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Lung ultrasonography: an effective way to diagnose community-acquired pneumonia

Xiao-lei Liu, Rui Lian, Yong-kang Tao, Cheng-dong Gu, Guo-qiang Zhang

Emergency Department of China-Japan Friendship Hospital, Beijing, China

Correspondecenn to
Dr Guo-qiang Zhang, Emergency Department of China-Japan Friendship Hospital, 2 Yinghua Dongjie, Hepingli, Chaoyang District, Beijing, 100029 China; zhangchong2003@vip.sina.com

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ABSTRACT

Purpose To analyse the ultrasonographic findings of community-acquired pneumonia (CAP) and its efficacy for diagnosis of CAP compared with chest X-ray (CXR).
Methods Patients who presented to the Emergency Department with suspected CAP were included in the study. Bedside ultrasonography was performed at each intercostal space in the midclavicular, anterior axillary, midaxillary and paravertebral lines. Any pulmonary consolidation, focal interstitial pattern, pleural-line abnormalities and subpleural lesions were recorded, and the numbers of subpleural lesions and intercostal spaces with pleural-line abnormalities were counted. All patients received bedside CXR and CT. Using CT scan as the gold standard, ultrasonography findings were compared between CAP group and non-CAP group, and between CAP patients with CT showing consolidation or diffuse ground-glass opacification. The sensitivity of ultrasonography was compared with CXR for the diagnosis of CAP.
Results Of 179 patients included in the study, 112 were diagnosed with CAP by CT. Patients in CAP group were more likely to have consolidation ($p<0.001$), focal interstitial pattern ($p<0.001$) and had higher number of subpleural lesions ($p<0.001$) and intercostal spaces with pleural-line abnormalities ($p<0.001$) on ultrasound than those without CAP. CAP patients whose CT showed consolidation were more likely to have consolidation ($p<0.001$) and had lower numbers of subpleural lesions ($p<0.001$) and intercostal spaces with pleural-line abnormalities ($p<0.001$) compared to CAP patients whose CT showed diffuse ground-glass opacification. The diagnostic sensitivity, specificity, and accuracy for ultrasonography and CXR were 94.6% versus 77.7% ($p<0.001$), 98.5% versus 94.0% ($p=0.940$) and 96.1% versus 83.8% ($p<0.001$), respectively.
Conclusions Lung ultrasonography has a better diagnostic sensitivity and accuracy for diagnosing CAP compared with CXR.

INTRODUCTION

Community-acquired pneumonia (CAP) is a common and serious infectious disease associated with high morbidity and mortality. It is the sixth leading cause of death and the most common infectious cause of death worldwide.[1] However, CAP is often misdiagnosed even now. Early and effective antibiotic treatment is important. An adequate treatment is thus reliant on an early diagnosis of pneumonia, yet the diagnosis is not always clear at presentation to the emergency department (ED). In a retrospective chart review of patients admitted with pneumonia, 22% of patients presented some reason for diagnostic uncertainty that could result in delayed antibiotics delivery.[2]

> **Key messages**
>
> **What is already known on this subject**
> Clinical studies have demonstrated that lung ultrasonography has a better diagnostic accuracy than chest X-ray for diagnosing community acquired pneumonia (CAP) with characteristic ultrasonographic findings of lung consolidation and focal interstitial pattern. However, the association of ultrasonographic findings of CAP patients with appearance on CT has not been studied.
>
> **What this study adds**
> In this prospective study, patients with CT findings of ground-glass appearance were more likely to show subpleural lesions and pleural-line abnormalities than those with a consolidation pattern on CT. By combining 4 patterns of ultrasonographic findings, bedside ultrasonography had a higher diagnostic sensitivity and accuracy than CXR.

The current imaging modalities used to diagnose CAP include chest X-ray (CXR) and CT. CXR is easier to perform than CT, but its diagnostic value is lower.[2,3] Despite being the more sensitive tool for the diagnosis of CAP, CT is not practical for some patients who are critically ill or difficult to move due to high-level ventilatory support. Ultrasonography is a fast and non-invasive investigation being used frequently in the ED. Several studies have shown that bedside ultrasonography can help to diagnose cardiogenic pulmonary oedema, pneumothorax, pneumonia and pulmonary embolism.[4–7] At present, the diagnosis of CAP via bedside ultrasonography mainly depends on detecting consolidation.[8,9] However, CAP patients do not always have consolidation, but may have interstitial pneumonia or diffuse pulmonary infiltrations. Even if consolidation is not detected, other abnormalities could be found by ultrasonography, such as focal interstitial pattern, pleural-line abnormalities and subpleural lesions. In this study, we analysed the characteristic ultrasonography findings of CAP and compared the diagnostic sensitivity, specificity and accuracy of ultrasonography with CXR.

