Chest ultrasound in the evaluation of complicated pneumonia in the ICU patients: Can be viable alternative to CT?

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Received 4 November 2013; accepted 5 February 2014
Available online 3 March 2014

Abstract  Objective: To compare ultrasound (US) and computed tomography (CT) for evaluating patients with complicated pneumonia admitted to the intensive care unit (ICU) to assess if US can be an alternative to CT.

Subjects and methods: We prospectively compared US and CT findings in 48 patients admitted to the ICU with complicated pneumonia with their final diagnosis at discharge. Images were evaluated for parenchymal findings (consolidation, necrosis, and abscess) and pleural findings (effusion, loculation or fibrin strands in the pleural fluid).

Results: US was similar to CT in the evaluation of parenchymal and pleural abnormalities except for two patients with consolidation and effusion, three patients with loculated effusion, one patient with pulmonary necrosis and another patient with lung abscess. US was superior to CT in detection of fibrin strands within pleural effusion.

Conclusion: Chest US provides an accurate evaluation of the pleural and parenchymal abnormalities associated with complicated pneumonia in the ICU patients. Considering that chest US is a bedside and avoids transportation of the patient outside ICU, free of radiation exposure and easily repeatable, chest US appears to be an attractive alternative to CT.

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1. Introduction

During the last 20 years, several studies have investigated chest US as an accurate diagnostic tool for the diagnosis of pneumonia and results of these studies have shown US to be superior to chest radiography in almost every setting ranging from ICUs to emergency departments and outpatient clinics (1–4). US has grown to such an extent that an evidence-based consensus conference was held in 2010 and 2011 bringing together
dosens of published experts from multiple countries around the world (5). The consensus conference found chest US to have broad utility in evaluating patients for different pathology pulmonary conditions including pneumonia and pleural effusion.

Management of the ICU patients with complicated pneumonia requires imaging techniques which are essential for optimizing diagnostic and therapeutic procedures. To date, imaging of these patients has relied on bedside chest radiography and chest CT for characterization of pleural effusion and underlying parenchymal disease before chest tube placement or surgery (6). However, performing a chest CT scan requires transportation of the patient to the radiology department, a risky procedure necessitating the presence of trained physicians and sophisticated cardio-respiratory monitoring (7). In addition, multi-detector row CT exposes the patient to a substantial radiation dose which limits the repeatability of the procedure (8). For these reasons, chest CT remains a radiological test, access to which is limited in many ICUs. It is, therefore, not surprising that alternative imaging strategy such as US has been investigated.

We prospectively compared the information obtained from chest US and chest CT in the ICU patients with complicated pneumonia with their final diagnosis at discharge to determine if US could serve as a useful alternative to CT. In those patients who underwent drainage of pleural effusion, imaging findings were correlated with data obtained from analysis of pleural fluid.

2. Subjects and methods

Among 2234 patients admitted to ICU for different diagnoses between June 2009 and July 2013, 52 patients were suspected to have complicated pneumonia on the basis of clinical examination and chest radiography. These patients underwent both chest US and chest CT and 48 patients had final diagnosis of complicated pneumonia and they were included in this study. Other four patients with uncertain diagnoses were excluded. There were 31 males and 17 females and their ages ranged from 28 to 67 years (mean age, 46 years). US was performed first and the mean time between US and CT was 2.7 days (range, 0–4 days).

Chest US was performed by an experienced radiologist using a scanner (Mindray DC-7) and a scanner (Medison SONOACE SA 9900), both scanners with a 3–7 MHz curved and 5–12 MHz linear-array transducers. The patient position was determined according to the side and site of chest abnormality that was localized on the basis of physical examination and chest radiography findings. US approaches used were direct intercostal and abdominal approaches. In direct intercostal approach, the transducer was directly applied to the chest whereas in abdominal approach, the transducer was directed superiorly from the abdomen to the lower reaches of the pleural space and the liver and spleen provided sonographic windows to the thorax. We used abdominal approach in most patients (33 patients) as lung consolidation or pleural effusion was found predominantly in dependant and dorsal lung regions and was easily distinguished from the liver or spleen once the diaphragm had been located. Longitudinal and transverse images were obtained for the region of the chest abnormality (9,10). After US examination, decontamination procedures were applied for probes and the US machine using an US disinfectant detergent (T-Spary, New Jersey, USA) with active ingredients (n-Alkyl, dimethyl Benzyl and ammonium chlorides) to avoid dissemination of resistant pathogens in the ICU (11,12).

