrasonography-guided interventions in patients with or without oxygen therapy**

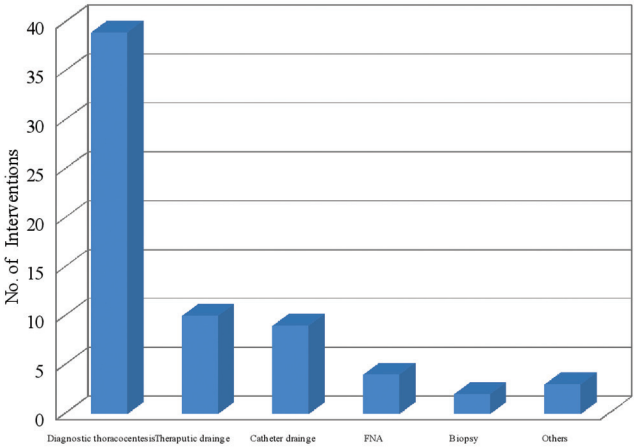
| Mode of ventilation | Total | Patients with interventions | Number of interventions | Number of complications |
|---|---|---|---|---|
| Mechanical ventilation | 25 | 17 | 31 | 1 |
| Nasal prong | 20 | 17 | 23 | 0 |
| Venturi mask | 2 | 1 | 1 | 0 |
| Face mask | 2 | 2 | 5 | 0 |
| Room air | 6 | 5 | 7 | 0 |
| Total number | 55 | 42 | 67 | 1 |

Seventeen patients underwent different therapeutic interventions. Some degree of favorable outcomes followed these interventions ($n$ = 12, 70.6%). In seven patients (41.1%) the fever subsided. Five patients (29.4%) showed improved oxygenation; three of them (17.6%) were successfully weaned from mechanical ventilation. Random blood sugar levels were controlled in two diabetic patients (11.7%). One patient (5.8%) showed improved drainage from the thoracostomy tube. Sometimes, more than one effect was elicited in the same patient. In only five patients (29.4%) was no effect noticed (Fig. 4).

## Evaluation of the training program

One of the researchers (I.A.) was evaluated as a model of the training process. The trainee performed a total of 34 examinations and 25 interventions. The trainee observed 21 cases before performing supervised examinations of 19 subsequent cases. The trainee then performed 15 cases single handedly with later confirmation by a radiology consultant. The trainees' scores were plotted chronologically against examinations, and a learning curve was obtained (Fig. 5). The learning curve initially showed steep fluctuations in scores, which then progressed to a more stable higher level. The mean score was 89.2 ± 8.84%. The minimum score recorded was 66% and the highest was 100%. Proficiency was acquired after 30 examinations – that is, the trainee was able to score 100% in the evaluation sheet after performing 30 examinations.

**Fig. 3**




Ultrasound-guided interventions.

## Selected cases

### *Case 1*

Case 1 was a 25-year-old man with no special habits of medical importance. He complained of progressive dyspnea, fever, cough, and expectoration of a large amount of sputum and was admitted to the RICU with diabetic ketoacidosis and fever. He was on room air.

Plain radiography showed multiple air–fluid levels on the right side (Fig. 6).

CT scanning showed encysted right hydropneumothorax and pleural thickening (Fig. 7).

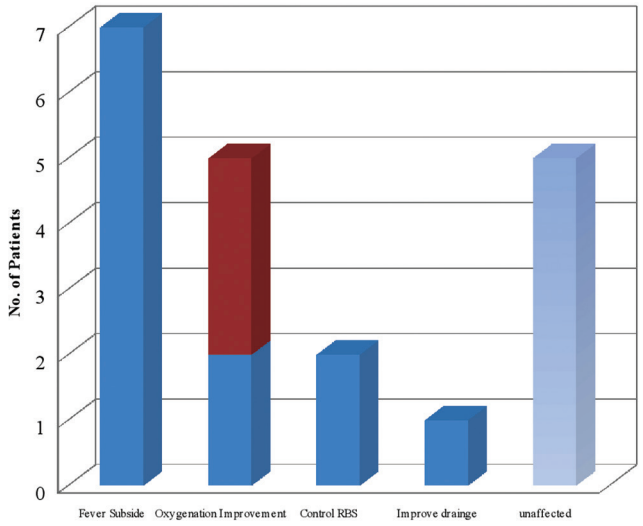
US showed large encysted hydropneumothorax (complex nonseptate pleural effusion with air locules) and thickened pleura (6 mm; Fig. 8). US-guided thoracocentesis, followed by US-guided catheter insertion for drainage of the pus was performed. The radiograph obtained immediately after insertion of the pigtail catheter into the pyopneumothorax showed evacuation of the pus and obliteration of the right costophrenic angle (Fig. 9).