MATERIALS AND METHODS

Patients

The study was performed at a metropolitan ED in Beijing that sees over 100 000 patients per year. We studied a consecutive sample of adult patients with suspected CAP admitted to the ED between

January 2011 and March 2012. Signs and symptoms considered as suggestive of CAP included: cough, pleuritic pain, sputum production, fever, dyspnoea, in accordance with American Thoracic Society guidelines.[10] Patients with suspected CAP who were admitted to a general or emergency medicine ward, were included in this study. Exclusion criteria were age under 18 years, pregnancy, no need to be hospitalised and more than 12 h between ultrasonography and CXR/CT. The study protocol was approved by the ethical committee of the China-Japan Friendship Hospital, and written informed consent was obtained from all included patients.

Methods

Ultrasonography was performed in patients with suspected CAP as soon as possible after their arrival at the ED. Lung ultrasonography was performed by three trained ED physicians using a Sonosite M-Turbo ultrasound machine equipped with a 3.5–5 MHz convex array probe. The three physicians who performed lung ultrasonography had received formal training on emergency bedside ultrasonography, and performed at least 50 cases of lung ultrasonography examination. The ultrasonography training comprised a 28 h course based on the US emergency medicine guidelines issued by the American College of Emergency Physicians in 2001.[11] The study was carried out 24 h/7 days by the three physicians. Ultrasonographic images of each patient were saved by the performer and later reviewed by the other two physicians to reach an agreement on the results. Images were obtained at each intercostal space in the mid-clavicular line, anterior axillary line, mid-axillary line, and paravertebral line, from the lung apex to the diaphragm. The findings of each image were recorded, noting any pulmonary consolidation, focal interstitial pattern, pleural-line abnormalities and subpleural lesions. The numbers of subpleural lesions and intercostal spaces with pleural-line abnormalities were counted.

Definitions

Consolidation

Intercostal scan shows a hypoechoic consolidated area that contains multiple echogenic lines that represent an air bronchogram. The presence of dynamic air bronchogram (branching echogenic structures with centrifuge movement with breathing) helps to rule out obstructive atelectasia (figure 1A).

Focal interstitial pattern

Focal interstitial pattern was defined as vertical hyperechoic comet-tail artefacts that arose strictly from the pleural line, spread to the edge of the screen without fading and appeared focally instead of diffusely (figure 1B).

Subpleural lesion

Subpleural lesion was defined as pleural-based hypoechoic nodules with no hyperechoic lines within it. It could be triangular, round, linear or polygonal shaped (figure 1C).

Pleural-line abnormalities

When the transducer was placed between the ribs horizontally, the pleural line could be recognised as a thin horizontal hyperechoic line normally. Pleural-line abnormalities were defined by the thickness of pleural line greater than 2 mm or its coarse appearance, eventually associated with abolished lung sliding, explained by inflammatory adherences due to exudates (figure 1D).

In addition to bedside ultrasound, all subjects underwent a bedside CXR (MUX-100DJ, Shimadzu, Japan) and chest CT (Aquilion TSX-101A, Toshiba, Japan). CXR and CT were read by a senior radiologist on duty. Physicians who were in charge of the patients and discharged them, and all radiologists, were always blind to ultrasonographic results. The physician who performed the ultrasonography did not take part in the treatment

