The value of chest ultrasonography applications in the respiratory ICU
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Background
Diverse imaging systems can be utilized for the evaluation of chest issues in ICU patients; ultrasound (US) is a decent analytic instrument without exposing the patients to radiation and risk of transfer.

Objectives
To compare the diagnostic performance of transthoracic US and bedside chest radiography (CXR) for the detection of various pathological abnormalities in fundamentally sick patients, using chest computed tomography as a gold standard.

Patients and methods
Two hundred and fifty-six patients who were admitted in the Respiratory Care Unit were included in this study. CXR, computed tomography, and transthoracic US were done to all the patients. Six pathological entities were evaluated: pleural effusion, pneumothorax, consolidation, interstitial lung diseases, pulmonary embolism, and neoplasms.

Results
All patients were evaluated by the three imaging techniques. The sensitivity and specificity of CXR were 42.1, 84.4% for pneumonia, 50.0, 90.0% for pleural effusion, 45.5, 90.6% for interstitial syndrome, 50.0, 94.8% for pneumothorax, 60, 100% for pulmonary embolism, and 66, 94% for neoplasm, while the values for chest US were 89.47, 100% for pneumonia, 60, 100% for pulmonary embolism, 100, 100% for pleural effusion, pneumothorax, interstitial syndrome, and neoplasm.

Conclusion
US examination of the chest is a noninvasive and promising bedside tool in the evaluation of patients in the Respiratory Care Unit.

Introduction
Chest ultrasonography (US) is given more consideration in critical care medicine [1]. The part of transthoracic sonography (TS) in the chest was generally been constrained to the assessment of pleural effusion and as a guide for aspiration. TS has turned into an undeniably profitable demonstrative apparatus in different chest diseases [2]. Its effect on the diagnosis and management has been established in several studies [3,4], particularly under crisis conditions by utilizing TS, a few conditions might be quickly diagnosed (e.g. pneumonia, pulmonary embolism, pleural, and in addition pericardial effusion, pneumothorax, and atelectasis), or even might be suspected (e.g. diffuse parenchymal lung infection) or may act as a guide for the following diagnostic or therapeutic options [e.g. computed tomography (CT), bronchoscopy, or thoracocentesis] [5]. Rather than CT, TS is noninvasive and does not utilize radiation and contrast materials. At long last, portable US permits patient assessment whenever and in wherever [6].

Aim of the work study
To compare the diagnostic performance of transthoracic ultrasound (TUS) and bedside chest radiography (CXR) for the detection of various pathological abnormalities in critically ill patients, using CT as a gold standard.
Doppler US on the lower limb was done in 20 patients, and on the upper limb in four of them. Abdominal US was done in 20 patients. Pleural fluid analysis was done in 56 patients with pleural effusion (physical, chemical, bacteriological, and cytological examination).

Conventional radiological methods:
(a) CXR (was done to all patients).
(b) CT of the chest (was done to all patients) (high-resolution CT of the chest was done in 44 patients with interstitial lung diseases and CT pulmonary angiography was done in 20 patients with pulmonary embolism).

TUS was performed to all patients included in the study using a portable digital color Doppler US system; model S6, SonoScape (Shanghai, China). Curvilinear probe was used with frequency ranging between 3.5 and 5 MHz. US-guided aspiration was done in 56 patients with pleural effusion diagnosed by TUS and US-guided biopsy was performed in 36 patients with neoplastic lesions diagnosed by TUS.

Interpretation and clinical applications of the sonographic images [7]

(1) US images were displayed on a gray scale. The strongest echo appears white while it appears black when no sound wave is reflected from the organs. Depending on the reflected wave amplitude, the following terms are used to define echogenicity.
(a) Anechoic: when no sound wave is reflected and the image appears black as in pleural effusion.
(b) Isoechoic: when the echoes are of comparable amplitude with the surrounding tissue as with the kidneys, liver, or spleen.
(c) Hyperechoic: when echoes are stronger than the surrounding tissue as in the diaphragm.
(d) Hypoechoic: when it is weaker than that from the surrounding tissue.

(2) Common sonographic signs that were used to describe the lesions:
(a) Sliding sign: dynamic transverse twinkling movement visible at the pleural line and synchronized with respiration.
(b) A lines: horizontal lines parallel to the pleural line recurring at regular intervals (normal sign).
(c) B lines: vertical pleural-based lines (normal sign if less than three lines per view).
(d) Consolidation: hypoechoic shadow.
(e) Pleural effusion: appears mostly as an anechoic, homogeneous space between parietal and visceral pleura.
(f) Lung point: sudden, on-off visualization of a lung pattern.
(g) Sinusoids sign: inspiratory centrifugal shifting of the visceral pleura with decrease in apparent thickness of the effusion identified as sinusoidal waveform on M mode and it is specific for pleural effusion.

