Role of chest ultrasonography in the diagnosis and follow-up of community-acquired pneumonia at Zagazig University Hospitals

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Background Pneumonia is one of the most common diseases with a high hospitalization rate and is potentially life threatening. Chest ultrasound (US) is increasingly being used as a valuable bedside tool in the diagnosis of various thoracic conditions, especially pneumonia.

Patients and methods A total of 120 patients clinically suspected as having pneumonia were selected. Chest US was performed for the number, location, shape, size, breath-dependent movement of pneumonia, incidence of necrotic areas, positive air bronchogram, fluid bronchogram, and pleural effusion either simple or septated. Follow-up was carried out on days 1, 5, 8, and 14.

Results Patients? ages ranged from 24 to 85 (58.5±15.2) years. Of them, 73 (60.8%) were male and 47 (39.2%) were female. Chest US showed positive findings in 116 (96.7%) patients, with a sensitivity of 97.4%, specificity of 25%, and accuracy of 95%. There was a highly significant difference ($P<0.001$) between chest US and plain chest radiography in detecting pneumonia, whereas there was no significant difference ($P>0.5$) between chest US and chest computed tomography. Chest US had a high significant difference ($P<0.001$) in detecting minimal pleural effusion over plain radiography. Moreover, it had a sensitivity of 93.8%, specificity of 99%, and accuracy of 98.3% in detecting complex septated pleural effusion. Improvement in pneumonia was detected in 111 patients (95.7%) with chest US, whereas improvement was detected in 76 (75.2%) patients with plain chest radiography after 14 days; this was highly significant ($P<0.001$).

Conclusion Chest US is a quick, bedside, noninvasive, nonionizing, and highly sensitive tool to detect and follow-up cases of pneumonia and parapneumonic effusion.
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Introduction

Pneumonia is one of the most common diseases with a high hospitalization rate and is potentially life threatening [1]. Pneumonia is considered the leading cause of death due to infectious disease, and the seventh leading cause of death overall in the ultrasound (US) [2]. Community acquired pneumonia (CAP) is responsible for 1.7 million hospital admissions per year, with mortality rate up to 22% [3]. Chest radiography is the main imaging approach in many settings; however, limitations for its use exist [4]. Moreover, its accuracy is 65% [5]. Thoracic computed tomography (CT) scan is the diagnostic gold standard but may not always be available and involves high radiation dose and high cost [6]. US examination is increasingly being used as a valuable bedside method in the diagnosis of various thoracic conditions and can be performed at any time and in any place [3,7]. The most common investigation used to image the lung in the ICU is the bedside chest radiography with a few limitations [8,9].

Aim of the study

The aim of this study was to assess the value of chest US in the early detection and follow-up of community-acquired pneumonia, in comparison with conventional radiological methods.

Patients and methods

The study was carried out at the Chest Department (inpatient general ward and respiratory ICU), Zagazig University Hospitals.

Sample size

A total of 120 patients suspected as having CAP during the period of the study were included in the study after approval of the IRB committee, Zagazig University.

Patients

The study was conducted on 120 adult patients clinically suspected as having pneumonia. They were randomly selected from the chest outpatient clinic attendants

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according to the medical history and clinical examination and included in the study. Symptoms that were suggestive of pneumonia included fever, chills, pleuritic chest pain, and cough. The cough may be nonproductive (dry) or productive of mucoid or purulent sputum. It may be rusty in color and frankly bloody. As regards physical examination, fever was usually present, but some patients may be hypothermic (a poor prognostic sign), and some were afebrile at the time of presentation with pneumonia. Crackles were heard on auscultation over the affected area of the lung and physical findings of consolidation were dullness to percussion, increased tactile vocal fremitus, whispering pectoriliquy, and bronchial breath sounds [10,11].