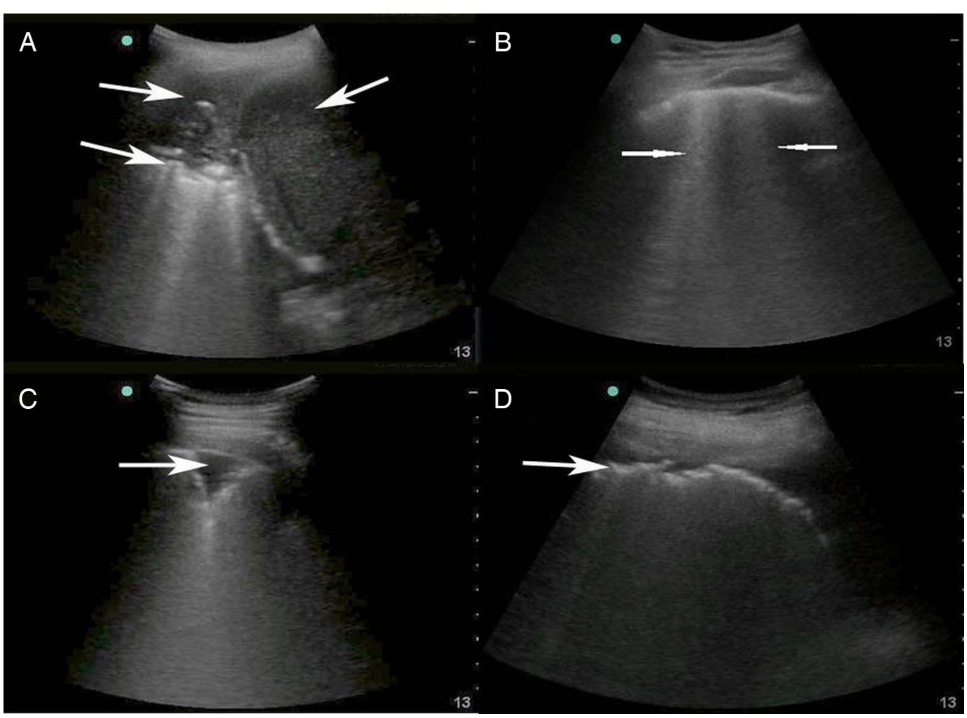

Figure 1 Ultrasonographic images of CAP patients. (A) Upper left arrow shows lung consolidation, lower left arrow shows air bronchogram, and right arrow shows the liver with echo intensity similar to that of lung consolidation. (B) Arrow shows interstitial pattern as hyperechoic comet-tail artifacts arose from the pleural line and spread to the edge of the screen without fading. (C) Arrow shows subpleural lesions as hypoechoic nodules. These may be shaped as a triangle, circle, line, or polygon. (D) Arrow shows pleural-line abnormalities.

of patients. CAP was defined as: a new pulmonary infiltration on CT, with clinical features including cough, pleuritic pain, sputum production, fever or dyspnoea. We analysed ultrasonographic findings of CAP patients and compared ultrasonographic sensitivity, specificity and accuracy for diagnosis of CAP with CXR.

Statistical analysis

All statistical analyses were performed using SPSS V.20.0 (SPSS, Chicago, Illinois, USA). Continuous variables were presented as the mean±SD and compared using the paired Student t test, and categorical variables were compared using the χ^2 test. Receiver operating characteristic (ROC) curves were used to determine the cutoff value for diagnosis; $p<0.05$ was considered to be statistically significant.

RESULTS

A total of 223 patients (124 males and 99 females) who presented to the ED with suspected CAP were admitted to general or emergency medicine ward. Thirty-one patients (18 men and 13 women) with a median age of 72.2 (range 46–85) years were finally excluded because the interval time between ultrasonography and CXR/CT was more than 12 h or no CT scan was finished. Thirteen patients (6 men and 7 women) with a median age of 69.3 (range 52–79) years refused to participate in the study. One hundred seventy-nine patients were finally included in this study with a median age of 71.5 (range 36–88) years. One hundred and twelve patients (61 men and 51 women) were finally diagnosed with CAP. The final diagnoses of patients without pneumonia were shown in table 1. There were no significant differences in age or gender between CAP group (112 patients) and non-CAP group (67 patients).

Comparison of ultrasonography findings between CAP group and non-CAP group

Ultrasonography detected consolidation in 80 patients in CAP group, and did not detect consolidation in any patients in non-CAP group ($p<0.001$) (table 2). Focal interstitial pattern was detected in 43 patients in CAP group and three patients in non-CAP group, which was a significant difference between these two groups ($p<0.001$) (table 3). There were significant differences between CAP group and non-CAP group in the number of subpleural lesions (1.79±1.73 vs 0.70±0.65; t=4.916, $p<0.001$) and the number of intercostal spaces with pleural-line abnormalities (5.13±4.47 vs 2.01±1.29; $p<0.001$).