Ultrasound-guided transthoracic needle biopsy (was done in 36 patients)

(1) The patient is positioned according to the site of lesion to be biopsied – prone for paravertebral lesions and supine for lateral or anterior lesions.
(2) Proper local anesthesia with lidocaine 2% was given.
(3) Biopsies were taken with automatic tru-cut needles 20 cm×18 G.
(4) Three or more core biopsies were obtained to ensure adequate tissue for histopathological diagnosis.
(5) A follow-up CXR was obtained postbiopsy.

Statistical analysis
All data were collected, tabulated, and statistically analyzed using STATA/SE, version 11.2 for Windows (STATA Corporation, College Station, Texas, USA). The collected data were summarized in terms of mean±SD and range for quantitative data and number and percentage for qualitative data. Receiver operating characteristics analysis was carried out to evaluate the diagnostic performance of the different radiological investigations in ICU patients. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were estimated and comparisons between CXR and US findings were carried out using the McNemar test ($\chi^2$).

Results
The total number of the studied group was 256 patients, 104 women and 152 men, their age ranged from 16 to 85 years with mean±SD 56.22±14.45. Patients of the study were classified according to their final diagnosis based on CT chest finding as a gold standard for diagnosis into: 76 with pneumonia, 24 with pneumothorax, 56 with pleural effusion of different etiologies, 20 with pulmonary embolism, 44 with interstitial lung diseases, and 36 with neoplasm (Table 1). Of the patients, 14.06% had normal CXR and 85.93% of patients had abnormal finding (23.44% consolidation, 18.76% homogeneous opacity, 15.63% diffuse interstitial pattern, 14.06% mass lesion, 9.37% jet black hyperlucency, and lastly 4.68% wedge-shaped...
However, only 6.25% of the patients had normal chest US study and 93.75% of the patients had abnormal chest US [anechoic lesion 21.87%, B profile 17.19%, hypoechoic mass lesion 9.38%, and M mode (barcode or stratosphere sign), lung point, and absent lung sliding 9.38%, and lastly hypoechoic pleural thickening 4.68%] (Table 3). In this study, 92 (35.9%) patients had undergone US-guided procedures, 36 (39%) of them had undergone US-guided biopsy, and 56 (61%) of them had undergone US-guided aspiration of the pleural fluid (Table 4).

In the present study, prevalence, sensitivity, specificity, PPV, and NPV of CXR among patients were: pneumonia 30, 42.1, 84.4, 53.3, and 77.6%, respectively, pleural effusion 22, 50, 90, 58.3, and 86.5%, respectively, pleural effusion 22, 50, 90, 58.3, and 86.5%, respectively, pulmonary embolism 7.8, 60, 100, 100, and 96.7%, respectively, and neoplasm 14, 100, 100, 100, and 100%, respectively (Table 5). In our study by comparing the overall accuracy of TUS findings in relation to CXR, it was found that TUS sensitivity, specificity, PPV, NPV were significantly higher than that of CXR (94.4, 100, 100, and 93.3% for TUS vs. 52.8, 57.1, 61.3, and 48.5% for CXR; $P<0.001$) in the diagnosis of parenchymal lung diseases, and it was 100, 100, 100, and 100% for TUS versus 56.5, 80.5, 61.9, and 76.7% for CXR; $P<0.001$) in pleural diseases and it was the same in vascular lung diseases (Table 7).
Discussion