A volume of 700 ml of pus was drained in the first 24 h.

The CT scan showed the pigtail catheter situated in the basal pleura, with evacuation of empyema (Fig. 10).

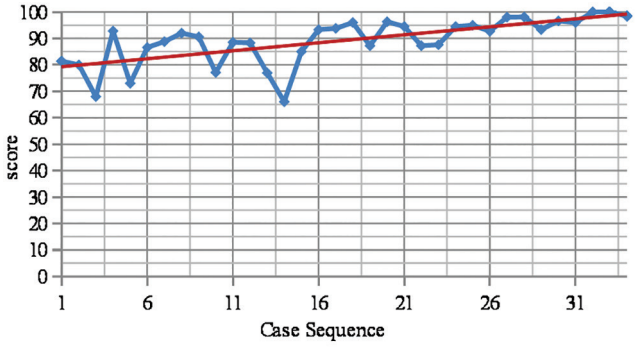
Follow-up US showed only pleural thickening (6 mm), which was detected using a linear transducer (L7.5 MHz) and in the Doppler mode to differentiate it from minimal effusion (Fig. 11). Blood sugar was controlled and the fever subsided, and the patient was transferred to the ward to continue treatment.

**Fig. 4**



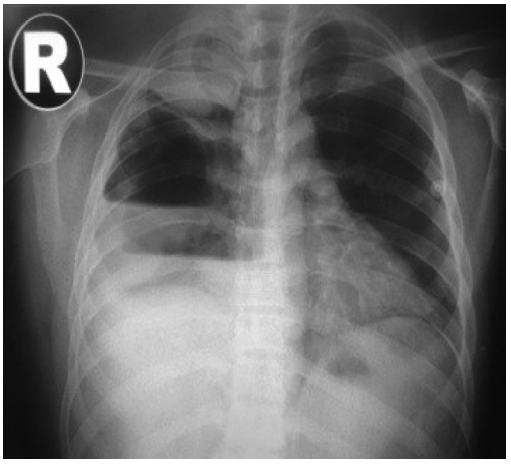

Outcome of therapeutic interventions.

**Fig. 5**



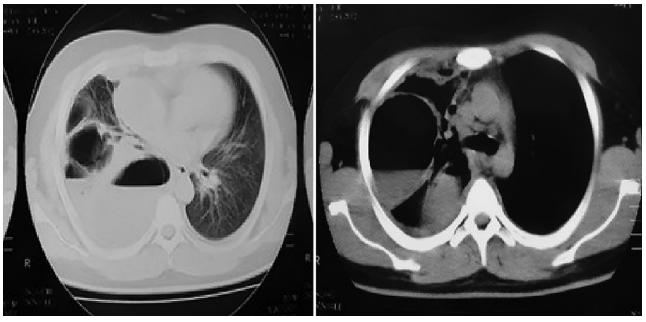

Trainee learning curve.

**Fig. 6**



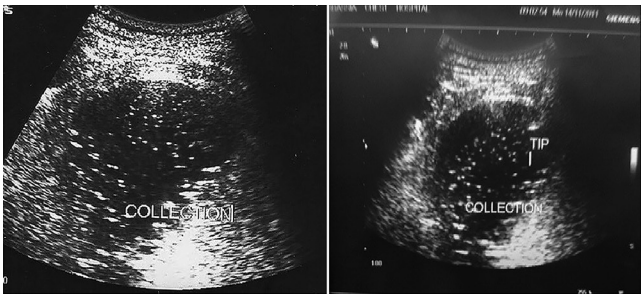

Plain radiograph obtained on admission.

**Fig. 7**



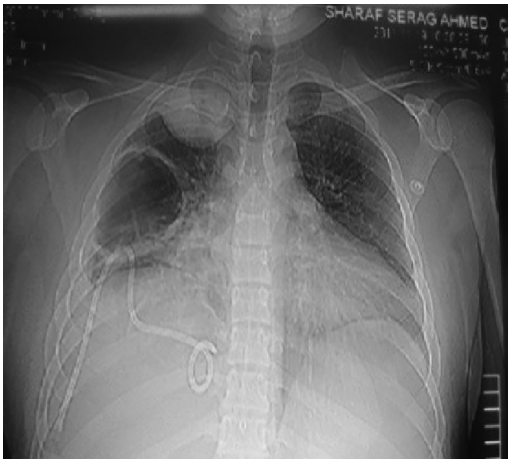
Computed tomography scan obtained on admission.