Table 1 Final diagnosis of patients with suspected CAP

Diagnosis	Case number
Community-acquired pneumonia	112
Cardiogenic pulmonary oedema	23
Chronic obstructive pulmonary disease	18
Acute bronchitis	12
Pulmonary embolism	8
Pneumothorax	6
Sum	179

CAP, community-acquired pneumonia.

Table 2 Lung consolidation on ultrasonography in CAP and non-CAP patients

	CAP group				
	Group A	Group B	Sum	Non-CAP group	Sum
Lung consolidation					
Positive	80	0	80	0	80
Negative	5	27	32	67	99
Sum	85	27	112	67	179

Group A: CT showed consolidation; Group B: CT showed diffuse ground-glass opacification.
CAP, community-acquired pneumonia.

3.2 Comparison of ultrasonography findings in CAP patients with different CT patterns

According to the predominant CT patterns, the CAP patients were further divided into Group A (CT showed consolidation) and Group B (CT showed diffuse ground-glass opacification), and ultrasonography findings were compared between these subgroups. There was no significant differences between Group A (85 patients) and Group B (27 patients) in age ($p=0.971$) or gender ($p=0.513$). Ultrasonography detected consolidation in 80 patients of Group A, and did not detect consolidation in any patients of Group B, which was a significant difference between the two groups ($p<0.001$) (table 2). Focal interstitial pattern was detected in 33 patients in Group A and 10 patients in Group B, and no significant difference was detected between these two groups ($p=0.832$) (table 3). There were significant differences between Group A and Group B in the numbers of subpleural lesions (1.16±1.07 vs 3.85±1.93; $p<0.001$) and the numbers of intercostal spaces with pleural-line abnormalities (3.14±2.20 vs 11.73±3.69; $p<0.001$).

Comparison of bedside ultrasonography and CXR diagnosis of CAP

ROC curves were used to determine the cutoff values of numbers of subpleural lesions and intercostal spaces with pleural-line abnormalities for diagnosis CAP. Area under the curve (AUC) of subpleural lesions for diagnosis of CAP was 0.693. Youden index was 0.271, and the cutoff value was 2 with a diagnostic sensitivity of 37.5% and specificity of 89.6%. AUC of intercostal spaces with pleural-line abnormalities for diagnosis of CAP was 0.726. Youden index was 0.378, and the cutoff value was 5 with a diagnostic sensitivity of 39.3% and specificity of 98.5%.

Table 3 Focal interstitial pattern on ultrasonography in CAP and non-CAP patients

	CAP group				
	Group A	Group B	Sum	Non-CAP group	Sum
Focal interstitial pattern					
Positive	33	10	43	3	46
Negative	52	17	69	64	133
Sum	85	27	112	67	179

Group A: CT showed consolidation; Group B: CT showed diffuse ground-glass opacification.
CAP, community-acquired pneumonia.

Table 4 Comparison of bedside ultrasonography and CXR on diagnosis of CAP

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Lung consolidation	71.4 (80/112)	100 (67/67)	82.1 (147/179)
Focal interstitial pattern	38.4 (43/112)	95.5 (64/67)	59.8 (107/179)
Subpleural lesions ≥2	22.3 (25/112)	100 (67/67)	51.3 (104/179)
Intercostal spaces with pleural-line abnormalities ≥5	39.3 (44/112)	98.5 (66/67)	61.5 (110/179)
Any one of the above four criteria	94.6 (106/112)	98.5 (66/67)	96.1 (172/179)
CXR	77.7 (87/112)	94.0 (63/67)	83.8 (150/179)

CAP, community-acquired pneumonia; CXR, chest X-ray.

Using CT as the gold standard, the diagnosis of CAP based on any one of the four criteria (lung consolidation, or focal interstitial pattern, or ≥2 subpleural lesions, or ≥5 intercostal spaces with pleural-line abnormalities) had a sensitivity of 94.6%, a specificity of 98.5% and a diagnostic accuracy of 96.1%. CXR had a sensitivity of 77.7%, a specificity of 94.0% and a diagnostic accuracy of 83.8% for the diagnosis of CAP. There was significant difference between ultrasonography and CXR for sensitivity ($p<0.001$) and diagnostic accuracy ($p<0.001$) but not for specificity ($p=0.940$) (table 4).