Laboratory testing

Routine laboratory investigations included the following:

(1) Complete blood count.
(2) Erythrocyte sedimentation rate.
(3) C-reactive protein levels.
(4) Random blood glucose.
(5) Kidney function tests.
(6) Liver function tests.
(7) Coagulation profile.
(8) Sputum culture and sensitivity.
(9) Pleural fluid aspiration and analysis (bio chemical and bacteriological) for any patient has pneumonia with parapneumonic effusion.
(10) Arterial blood gases [10].

Chest ultrasound

Chest US was performed at first. Patients in whom a chest radiography had already been performed at the time of the US examination could be enrolled if the chest US had been performed within 24 h after the radiograph and if the radiographic findings were neither available nor known to the sonographer. CT of the chest was performed on admission as the gold standard for diagnosis. Patients were examined posteriorly in a sitting position and anteriorly in a supine position; a systematic examination of all intercostal spaces was performed. Chest US was assessed for the number, location, shape, size, and breath-dependent movement of pneumonia. Furthermore, the incidence of necrotic areas, positive air bronchogram, fluid bronchogram, and local and basal pleural effusion were determined. This technique was performed on days 1, 5, 8, and 14. Follow-up of the patients included in this study was performed as regards clinical symptoms, C-reactive protein, total and differential leukocytic count, radiological examination (chest US and plain chest radiography) on days 1, 5, 8, and 14 [12].

Plain chest radiography

Posteroanterior and lateral chest radiography was performed on days 1, 5, 8, and 14. The result of its interpretation was compared with chest US inter pretation [13].

Chest computed tomography

A low-dose CT scan with or without contrast was performed on admission. If other diagnoses were suspected, spiral/multislice CT scan with a contrast agent was performed [13].

Chest ultrasound technique

Chest US was performed with YD-9000A (Full Digital Ultrasound Diagnostic System ,Huashan Road Chengbei Industrial Park Xiannv Town Jiangdu District Yangzhou City Jiangsu, China) and Logiq C3 Premium US machine (GE Healthcare Clinical Systems Asia 3/F, GE China Technology Park, 1 Hua Tuo Road, Shanghai 201203, China T 86 21 3876 4136 F 86 21 3877 7498) using a 3.5–5-MHz convex probe that allows visualization and quick survey of the pleura and lungs. A high-resolution 7.5–10-MHz linear probe was used to provide a detailed depiction of any pleural or peripheral lung abnormality. Each hemithorax was divided into five areas, two anterior, two lateral, and one posterior, for a total of 10 areas bilaterally. The anterior chest wall was marked off from the parasternal line to the anterior axillary line. This zone was split into an upper region (from the collar bone to the second intercostal space) and a lower region (from the third intercostal space to the diaphragm). The lateral area (anterior to posterior axillary line) was split into upper and lower halves. Finally, the posterior area was identified from the posterior axillary line to the paravertebral line [8]. The US transducer was moved until a rib interspace was located. The probe was then panned horizontally and vertically to the extent possible to allow the broadest sweep through the area being imaged [12]. Raising the arm above the head increases the rib space distance and facilitates scanning. Scanning was performed during quiet respiration, to allow for assessment of normal lung movement, and, in suspended respiration, when a lesion can be examined in detail. The echogenicity of a lesion was compared with that of the liver and characterized as hypoechoic, isoechoic, or hyperechoic [13]. The key to US visualization of pneumonia in the lungs was a relative loss of aeration in a portion of the lung and a concomitant increase in the fluid content indicating lung consolidation. Once this consolidation reaches the pleura, it can be seen with US; however, some very early pneumonia were highly localized and in contact at some points with the pleura and could thus be imaged with US [14].

Within the consolidation, multiple bright dot-like and branching linear structures were found, which represent air in the bronchi and scattered residual air in the alveoli. This appearance is termed as sonographic air bronchogram [15]. Consolidations may contain dynamic air bronchograms (branching echogenic structures showing centrifugal movement with breathing) [16]. If the bronchial tree was filled with fluid rather than air, a branching pattern of anechoic or hypoechoic tubular structures was seen, an appearance termed as sonographic fluid or mucous bronchogram. When pneumonia was complicated by lung abscess, it was identified at US as a hypoechoic lesion with a well-defined or irregular wall and anechoic center sometimes with internal echoes and septations [17,18]. Parapneumonic effusion appeared anechoic, complex but nonseptated, complex and septated, or echogenic [13]. Lung sliding was absent as a result of adhesions, which were seen as mobile strands of echogenic tissue representing fibrin strands [13,19].