**Fig. 8**




US examination: left: loculated complex nonseptated pleural effusion; right: US-guided thoracocentesis showing tip of the needle. US, ultrasound.

**Fig. 9**




Radiograph obtained after insertion of a pigtail catheter.

*Case 2*

Case 2 was a 21-year-old woman with no special habits of medical importance. She complained of right-sided heaviness for 2 months. The patient was admitted to the RICU with respiratory distress and respiratory failure type I. She was on nasal prong at 5 l/min.

The radiograph obtained showed homogenous opacity occupying all of the right hemithorax, obliterating the right costophrenic angle and shifting the mediastinum to the opposite side (Fig. 12). The CT scan showed a right large pleural mass occupying

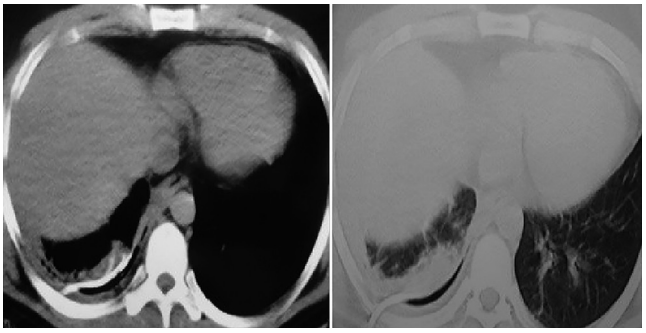
all of the right hemithorax only (Fig. 13). US showed an echoic pleural mass and minimal anechoic pleural effusion not seen on the CT scan (Fig. 14). US-guided core pleural biopsy was performed (Fig. 15). Histopathological analysis proved the case to be solitary pleural fibroma.

*Case 3*

Case 3 was a 57-year-old man who was a smoker with a 60 pack-year history. He complained of progressive dyspnea and stabbing chest pain on the right side and was admitted to the RICU after a cardiac arrest, in a comatose state, and was mechanically ventilated. He had inaudible arterial blood pressure and bradycardia.

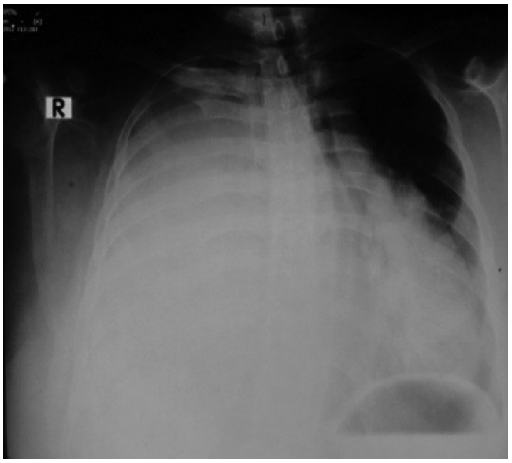
Radiography showed homogenous opacity occupying all of the right hemithorax (Fig. 16). CT scanning showed a large free pleural effusion with multiple focal pleural thickening (Fig. 17). US showed a large complex septated effusion with multiple focal pleural thickening ranging from 2.5 to 10 mm (Fig. 18).

**Fig. 10**



Computed tomography scan showing the pigtail catheter in the pleural space.

**Fig. 12**




Plain radiograph obtained on admission.

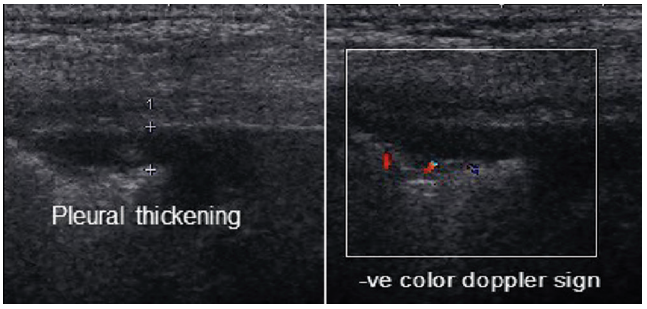
US-guided thoracocentesis was performed (Fig. 19). Cytological analysis of the pleural effusion confirmed malignant mesothelioma of the sarcomatous type.

## Discussion

The role of US in diagnosing and treating pleural diseases in a non-ICU setting has been studied previously [14–22]. However, nowadays bedside chest US is being increasingly used among patients managed in the ICU and has been a focus of research [23–25].