Chest CT was performed using 8-MDCT scanner (Hitachi Healthcare) in a supine position with head first. Patients were instructed to hold breathing for the duration of scan (25 s). The images were acquired from the level of the thoracic inlet to the diaphragm with 5 mm slice thickness obtained at 5 mm intervals. 0.8 s scan time, a collimation of 2.5 x 8, 120 kV X-ray tube voltage, 225 MA current, 350 field of view (FOV) and scan type was volume scan. All patients underwent CT following bolus injection of 50 ml of non-ionic, low osmolar contrast medium, Iohexol (Omnipaque 300 mg I/ml-GE healthcare, Ireland) through an 18–24 gauge cannula placed in a superficial arm vein. Images were printed at mediastinal window setting (level, 20 H; width, 350 H) and lung window setting (level, −650 H; width, 1500 H).

US and CT images were examined for the presence of parenchymal consolidation, lung necrosis, abscess, pleural effusion and the presence of loculation or fibrin strands within the pleural fluid. In addition, the volume of pleural effusion was assessed by multiplying the height of the pleural effusion by its transversal area, measured half-way between upper and lower limits (13), this was enough to quantify small (<500 ml) and large (>1000 ml) pleural effusions (14,15).

On chest US, pleural effusion was seen as dark zone free of echo in dependant lung regions delineated by the chest wall and the diaphragm (9). Pleural effusion was defined as loculated if the collection had a lobulated or lenticular shape with a convex border (16,17). Parenchymal consolidation was defined as a wedge-shaped hypoechoic tissue structure containing bright linear and branching echoes representing sonographic air bronchograms (air-filled bronchi) (18). Pulmonary necrosis was defined as a focal rounded area of decreased echogenicity within a portion of consolidated lung (19). Abscess was defined as an intrapulmonary rounded hypoechoic lesion with outer margins containing fluid and/or air (20,21).

On chest CT, pleural effusion was defined as loculated if the collection had a lobulated or lenticular shape with a convex border (16,17). Parenchymal consolidation was defined as air-space density with air bronchograms (22). Pulmonary necrosis was defined as a low-density area within a consolidated lung that had diminished enhancement relative to the adjacent parenchyma (16). Abscess was defined as an intrapulmonary cavity containing fluid and/or air with no central enhancement (23).

According to previous studies (6,24–26), patients in our study were treated with either antibiotics (17 patients) or with antibiotics and drainage of pleural effusion (31 patients) either by US-guided (18 patients) or by chest tube (13 patients). The response to therapeutic management was monitored by performing frequent follow up US examination at the bedside according to the clinical status (9).

The patients who underwent US-guided drainage of pleural effusion (thoracentesis) were informed about the nature of the procedure and a signed consent form was obtained from the patients. After identification of location of pleural effusion by US when the patient was in a sitting upright position, the largest and most accessible area of fluid accumulation was identified and the depth for the needle to penetrate was measured and deepest possible site in the dorsal part of the thorax was marked for pleural puncture. The area was cleaned with povidone iodine, followed by injection of 1% lidocaine intra-dermally,
subcutaneously, and into the parietal pleura as local anesthetic. A 14–16 gauge plastic catheter needle system was used to enter the pleural space with constant aspiration until pleural fluid was obtained. The free hand approach was used in which the needle was inserted through the skin directly into the plane of view of the transducer without a guide and the transducer was positioned away from the actual entry site. US images were obtained for the pleural effusion before, during and after the procedure (10,25,26). Post procedure radiographs were done for the presence of pneumothorax. The aspirated pleural fluid sample was sent to laboratory for analysis of pH, total protein, specific gravity, lactate dehydrogenase (LDH), bacterial cultures, Gram stain, acid-fast stain, total and differential leukocyte counts, and cytological parameters. Parapneumonic effusion was defined as exudative pleural effusion with pneumonia. Empyema was defined as exudative pleural effusion with pneumonia. Empyema was defined as exudative pleural effusion with pneumonia. Empyema was defined as exudative pleural effusion with pneumonia. Tuberculous effusion was defined as exudative producing positive culture of Mycobacterium tuberculosis with no evidence of malignancy (27). The US findings were compared with the CT findings and the findings obtained from each modality were compared with final diagnosis at discharge through data obtained from conservative management or drainage of pleural effusion either by US-guided thoracentesis or chest tube drainage.