Imaging assumes a critical part in conjunction with clinical information in the evaluation and management of patients in the Respiratory Care Unit [8]. To date, radiography and CT are the imaging modalities utilized for detection and follow up of thoracic diseases together with portable US machines which is accessible, bedside, safe, and cheaper [9]. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pneumonia were 30, 42.1, 84.4, 53.3, and 77.6%, respectively. The corresponding values for TUS were 30, 89.47, 100, 100, and 95.7%, respectively. Agmy et al. [10] found that the sensitivity and specificity of CXR were 40 and 85% for consolidation and the corresponding values for TUS were 87 and 100%. These results were also in agreement with the study of Cortellaro et al. [11] who found that the sensitivity and specificity of TUS were 98 and 95% for pneumonia, the feasibility of US was 100%, and the procedure was always done in less than 5 min. On the other hand Nafae et al. [12] found that the sensitivity and specificity of CXR were 77.5 and 60% and the corresponding values for TUS were 75 and 97% for pneumonia. In this study, the sensitivity and specificity of CXR in the diagnosis of pleural effusion were 22, 50, 90, 58.3, and 86.5%, respectively and the corresponding values for TUS were 22, 100, 100, 100, and 100%, respectively. These results agreed with Remerand et al. [13] who found that the sensitivity and specificity of CXR in the diagnosis of pleural effusion were 65, and 81%, respectively, and the corresponding values for TUS were 100 and 100%. In the present study the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pneumothorax were 9.4, 50, 94.8, 50, and 94.8%, respectively and the corresponding TUS has been successfully used for the identification of pneumothorax in all patients with sensitivity and specificity of 100 and 100%, respectively. Hyacinthe et al. [14] found that the sensitivity and specificity of CXR were 75, and 98% for the diagnosis of pneumothorax and the corresponding values for TUS were 98 and 100%, respectively. Interstitial syndrome is of prime importance for diagnosing acute respiratory failure and acute circulatory failure. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of interstitial lung diseases were 17, 45.5, 90.6, 50, and 88.9%, respectively and the corresponding TUS values were 17, 100, 100, 100, and 100%, respectively, making chest US much more sensitive and specific than bedside CXR in identifying interstitial syndrome. These results were closer to Galbois et al. [15] who found that sensitivity and specificity of CXR were 46, and 80% and the corresponding values for TUS were 94, and 93% for interstitial syndrome, respectively. In the current study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of pulmonary embolism were 7.8, 60, 100, 100, and 88.9%, respectively and the corresponding TUS were 7.8, 60, 100, 100, and 96.7%, respectively. Pulmonary infarcts were diagnosed in 12 (4.68%) patients from 20 (7.81%) cases with pulmonary embolism diagnosed with CT pulmonary angiography; so normal chest US dose not rule out pulmonary embolism. This results were closer to Suzan et al. [16] who found that sensitivity and specificity of TUS of 71.9% and 80.9% for pulmonary embolism. However, these results disagreed with Lechleitner et al. [17] who found that sensitivity and specificity of TUS were 86% and 67% for pulmonary embolism. The main problem in many prospective studies which dealt with the accuracy of chest sonography in the diagnosis of pulmonary embolism, is the virtual absence of a gold standard signs. In our study, the prevalence, sensitivity, specificity, PPV, and NPV of CXR in cases of neoplasm were 14, 66.7, 94.5, 66.7, and 94.5%, respectively and the corresponding TUS were 14, 100, 100, 100, and 100%, respectively. These results agreed with Wernecke and Diederich [18].

Table 6 Diagnostic performance of ultrasonography regarding the final diagnosis

| Diagnosis                      | Prevalence (N=256) | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|--------------------------------|--------------------|----------------|-----------------|---------|---------|
| Pneumonia                      | 30.0               | 89.47          | 100             | 100.0   | 95.7    |
| Pneumothorax                   | 9.4                | 100.0          | 100             | 100.0   | 100.0   |
| Pleural effusion               | 21.8               | 100.0          | 100             | 100.0   | 100.0   |
| Pulmonary embolism (infarction)| 7.8                | 60.0           | 100             | 100.0   | 96.7    |
| Interstitial lung diseases     | 17.0               | 100.0          | 100             | 100.0   | 100.0   |
| Neoplasm                       | 14.0               | 100.0          | 100             | 100.0   | 100.0   |

Table 7 Statistical comparison between chest radiography and chest ultrasonography as a diagnostic tool in parenchymal, pleural, and vascular lung diseases

|                       | Parenchymal CXR US | Pleural CXR US | Vascular CXR US |
|-----------------------|--------------------|----------------|-----------------|
| Prevalence (%)        | 56.0               | 36.0           | 7.8             |
| Sensitivity (%)       | 52.8               | 94.4           | 65.5            |
| Specificity (%)       | 75.1               | 100            | 100             |
| PPV (%)               | 61.3               | 100            | 100             |
| NPV (%)               | 84.4               | 93.3           | 76.7            |
| p                  | <0.001 (HS)        | <0.001         | –               |

CXR, chest radiography; HS, highly significant; NPV, negative predictive value; PPV, positive predictive value; US, ultrasound.
who found that the sensitivity and specificity of TUS in the assessment of lung and mediastinal masses were 99 and 100%. But in the paravertebral compartment CT was the gold standard. The current study also agreed with Diacon et al. [19] who reported that chest US guidance improves the appropriateness of needle insertion site selection and also reported 86% sensitivity and 100% specificity with TUS-guided biopsy. In the present study by comparing the overall accuracy of TUS findings in relation to CXR, it was found that TUS accuracy was significantly higher than that of CXR (94.4 vs. 52.8%; \(P<0.001\)) in the diagnosis of parenchymal lung diseases, and it was 100 versus 56.5% \(P<0.001\) in pleural diseases. Indeed, bedside TUS has been shown to have superior accuracy when evaluating patients with pneumonia, pneumothorax, pleural effusion, neoplasm, or interstitial syndrome, compared with CXR. Also, Koenig et al. [20] found that the US was significantly more accurate than CXR in the diagnosis of chest diseases (83 vs. 63%, respectively; \(P<0.02\)). Brook et al. [21] also found that in a general ICU population lung US has a considerably better diagnostic performance than bedside CXR for the diagnosis of most common pathologies.

Conclusion

US examination of the chest is a noninvasive and promising bedside tool for the examination of Respiratory Care Unit patients. TUS has a better diagnostic performance than CXR for the diagnosis of most common respiratory pathologies.

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Conflicts of interest

There are no conflicts of interest.

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