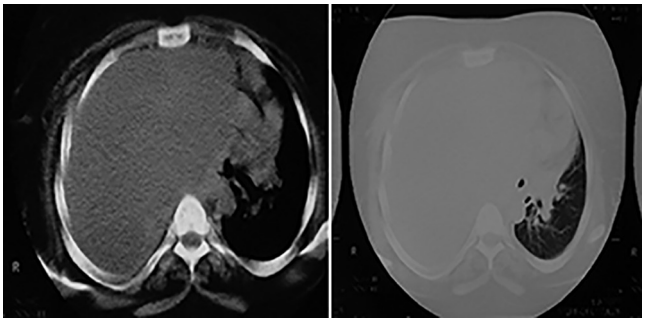
The main finding of this study is that, in RICU patients, chest US is more significantly sensitive than chest radiography in the diagnosis of pleural effusions and pleural thickening. In contrast, US had a comparable diagnostic performance to chest radiography in the diagnosis of pneumothorax and pleuroparenchymal masses. There was almost perfect agreement between US results and the final diagnosis. US examination and/or interventions affected the diagnosis and altered the treatment policy, with recorded favorable outcomes. US-guided interventions had a success rate of 94%, with only one recorded iatrogenic pneumothorax, which did not compromise the patient's condition. Short-term, goal-directed training programs could enable intensivists to master chest US after 30 examinations.

**Fig. 11**



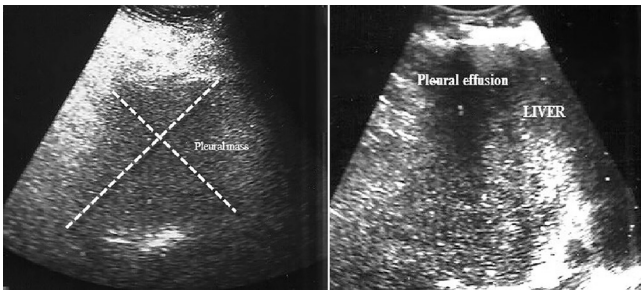

Pleural thickening as shown by gray scale ultrasonography (right) and by color Doppler mode (left).

**Fig. 13**



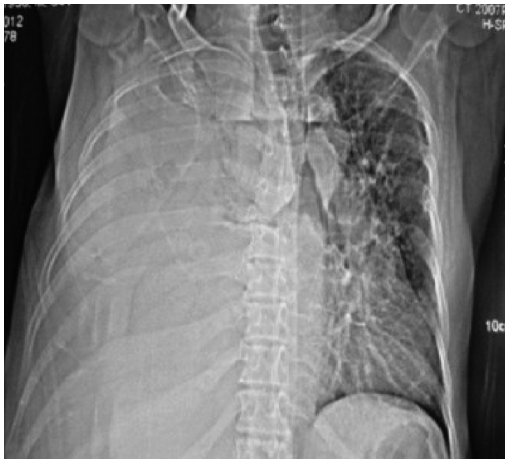
Computed tomography scan obtained on admission.

**Fig. 14**



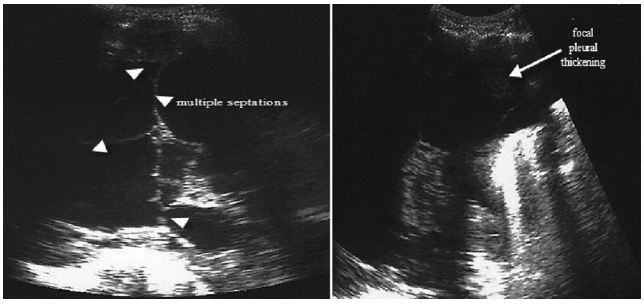

Ultrasound showing pleural mass (right) and minimal pleural effusion (left).

**Fig. 16**



Plain radiograph obtained on admission.

**Fig. 18**

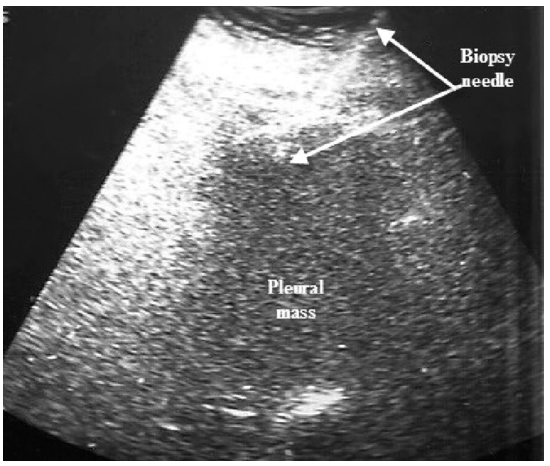



Ultrasound examination.