DISCUSSION

CAP is a common and serious infectious disease and is often misdiagnosed even now. Early and effective antibiotic treatment is important. At present, CXR is the imaging modality most commonly used to diagnose CAP. Although CXR can be performed at the bedside without moving the patient, it only provides limited information on one or two plain films, thus often resulting in misdiagnosis.[12] CT is considered to be more sensitive for diagnosing pneumonia, but exposes the patients to substantial radiation[13] and cannot be completed at bedside. The use of bedside ultrasonography for lung scanning has been accepted by an increasing number of physicians, and a few examination protocols have been developed.[14–17]

Several studies have shown that bedside ultrasonography is useful for diagnosing cardiogenic pulmonary oedema,[18–21] and that ultrasonography is more accurate than CXR for diagnosing pneumothorax.[5 22 23] Zhang M *et al*[23] reported that the average time for ultrasonography examination (2.3±2.9 min) to detect pneumothorax was much shorter compared to CXR (19.9±10.3 min). Bedside ultrasonography is also a useful non-invasive investigation for diagnosing pulmonary embolism.[24 25] Cortellaro *et al*[6] reported that the sensitivity of CXR for diagnosing pneumonia was 69%, whereas that of bedside ultrasonography was significantly higher at 96%. Parlamento *et al*[8] reported that CXR diagnosed 75% of cases of pneumonia, whereas ultrasonography diagnosed 96.9% of cases. Lichtenstein *et al*[26] found that the dynamic air bronchogram can distinguish lung consolidation from atelectasis. The present study also found that by combining four patterns of ultrasonographic findings, bedside ultrasonography had a higher sensitivity (94.6%) for diagnosing CAP than CXR (77.7%). It is possible for chest CT or ultrasonography to show lung consolidation even when the CXR shows no obvious abnormality (figure 2). This could be attributed to the overlapping images on a CXR film, in which the heart, mediastinum or diaphragm may partially obscure lung lesions. In comparison, ultrasonography can be used to image each intercostal space, thus providing more information than CXR and contributing to the diagnosis of CXR-negative patients with CAP. However, four combined patterns of ultrasonographic findings achieved better diagnostic sensitivity and accuracy than CXR in this study. This