Statistical analysis

All data were collected, tabulated, and statistically analyzed using SPSS 20.0. Quantitative data were expressed as the mean±SD and range, and qualitative data were expressed as absolute frequencies 'number' and relative frequencies (percentage). Percent of categorical variables was compared using the χ^2-test or Fisher's exact test when appropriate. Percent of paired categorical variables was compared using McNemar's test. Validity of chest US in the detection of pneumonia was calcu lated using diagnostic performance. The sensitivities, specificities, positive predictive values, negative predictive values, and accuracies with their respective 95% confidence intervals were calculated. All tests were two sided. *P*-value less than 0.05 was considered statistically significant (S), *P*-value less than 0.001 as statistically highly significant (HS), and *P*-value of 0.05 or more was considered statistically nonsignificant (NS).

Results

The study was conducted on 120 patients between 24 and 85 (mean=58.50±15.20) years of age; of them, 73 were male (60.8%) and 47 were female (39.2%) (Table 1). The chest US showed positive findings in 116 (96.7%) patients in the form of dynamic air bronchogram alone in 23 (19.2%) patients, and was associated with all other sonographic signs of the studied patients (Table 2). There was a highly significant difference ($P<0.001$) between chest US and plain chest radiography in detecting pneumonia; pneumonia was detected in 116 pati ents (96.7%) with chest US, whereas in 101 patients (84.6%) with radiography. However, there

Table 1 Demographic distribution of the studied cases

Sociodemographic distribution	All patients [*n* (%)]
Sex	
Male	73 (60.8)
Female	47 (39.2)
Age (years)	
Mean±SD	58.50±15.20
Range	24–85

Table 2 Chest ultrasound findings of pneumonia in the studied cases

Chest US findings	All patients (*n*=120) [*n* (%)]
Free	4 (3.3)
Positive	116 (96.7)
Dynamic air bronchogram	23 (19.2)
Fluid bronchogram and air bronchogram	14 (11.7)
Dynamic air bronchogram and B-lines	11 (9.2)
Fragment pleural lines and dynamic air bronchogram	21 (17.5)
Isoechoic area	9 (7.5)
Dynamic air bronchogram and hypoechoic area	7 (5.8)
Dynamic air bronchogram and free pleural effusion	13 (10.8)
Dynamic air bronchogram and complex nonseptated pleural effusion	8 (6.7)
Dynamic air bronchogram and complex septated pleural effusion	10 (8.3)

US, ultrasound.

Table 3 Comparison between plain chest radiography, chest computed tomography, and chest ultrasound findings in detecting pneumonia

	Plain chest radiography (*N*=120) [*n* (%)]	Chest US (*N*=120) [*n* (%)]	*P*-value
Signs of pneumonia			
Absent	19 (5.8)	4 (3.3)	<0.001
Present	101 (84.2)	116 (96.7)	
Signs of pneumonia	Chest US (*N*=120)	Chest CT (*N*=120)	
Absent	4 (3.3)	4 (3.3)	>0.05
Present	116 (96.7)	116 (96.7)	

CT, computed tomography; US, ultrasound.