In this study, the final diagnosis was considered the reference standard to compare the results of all available imaging modalities. This methodology was similar to that of several previous studies dealing with US and pleural disease [26–28]. Other studies used CT scans as the reference standard for comparison [16,21,29], whereas this methodology requires CT scans to be performed in all studied patients, which is impossible in critically ill patients.

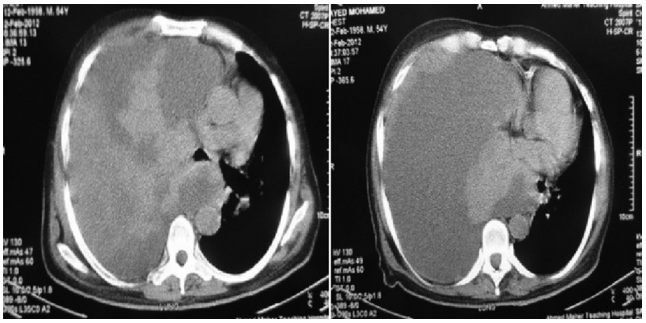
The mean age of the patients (49.5 ± 18.3 years) and the age range (19–81 years) in the current study were

**Fig. 15**



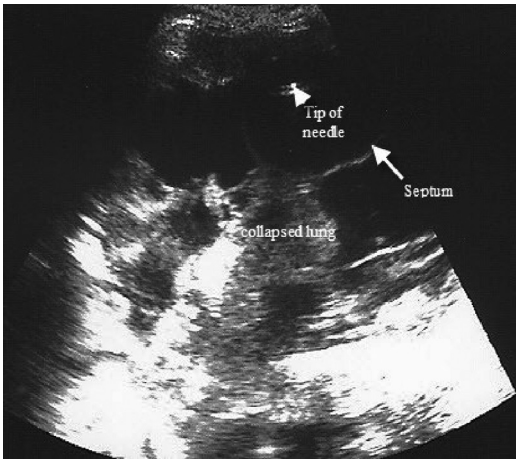

Ultrasound-guided pleural biopsy Arrows showing the hyperechoic line representing the biopsy needle.

**Fig. 17**



Computed tomography scan obtained on admission.

**Fig. 19**




Ultrasound-guided thoracocentesis showing tip of the needle in septated effusion and collapsed lung.

comparable to those in previous US studies of pleural disease in non-ICU settings in Egypt [14,17]. A different mean age (58.8 ± 14.64 years) was reported by Yousef [25] in a population of 25 mechanically ventilated patients while studying the possibility of

replacement of routine chest radiography by chest US in mechanically ventilated patients admitted to the RICU of Ain Shams University Hospitals. In contrast, a higher mean age (66 ± 19 years) and an extended age range (22–92 years) were reported in a Taiwanese study dealing with the role of chest US in pleural effusions in febrile medical ICU patients [12].

In the present study, US was more significantly sensitive and specific than radiography as regards the detection of pleural effusion. A similar significance was reported by Zanobetti and colleagues while studying the possibility of replacing standard chest radiography with chest US in the evaluation of critically ill patients in an emergency department in Italy. In their study, ultrasonography exhibited significantly greater sensitivity than radiography in patients with free pleural effusion ($P < 0.001$) [29]. A similar significance was reported by Yousef. In his study, ultrasonography exhibited significantly greater sensitivity than chest radiography in patients with free pleural effusion ($P < 0.001$) [25]. In another Greek study, conducted on 42 mechanically ventilated patients in a medical–surgical ICU, US demonstrated significantly greater sensitivity, specificity, positive predictive value (PPV), negative predictive value, and accuracy than radiography in the detection of pleural effusion, in agreement with the results of the current study [23]. In addition, Motogna *et al.* [21] reported similar superiority of US over radiography in pleural effusion detection, with sensitivities of 100 and 70%, respectively.

In the present study, US was superior to CT scanning in detecting pleural effusions. However, the differences did not reach significance. A similar experience was described by Chira *et al.* [22]. They retrospectively reviewed files of 131 hospital patients while comparing US and CT scanning. The study reported that US diagnosed a higher number of cases of pleural effusion compared with CT. However, their results did not report a statistically significant difference.

In this study, US was significantly more sensitive than chest radiography for detecting pleural thickening. These results were in concordance with those of many other studies in the literature [16,21].