3. Results

Chest US examination was technically limited in two of the 48 patients who had final diagnosis of complicated pneumonia due to patient’s obesity. All remaining 46 patients had parenchymal consolidation and pleural effusion on US (Fig. 2). Pleural effusion was loculated in 19 patients and had fibrin strands in 31 patients (Fig. 1). Parenchymal consolidation was associated with pulmonary necrosis in two patients (Fig. 3) and with pulmonary abscess in three patients. Average time for chest US examination was around 10 min.

Chest CT of the same 48 patients showed that all 48 patients had parenchymal consolidation and pleural effusion. Pleural effusion was loculated in 22 patients and had fibrin strands in eight patients. Parenchymal consolidation was associated with pulmonary necrosis in three patients (Figs. 3 and 4) and with pulmonary abscess in two patients (Fig. 5).

US findings were compared to CT findings in Table 1. Chest US could not determine parenchymal consolidation and pleural effusion in two patients due to patient’s obesity as mentioned previously, loculation of pleural effusion in three patients, parenchymal necrosis in one patient and lung abscess in another patient who showed pyo-pneumothorax on CT (Fig. 6), this could be due to rupture of lung abscess detected.
on US at the delayed time between US and CT examination (four days). Fibrin strands within pleural effusion were better visualized on US (of the 31 patients who had fibrin strands on US, only eight patients had fibrin strands on CT) (Fig. 1).

Chest US and CT findings were compared with data obtained from the analysis of the aspirated pleural effusion. Of the 19 patients who had loculated effusion on US, 15 patients underwent drainage of pleural collection. Of these 15 patients,
loculation correlated with the presence of empyema in 13 patients, all had fibrin strands within pleural fluid on US. Of the 22 patients who had loculation on CT, 16 patients underwent drainage of pleural collection. Of these 16 patients, loculation correlated with the presence of empyema in 15 patients and all eight patients who had fibrin strands within pleural fluid on CT, were found to have empyema.

4. Discussion

Previous studies that assessed the diagnostic performance of chest US for the diagnosis of pneumonia have compared US to chest radiography using CT as a gold standard (1,3,4). Other studies have compared the efficacy of US compared to CT in patients with complicated pneumonia both in adults (28,29) and children (6,16,30). However, these studies were performed for outpatient clinics and did not include the ICU patients. Therefore, no consensus exists on the optimal technique for imaging complicated pneumonia in the ICU patients.

Chest CT is now considered as the gold standard for the diagnosis of pneumonic consolidation and pleural effusion and outperformed chest US in the evaluation of advanced parenchymal disease associated with pneumonia such as pulmonary necrosis and abscess (9,31). This can be clinically significant because the presence of necrotizing pneumonia requires a prolonged course of antibiotics (17). However, in our study, US was nearly similar to CT in its ability to diagnose pulmonary consolidation, pulmonary necrosis and abscess. Parenchymal consolidation was shown in all 48 patients on CT compared to 46 patients on US. Parenchymal necrosis was shown in two patients on both US and CT but CT showed pulmonary necrosis in a third patient in whom consolidation was also not detected by US. Lung abscess was suspected in three patients on US but was confirmed in two patients on CT, the third patient showed pyo-pneumothorax on CT.

Chest US was also able to detect pleural effusion associated with pneumonia in our patients when compared with CT except for two patients. Loculation of pleural effusion seen on CT could not be determined on US in three patients whereas US was superior to CT in its ability to detect fibrin strands within the pleural fluid, which may indicate early organization of an effusion (32). Of the 31 patients who had fibrin strands on US, eight patients had fibrin strands on CT. Similar results were mentioned by studies published previously on the use of US in the evaluation of parapneumonic effusion except for loculation of pleural effusion which was equally detected by US and CT in these studies (17,31).