was no significant difference (P>0.5) between chest US and chest CT in detecting pneumonia; 116 patients (96.7%) had positive signs of pneumonia with chest US as well as chest CT (Table 3). Moreover, chest US had a sensitivity and positive predictive value of 97.4%, specificity of 25%, and accuracy of 95% in the detection of pneumonia (Table 4). Moreover, chest US had a sensitivity of 94.4%, specificity of 99.4%, positive predictive value of 98.8%, and accuracy of 97.6% in the detection of bilateral pneumonia (Table 5). Moreover, there was a significant difference (P<0.001) between plain chest radiography and chest US in the detection of minimal pleural effusion, wherein five (4.2%) of the studied patients had minimal pleural effusion with plain chest radiography in comparison with 19 (15.8%) with chest US as well as 19 (15.8%) with CT of the chest (Table 6). Meanwhile, chest US had a sensitivity of 93.8%, specificity of 99%, positive predictive value of 93.8, and accuracy of 98.3% in the detection of complex septated pleural effusion (Table 7). There was a significant difference between chest US and plain chest radiography in the detection of improvement in pneumonia after 5, 8, and 14 days of admission; on day 5, 27 (26.7%) patients showed improvement on plain chest radiography, whereas 62 (53.4%) patients showed improvement on chest US (P<0.001). After 8 days of admission, 54 (53.5%)

Table 4 Diagnostic performance and validity of chest ultrasound in relation to chest computed tomography in detecting pneumonia

	Chest CT		Total
	Present	Absent	
Chest US			
Present	113	3	116
Absent	3	1	4
Total	116	4	120
Value (95% CI)			
SN (%)	97.4%	94.5–100	
SP (%)	25%	0–67.4	
PPV (%)	97.4%	94.5–100	
NPV (%)	25%	0–67.4	
Acc (%)	95%	91.1–98.9	

Acc, accuracy; 95% CI, 95% confidence interval; CT, computed tomography; NPV, negative predictive value; PPV, positive predictive value; SN, sensitivity; SP, specificity; US, ultrasound.

Table 6 Comparison between plain chest radiography, chest computed tomography, and chest ultrasound in detecting minimal pleural effusion

	Plain chest radiograph (N=120) [n (%)]	Chest US (N=120) [n (%)]	P-value
Minimal effusion			
Absent	115 (95.8)	101 (84.2)	<0.001
Present	5 (4.2)	19 (15.8)	
Minimal effusion	Chest US (N=120)	Chest CT (N=120)	>0.05
Absent	101 (84.2)	4 (3.3)	
Present	19 (15.8)	116 (96.7)	

CT, computed tomography; US, ultrasound.

Table 5 Diagnostic performance of chest ultrasound in relation to plain chest radiography in detecting bilateral pneumonia

	Plain chest radiograph (N=120) [n (%)]	Chest US (N=120) [n (%)]	P-value
Bilateral pneumonia			
Absent	103 (85.8)	78 (65)	<0.001
Present	17 (14.2)	42 (35)	
Value (95% CI)			
SN (%)	94.4%	87.8–100	
SP (%)	99.4%	97.6–100	
PPV (%)	98.8%	95.6–100	
NPV (%)	96.8%	93–100	
Acc (%)	97.6%	94.8–100	

Acc, accuracy; 95% CI, 95% confidence interval; NPV, negative predictive value; PPV, positive predictive value; SN, sensitivity; SP, specificity; US, ultrasound.

Table 7 Diagnostic performance of chest ultrasound in relation with chest computed tomography in detecting complex septated pleural effusion

	Chest CT		Total
	Complex septated	Other	
Chest US			
Complex septated	7	0	7
Other	0	48	48
Total	7	48	55
Value (95% CI)			
SN (%)	93.8%	77–100	
SP (%)	99%	96.2–100	
PPV (%)	93.8%	77–100	
NPV (%)	99%	96.2–100	
Acc (%)	98.3%	95–100	

Acc, accuracy; 95% CI, 95% confidence interval; CT, computed tomography; NPV, negative predictive value; PPV, positive predictive value; SN, sensitivity; SP, specificity; US, ultrasound.

Table 8 Comparison between the results of follow-up using chest ultrasound and radiography at 5, 8, and 14 days from admission

	Plain chest radiography (N=101) [n (%)]	Chest US (N=116) [n (%)]	P-value
Improvement			
Follow-up on day 5	27 (26.7)	62 (53.4)	<0.001
Follow-up on day 8	54 (53.5)	82 (70.7)	<0.05
Follow-up on day 14	76 (75.2)	111 (95.7)	<0.001

US, ultrasound.