In the present study, the sensitivity of US for pneumothorax was 93% and the PPV was 93% because of one false-positive result. Comparing US parameters with either radiography or CT rendered no statistically significant differences. Galbois *et al.* [30] compared US with radiography in detecting pneumothorax in intermediate ICU patients. They reported comparable PPVs (90%), with one false-positive result on US. However, they still reported the sensitivity of US to be higher than that of radiography. They added that when lung point was observed the PPV reached 100%. In addition, Zanobetti *et al.* [29] reported no significant statistical differences between the sensitivities of US and radiography for detecting pneumothorax in their evaluation of patients presenting with acute dyspnea to the emergency department. In the current study, CT scanning and US had equal sensitivities for detecting pneumothorax. The same result was elicited by Rowan *et al.* [31] who studied 27 critically ill patients in the emergency department.

In the present study, radiography showed 100% sensitivity for detecting pleuroparenchymal masses. However, there was no statistically significant difference on comparing it with US sensitivity. This result coincided with that of Uibu *et al.* [32], who conducted a case–control study to investigate asbestos-related pleural diseases in a non-ICU setting. They reported that all pleural masses were visible on chest radiography (i.e.100% sensitivity for radiography).

The results in the present study were identical to those of Kamel *et al.* [17]. In both studies US was able to diagnose five pleuroparenchymal masses out of six diagnosed by the CT scanning. As in the present study, the difference was not statistically significant. Both studies were conducted in Cairo, Egypt, and enrolled a small number of patients (52 patients in the study by Kamel and colleagues vs. 55 in the present study).

In the present study, κ-values were calculated for each of the different pleural pathologies as a measure of concordance between the US imaging results and the final diagnosis. There was almost perfect agreement between US results and the final diagnosis for all pleural diseases. This is in accordance with the results obtained by Lichtenstein and Mezière, who performed US on patients admitted to the ICU with acute respiratory failure, comparing lung ultrasonography on initial presentation with the final clinical diagnosis by the ICU team. Ultrasonography provided an overall almost-perfect agreement (90.5%) in their cases [26].

In the present study, there was a significant relation between being feverish and obtaining US images suggestive of empyema (complex and echoic effusions). While studying pleural effusions in febrile medical ICU patients, Tu and colleagues found that most febrile patients had a common pleural effusion pattern (40% anechoic pattern), which disagreed with the current results. This was mostly because the study by Tu and colleagues took place in the general medical ICU and the causes of fever were general, and empyema constituted only 16% of effusions. However, when all patients with thoracic empyema where analyzed,

they had distinct sonographic patterns, consisting of complex and homogenously echogenic patterns [12].

In the present study, US impacted the patient's diagnosis either by specifying a definite diagnosis, adding new findings, confirming a provisional diagnosis, or excluding differential diagnosis in an appreciable number of patients. Medford and Entwisle reported comparable findings. In their observational study on the indications for thoracic US in chest medicine that included 80 patients they reported that US significantly changed patient management in 65% of cases, including 18% of cases in which US detected an effusion not visible on chest radiography, and led to exclusion of deferential diagnosis in 25% of cases [19].

In the current study US-guided empyema drainage in ICU patients was significantly correlated with favorable outcome in patients in comparison with non-US-guided drainage. Akhan and colleagues reported an improvement rate of 92.5% on image-guided catheter drainage of infected effusions at the radiology department only. The difference in the improvement may be attributed to enrollment of no critically ill patients in the radiology department and confinement of therapeutic interventions to drainage of infected pleural effusions only. Further, Akhan and colleagues considered patient improvement after 3 months. In addition, in the study by Akhans and colleagues, study image guidance was either by ultrasonography, fluoroscopic guidance, or CT [19].

The success rate for different US-guided interventions (94%) was close to the success rate reported by Wafy *et al*. [16], who reported 95.6% successful thoracocentesis. However, the success rate of the present study was attributed to all US-guided interventions and not merely thoracocentesis. Segura [33] retrospectively studied various US-guided interventions in a thoracic surgery department in Argentina. They reported 100% success rate for different interventions including intrapleural catheter placement, pleural biopsies, thoracocentesis, and fine-needle aspiration.

In the study on critically ill patients receiving mechanical ventilation by Mayo *et al*. [3], the rate of iatrogenic pneumothorax after US-guided thoracocentesis was 1.3%, in comparison with 1.4% in the present study. In contrast, Heidecker *et al*. [34] reported a higher percentage of iatrogenic pneumothorax (5.7%), in addition to other complications such as hemothorax and hypotension, while performing thoracocentesis in a critical care setting. The higher level of complications in their study might be attributed to the larger size of the study population (401 interventions) in comparison with the present study (67 interventions).