Chest US is increasingly used for guiding thoracentesis at the bedside (10,25,26). It provides the possibility of detecting pleural adherences that may hamper efficient thoracic drainage and transform thoracentesis into a risky procedure. It enables the safe thoracic drainage of small and/or loculated pleural effusions as well as lung abscesses (20,21,33). In our study, we did US-guided thoracentesis at the bedside for 18 of the 31 patients who underwent drainage of pleural effusion. The procedure was effective and safe as we have a good experience regarding US-guided thoracentesis which was performed for 90 patients in our study published previously on the ability of US to detect the nature of pleural effusion (10). The presence of loculated effusion on either US or CT correlated with empyema in all patients except for two patients with loculated effusion on US and one patient on CT. All patients who had fibrin strands within pleural fluid on either US or CT, were found to have empyema. Our results were similar to those mentioned by previous studies (10,29).

Last but not least, chest US was used frequently at the bedside to monitor the response to therapy in our patients. The indications of bedside chest radiography can be restricted to the assessment of the intrathoracic position of catheters and endotracheal tubes and to patients where US is not feasible (9). As a consequence, radiation exposure to physicians, nurses and patients is reduced as well as costs.

It is clear that chest US was similar to chest CT in the evaluation of pleural and parenchymal abnormalities associated with complicated pneumonia except for two patients with

![Image](image.png)

**Fig. 6** 58-year-old patient with complicated pneumonia and US diagnosis of right lung abscess. Chest US image (A) shows rounded hypoechoic lesion in the right hemithorax with outer echogenic margins and non-homogenous fluid content (arrows) interpreted as lung abscess. Axial contrast-enhanced chest CT image (B) shows air filled cavity with small basal fluid consistent with right pyo-pneumothorax (arrows).
consolidation and pleural effusion, three patients with loculated effusion, one patient with pulmonary necrosis and another patient with lung abscess. The main reason for these discrepancies was the technical limitation of US in two patients in whom consolidation and pleural effusion could not be determined. Technical limitation of US was due to patient’s obesity with increased thickness of their thoracic cage made difficult the evaluation of the lung; a known limitation of US (9). The last patient in whom lung abscesses was suspected on US, had pyo-pneumothorax on CT. This may be explained by rupture of the lung abscess seen on US during the delayed time between US and CT examination (4 days) with resultant pyo-pneumothorax or could be due to false US diagnosis. However, this was of little clinical significance as chest tube placement was the preferred method of treatment in our patient, which is the same initial management strategy for lung abscesses. Chest US was superior to CT in its ability to detect fibrin strands within pleural effusion which corresponded to the presence of empyema in all patients, a clinically significant finding necessitating early intervention. US-guided drainage of pleural effusion was an additional therapeutic and diagnostic procedure.

Chest US has many limitations in the ICU. Chest US examination and correct interpretation of the resulting images require formal training aimed at acquiring the necessary knowledge and skills (34). Chest US has intrinsic limitations that are not operator dependent but patient dependent. Obese patients are frequently difficult to examine using US because of the thickness of their rib cage as noted in two patients in our study. The presence of subcutaneous emphysema or large thoracic dressings alters or precludes the propagation of US beams to the lung periphery. In addition, dorsal lung segments of upper lobes, located behind the scapula cannot be explored by US. The probes and the US machine can be the vector for infection and avoid transportation of the patient outside ICU, free of transportation costs. We suggest that the optimal technique for imaging complicated pneumonia in the ICU patients should comply with repeated decontamination procedures. In our study, chest US provided an accurate evaluation of the pleural and parenchymal abnormalities associated with complicated pneumonia in the ICU patients as well as for guiding thoracentesis. Considering that chest US is a bedside and avoids transportation of the patient outside ICU, free of radiation exposure, rapid, noninvasive technique, lower cost and easily repeatable, chest US appears as an attractive alternative to chest CT. We suggest that the optimal technique for imaging complicated pneumonia in the ICU patients should include preliminary chest radiography and bedside chest US. Chest CT may be reserved for patients in whom chest US is technically difficult or does not correlate with the clinical data or preliminary chest radiography findings.

Conflict of interest

We have no conflict of interest to declare.

References