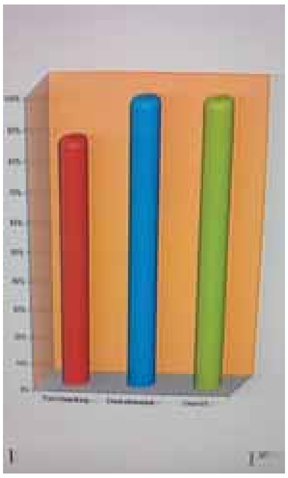
patients showed improvement on plain chest radiography, whereas 82 (70.7%) patients showed improvement on chest US ($P<0.05$), and after 14 days of admission 76 (75.2%) patients showed improvement on plain chest radiography, whereas 111 (95.7%) of the studied patients showed improvement on chest US ($P<0.001$) (Table 8).

Discussion

The use of chest US in the evaluation of pneumonia is growing rapidly and in each clinical setting shows increased efficiency. Although many traditional imaging applications are still indicated and will be used indefinitely for patients with possible pneumonia, chest US can substantially decrease the practical delays associated with plain chest radiography and in some cases can obviate the need for chest CT when a definitive diagnosis is obtained on US imaging, thus avoiding a large radiation dose. In many cases, when pneumonia is the differential diagnosis, lung US should be performed first [12].

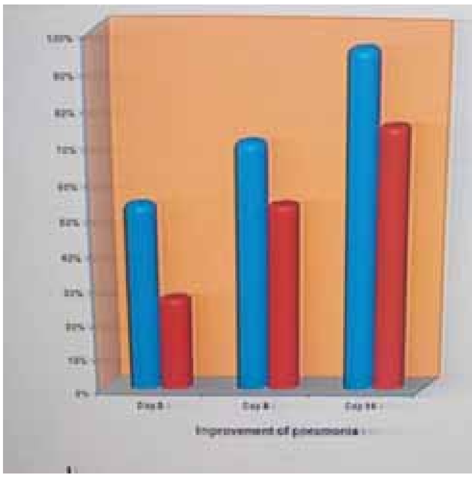
In our study, dynamic air bronchogram was observed in 23 of the 116 cases with pneumonia (19.2%), but present in association with other signs in all other cases. This is a main sonographic sign of pneumonia. Pleural line fragmentation was seen in 21 cases (17.5%), but in association with air bronchogram. Simple pleural effusion was seen in 13 cases (10.8%), but in association with air bronchogram. Alveolointerstitial syndrome (B-lines) was seen in 11 cases (9.2%) in association with air bronchogram. These results are in agreement with those of Parlamento *et al.* [3], who reported that air bronchogram was found in 22 (68.8%) patients with confirmed pneumonia diagnosis; 50% of the patients with confirmed pneumonia presented with B-lines and dynamic air bronchograms, whereas pleural effusion was found in 11 (34.4%) patients. The results of the present study are partially in agreement with those of Cortellaro *et al.* [20], who performed chest US and chest radiography in adult patients admitted in the emergency department for suspected pneumonia. They stated that pneumonia appeared as a pattern of consolidation with dynamic air bronchogram in 73 of 80 patients (91.3%) and an alveolointerstitial syndrome in 42 cases (52.5%) as an expression of perilesional inflammatory edema. An interstitial syndrome was the prevailing pattern in the remaining seven (8.8%) patients. Pleural effusion was present in 31 of 80 patients (39%) with final diagnosis of pneumonia and in six of 39 (15%) patients without pneumonia, confirming it to be a nonspecific sign. The findings of Liu *et al.* [21] are also partially in agreement with the current study. They performed chest US on neonates admitted with severe neonatal pneumonia; dynamic air bronchograms were observed in 21 (52.5%) of the 40 cases with pneumonia, interstitial syndrome in the 40 cases (100%), and pleural effusion in 20%. However, Caiulo *et al.* [22], who carried out their study on 102 hospitalized children with symptoms and signs suggestive of pneumonia, found dynamic air bronchogram in 65 (79%) patients, alveolointerstitial syndrome in 59 (66.3%) patients, pleural line abnormalities in 18 (20.2%) patients, and pleural effusion in 16 (18%) patients. This disagreement may be due to our criteria of patient's selection with early pneumonia. The current study also matched with the study by Agmy and Ahmed [23], who performed lung US, chest radiography, and CT scan on 284 patients presented to the emergency department with suspected community-acquired pneumonia; air bronchogram was found in 213 (82%) patients of 260 with confirmed pneumonia. Our study is in disagreement with the study by Agmy and Ahmed [23] in the number of cases, with interstitial syndrome in 182 (70%) patients and pleural effusion in 130 (50%) cases. This incompatibility may be due to our criteria for patients' selection with early pneumonia, which is not evident on chest radiography (stage of congestion), and the large number of cases in their study. In the more recent study by Alkhayat and Alam Eldeen [24], air bronchogram was seen in 54 patients (87%) and blurred margins but pleural effusion were present in 44 patients (54%). This discrepancy with the current study may be attributed to the selection of patients with early pneumonia based on the early clinical data. According to the current study, chest US was diagnostic in 116 of 120 patients with CT-confirmed pneumonia; the sensitivity of chest US was 97.4%, with an accuracy of 95% in the diagnosis of pneumonia, whereas that of chest radiography was 84.5% (101 of 120 patients), with an accuracy of 82.5% in comparison with chest CT. These data were partially concordant with those of Cortellaro *et al.* [20], in which the sensitivity of chest US was 96% (25 of 26 patients), whereas that of chest radiography was 69% (18 of 26 patients). Agmy and Ahmed [23] reported similar results, wherein the sensitivity of chest US was 97%. The results by Parlamento *et al.* [3] were also similar, in which the sensitivity of chest US was 96%, whereas that of chest radiography was 69%. Liu *et al.* [21] stated that large areas of consolidation with irregular margins had a sensitivity of 100% in severe neonatal pneumonia.