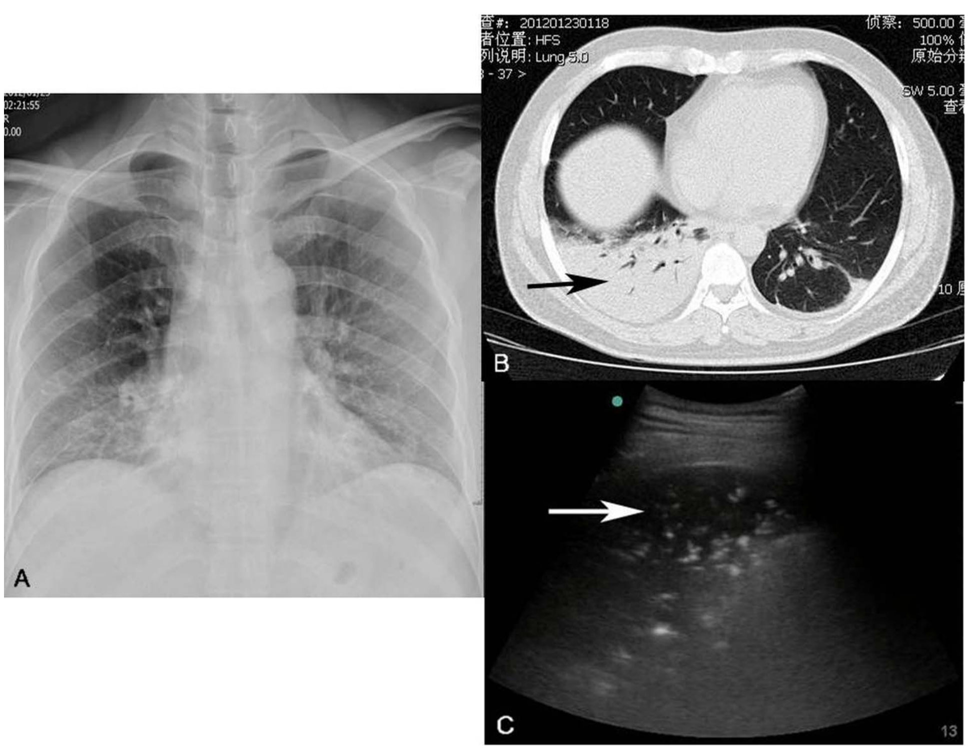

Figure 2 A 42-year-old male CAP patient. (A) CXR showed no obvious abnormality. (B) Chest CT showed consolidation of the right posterior lung (arrow). (C) Ultrasonography showed consolidation (arrow) and air bronchogram.

was as much a weakness as a strength of the use of ultrasonography.

Most researchers use the detection of lung consolidation to diagnose CAP on bedside ultrasonography.[6 8 17 27] In a recent multicenter research, Reissig *et al*[28] reported that ultrasonongraphy had 93.4% sensitivity and 97.7% specificity for diagnosis of CAP, and 86.7% CAP patients had air bronchogram. Consolidation is a common ultrasonography finding for CAP, but not always present. Several reports had demonstrated an interstitial pattern (B line) on ultrasonography was indicative for CAP,[6 16] and patients with this change may have diffuse ground-glass opacification on CT. B line correlated with interstitial oedema and may be focal (pneumonia, lung contusion) or diffuse (acute respiratory distress syndrome (ARDS), cardiogenic pulmonary oedema). Coetellaro reported that 49% CAP patients could have an interstitial pattern, and most of the interstitial patterns were near the lesion.[6] In this study, focal interstitial pattern and consolidation had 38.4% and 71.4% sensitivity for diagnosis of CAP, respectively.

Some CAP may be interstitial pneumonia, which shows diffuse ground-glass opacification on CT. In this study, we divided CAP patients into two groups according to their different CT patterns. In patients of Group B (CT showed diffuse ground-glass opacification), lung inflammation may result in focal interstitial pattern, subpleural lesions or pleural-line abnormalities (figure 3). Although 49% of CAP patients had focal interstitial pattern in this study, no difference was found between Group A (CT showed consolidation) and B. This means focal interstitial pattern may be a sign for CAP, but not specific for interstitial pneumonia. Subpleural lesions are detected as hypoechoic subpleural nodules shaped as triangles, polygons, or circles. A number of studies have used detection of a triangular subpleural lesion to diagnose pulmonary embolism,[7 24 25 29–31] and subpleural lesion is also detected on CAP patients on another study (consolidation with neither air bronchogram nor fluid bronchogram).[28] The present study also showed that subpleural lesions may occur in CAP patients. The patients of Group B had more subpleural lesions than those of Group A. Subpleural lesions may have a different mechanism than consolidation. Consolidation is due to infiltration in pulmonary alveoli, with air bronchogram or fluid bronchograms in it. However, the mechanism of subpleural lesion may be that the pulmonary inflammatory response causes inflammatory embolisms of the small blood vessels that supply the peripheral lung tissues, resulting in lung tissue ischaemia and necrosis. The hypoechoic subpleural nodules may be larger in patients with pulmonary embolism than CAP patients, but we did not compare the number or size of subpleural lesions between these two groups due to the small number of pulmonary embolism patients (eight cases) in this study.

Copetti *et al*.[32] reported that pleural-line abnormalities may occur in patients with ARDS and cardiogenic pulmonary oedema, and the number of abnormalities was significantly different in the two entities Testa reported that 7 of 16 H1N1 pneumonia patients had pleural-line abnormalities on ultrasonography, and their CTs showed ill-defined ground-glass opacities.[33] In this study, we also detected pleural-line abnormalities including thickening and irregularities in CAP patients. Pleural-line abnormalities were detected in a higher number of intercostal spaces in patients in the CAP group than in the non-CAP group. Patients in group B had a higher number of intercostal spaces with pleural-line abnormalities than patients in group A. It is likely that lung inflammation is confined to one or several segments in patients with significant consolidation. However, patients with interstitial pneumonia may have more widespread involvement of the lung tissues and pleura, causing