The study researcher in this study achieved a steep US learning curve. Comparably, Bandi and colleagues described the same curve pattern for chest US. In their study, house officers were trained to detect chest wall invasion from a thoracic mass in 90 non-ICU patients. They reported increased proficiency after ~4 h of training, followed by 20 supervised examinations. Both learning curves demonstrated the rapid nature of acquiring US examination skills [35].

In the present study, the trainee score ranged from 66 to 100%, which is close to the range reported by Galbois [30] (80–100%). The trainees in both studies reached full concordance with the radiologist at the end of the training program, after 30 examinations in this study in comparison with 40 examinations in theirs. However, Galbois *et al*. [30] were studying only pneumothoraxes in the ICU.

The present study has some limitations, mainly the small number of patients. This was because of the limited number of patients in the ICU. However, evaluation of the performance of chest US separately on each hemithorax, thus increasing the number (from 55 to 110), partly helped overcome this limitation. The small number led to defects in representing some pathologies such as pleuropulmonary masses. In addition, some interventions were not studied thoroughly because of the small number of patients. Not all patients underwent CT scanning, and among those who did the time interval between thoracic US and CT scanning could not be controlled. This might contribute to an unknown extent to the observed discrepancy between the methods. As the study was conducted in the ICU, US accessibility was difficult for some patients because of tissue edema, a pre-existing chest tube, subcutaneous emphysema, and obesity. The training program was applied only to one researcher, and thus the results cannot be generalized.

Finally, it can be concluded that US is an efficient and suitable method for the evaluation of different pleural diseases in critically ill patients in the RICU. US is mostly sensitive and specific in diagnosing pleural effusions. US-guided diagnostic and therapeutic pleural interventions are successful in achieving their goal with favorable outcomes and minimal complications. Short-term, goal-directed training programs could enable pulmonologists to properly use US.

## Acknowledgements

### Conflicts of interest

There are no conflicts of interest.

## References


**1** Feller-Kopman D. Ultrasound-guided thoracentesis. *Chest* 2006; **129**:1709–1714.

**2** Keske U. Ultrasound-aided thoracentesis in intensive care patients. *Intensive Care Med* 1999; **25**:896–897.

**3** Mayo P, Goltz H, Tafreshi M, *et al.* Safety of ultrasound guided thoracentesis in patients receiving mechanical ventilation. *Chest* 2004; **125**:1059–1062.

**4** Yang PC, Luh KT, Chang DB, Wu HD, Yu CJ, Kuo SH. Value of sonography in determining the nature of pleural effusion: analysis of 320 cases. *Am J Roentgenol* 1992; **159**:29–33.

**5** Eibenberger K, Dock W, Ammann M, *et al.* Quantification of pleural effusions: sonography versus radiography. *Radiology* 1994; **191**:681–684.

**6** Doelken P, Strange C. Chest ultrasound for "Dummies". *Chest* 2003; **123**:332–333.

**7** Weingardt J, Guico R, Nemcek A, *et al.* Ultrasound findings following failed, clinically directed thoracenteses. *J Clin Ultrasound* 1994; **22**:419–426.

**8** Jones P, Moyers J, Rogers J, *et al.* Ultrasound-guided thoracentesis: Is it a safer method? *Chest* 2003; **123**:418–423.

**9** Chih-Yen T, Wu-Huei H, Te-Chun H, *et al.* Pleural effusions in febrile medical ICU: Chest Ultrasound Study. *Chest* 2004; **126**:1274–1280.

**10** Maurey E, Guglielminotti J, Alzieu M, *et al.* Ultrasonic examination: an alternative to chest radiography after central venous catheter insertion. *Am J Respir Crit Care Med* 2001; **164**:403–405.

**11** Mayo P, Beaulieu Y, Doelken P, *et al.* American College of Chest Physicians/La Société de Réanimation de Langue Française statement on competence in critical care ultrasonography. *Chest* 2009; **135**:1050–1060.

**12** Tu CY, Hsu WH, Hsia TC, Chen HJ, Tsai KD, Hung CW, Shih CM. Pleural effusions in febrile medical ICU patients: chest ultrasound study. *Chest* 2004; **126**:1274–1280.

**13** Mathis G, Sparchez Z, Volpicelli G. Chest sonography. In Dietrich CF editor. *EFSUMB; European Course Book Italy*. EFSUMB; 2010; 2–21.