Figure 1



Bar chart showing the distribution of studied patients as regards accurate detection of pneumonia: 84.2% were detected with chest radiograph and 96.7% had positive signs of pneumonia with chest ultrasound (US) as well as chest computed tomography (CT).

Figure 2



Follow-up for improvement of pneumonia on days 5, 8, and 14.

This was because the study only included patients with well-established pneumonia based on clinical criteria and does not report the lung US findings in patients with early pneumonia. These results were partially in accordance with those of Caiulo *et al*. [22], in which chest US showed findings consistent with pneumonia in 88 (98.9%) of 89 children, whereas chest radiography was positive for pneumonia in 81 (91%) children. The present study reveals a significantly higher sensitivity of chest US for the diagnosis of acute pneumonia compared with chest radiography (97.4 vs. 84.5%). In the current study, four patients (3.3%) with chest US showed no signs of pneumonia but had an abnormal CT showing a lung consolidation, whereas 19 patients (15.8%) had chest radiograph not consistent with pneumonia but had chest CT consistent with lung

Figure 3

(a) Chest radiography showed Rt basal ill-defined hazy shadow. (b) Longitudinal chest ultrasound (US) image revealed Rt basal lung consolidation showing air bronchogram.

consolidation. This may be attributed to the timing of US examination before the consolidation is well evident on chest radiography. This study shows a clear superiority of chest US over chest radiographs for the diagnosis of acute pneumonia. Given the US performance for the diagnosis of acute pneumonia, chest US could replace chest radiography as the first-line imaging investigation. In difficult cases (deep lesion) or in cases of negative US findings, thoracic CT scan could be performed (Figs 1–3).

Conclusion

Chest US is a quick, bedside, easy, noninvasive, nonionizing, and very sensitive tool to detect and follow-up the cases of pneumonia and parapneumonic effusion.

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Conflicts of interest

There are no conflicts of interest.

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