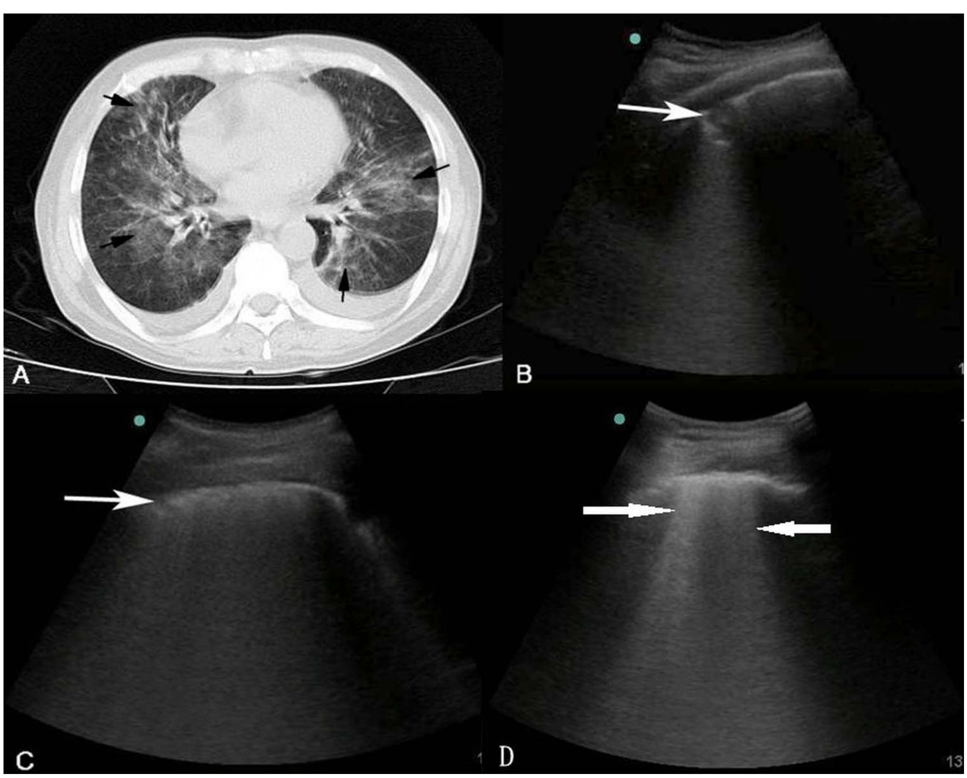

Figure 3 A 55-year-old female CAP patient. (A) Chest CT showed diffuse ground-glass opacification (arrow). (B) Ultrasonography showed a subpleural lesion (arrow). (C) Ultrasonography showed pleural-line abnormalities (arrow). (D) Ultrasonography showed interstitial pattern (arrow).

pleural congestion and oedema, detected as pleural-line abnormalities on ultrasonography.

Limitations

Ultrasonography is an operator-dependent examnination. The results of this paper are based on the three trained physicians being in agreement which may limit external validity. Only admitted CAP patients were included in this study and the selected patient population was likely to reflect those with more severe CAP. The results of this study may not generalise to all CAP patients. There was no consensus on what level of training is required to achieve competency in lung ultrasonography, and the results in other settings may be different, due to different skills and experiences.

Conclusions

Ultrasonographic findings of CAP included consolidation, focal interstitial pattern, subpleural lesion and pleural-line abnormalities. Consolidation and focal interstitial pattern are not always the ultrasonographic findings of CAP. CAP patients with diffuse ground-glass opacification on CT are more likely to show subpleural lesion and pleural-line abnormalities on ultrasonography. Lung ultrasonography has a better diagnostic sensitivity and accuracy compared with CXR for diagnosing CAP.

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Contributions G-qZ and X-lL contributed to the study design. X-lL, RL and Y-kT performed ultrasonography. C-dG recruited patients, collected and analysed data. G-qZ and X-lL drafted the manuscript.

Competing interests None.

Patient consent Obtained.

Ethics approval Ethical Committee of China-Japan Friendship Hospital.

Provenance and peer review Not commissioned; internally peer reviewed.

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Notes