**14** Gomaa M. Role of ultrasonography in the diagnosis of different chest diseases. Thesis submitted for partial fulfillment of MD degree in Thoracic Medicine and Tuberculosis 1998 Ain Shams University, Faculty of Medicine Cairo, Egypt.

**15** Abo mosallam A. Diagnostic role of transthoracic ultrasound in peripheral pulmonary and pleural lesions. Thesis submitted for partial fulfillment of MD degree in thoracic medicine and tuberculosis. Mansoura University Egypt 2013.

**16** Wafy S, Hessiun A, Agamy G. Value of chest ultrasound in diagnosis and management of different pleural diseases. *Egyptian J Chest* 2011; **60**:294–302.

**17** Kamel K, Abd el-hafeez A, Fathalla W, *et al.* Diagnostic role of thoracic ultrasonography in pleural effusion. *Egyptian J Chest* 2011; **60**:283–293.

**18** Slater A, Goodwin M, Anderson K, *et al.* COPD can mimic the appearance of pneumothorax on thoracic ultrasound. *Chest* 2006; **129**:545–550.

**19** Medford A, Entwisle J. Indications for thoracic ultrasound in chest medicine: an observational study. *Postgrad Med J* 2010; **86**:8–11.

**20** PopićRamac J, Hebrang A, Ivanovi-Herceg Z, *et al.* The possibilities and limitations of direct digital radiography, ultrasound and computed tomography in diagnosing pleural mesothelioma. *Coll Antropol* 2010; **34**:1263–1271.

**21** Motogna M, Maratou K, Paianid I, *et al.* Application of color Doppler ultrasound in the study of small pleural effusion. *Med Ultrason* 2010; **12**:12–16.

**22** Chira R, Chira A, Mircea P. Intrathoracic tumors in contact with the chest wall ultrasonographic and computed tomography comparative evaluation. *Med Ultrason* 2012; **14**:115–119.

**23** Xirouchaki N, Magkanas E, Vaporidi K, *et al.* Lung ultrasound in critically ill patients: comparison with bedside chest radiography. *Intensive Care Med* 2011; **37**:1488–1493.

**24** Ashton-Cleary D. Is thoracic ultrasound a viable alternative to conventional imaging in the critical care setting? *Br J Anaesth* 2013; **111**:152–160.

**25** Yousef Y. Could chest ultrasonography replace routine chest X-rays in mechanically ventilated patients? MSc Thesis Ain Shams University, Faculty of Medicine Cairo, Egypt 2013.

**26** Lichtenstein D, Mezière G. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008; **134**:117–125.

**27** Qureshi N, Rahman N, Gleeson F. Thoracic ultrasound in the diagnosis of malignant pleural effusion. *Thorax* 2009; **64**:139–143.

**28** Chen H, Yu Y, Tu C, *et al.* Ultrasound in peripheral pulmonary air-fluid lesions. Color Doppler imaging as an aid in differentiating empyema and abscess. *Chest* 2009; **135**:1426–1432.

**29** Zanobetti M, Poggioni C, Pini R. Can chest ultrasonography replace standard chest radiography for evaluation of acute dyspnea in the ED? *Chest* 2011; **139**:1140–1147.

**30** Galbois A, Ait-Oufella H, Baudel JL, *et al.* Pleural ultrasound compared with chest radiographic detection of pneumothorax resolution after drainage. *Chest* 2010; **138**:648–655.

**31** Rowan K, Kirkpatrick A, Liu D, *et al.* Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT-initial experience. *Radiology* 2002; **225**:210–214.

**32** Uibu T, Järvenpää R, Hakomäki J, *et al.* Asbestos-related pleural and lung fibrosis in patients with retroperitoneal fibrosis. *Orphanet J Rare Dis* 2008; **3**:29.

**33** Akhan O, Özkan O, Akıncı D, *et al.* Image-Guided Catheter Drainage of Infected Pleural Effusions. DiagnIntervRadiol 2007;**13**:204–209.

**34** Segura G, Nowydwor B, Fernández J, *et al.* Ultrasound-Guided Intervention in Thoracic Pathology.HospAeronáut Cent 2013;**8**:63–66.

**35** Heidecker J, Huggins J, Sahn S, *et al.* Pathophysiology of Pneumothorax Following Ultrasound-Guided Thoracentesis. Chest 2008;**130**:1173–1184.

**36** Bandi V, Lunn W, Ernst A, *et al.* Ultrasound vs CT in Detecting Chest Wall Invasion by Tumor, A Prospective Study. Chest 2008;**133**:881–886.