Diagnosing pulmonary edema: lung ultrasound versus chest radiography

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Background **Diagnosing the underlying cause of acute dyspnea can be challenging. Lung ultrasound may help to identify pulmonary edema as a possible cause.**

Objective **To evaluate the ability of residents to recognize pulmonary edema on lung ultrasound using chest radiographs as a comparison standard.**

Methods **This is a prospective, blinded, observational study of a convenience sample of resident physicians in the Departments of Emergency Medicine (EM), Internal Medicine (IM), and Radiology. Residents were given a tutorial on interpreting pulmonary edema on both chest radiograph and lung ultrasound. They were then shown both ultrasounds and chest radiographs from 20 patients who had presented to the emergency department with dyspnea, 10 with a primary diagnosis of pulmonary edema, and 10 with alternative diagnoses. Cohen's κ values were calculated to describe the strength of the correlation between resident and gold standard interpretations.**

Results **Participants included 20 EM, 20 IM, and 20 Radiology residents. The overall agreement with gold standard interpretation of pulmonary edema on lung ultrasound (74%, $\kappa = 0.51$, 95% confidence interval 0.46–0.55) was superior to chest radiographs (58%, $\kappa = 0.25$, 95% confidence interval 0.20–0.30) ($P < 0.0001$). EM residents interpreted lung ultrasounds more accurately than IM residents. Radiology residents interpreted chest radiographs more accurately than did EM and IM residents.**

Conclusion **Residents were able to more accurately identify pulmonary edema with lung ultrasound than with chest radiograph. Physicians with minimal exposure to lung ultrasound may be able to correctly recognize pulmonary edema on lung ultrasound.** ***European Journal of Emergency Medicine*** **20:356–360** © **2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Diagnosing the cause of acute dyspnea is challenging, especially in patients with both cardiac and pulmonary disease. Chest radiography can aid in identifying pulmonary edema as an underlying cause, but the overall accuracy of the presence or absence of congestive heart failure on radiographs may be as low as 69% [1]. Findings of pulmonary edema on chest radiographs are known to lag behind clinical changes [2].

Lung ultrasound may help to rapidly discriminate between cardiogenic and noncardiogenic causes of dyspnea [3,4]. Lung ultrasound is based on imaging artifacts created by the different acoustic properties of air and water. In the presence of pulmonary edema, these artifacts appear as sonographic B-lines, vertical hyperechoic beams that extend from the pleural surface to the bottom of the ultrasound screen (Fig. 1b), and move with respiration. B-lines correlate with interstitial edema identified by chest radiograph [5], computed tomography [6], pulmonary capillary wedge pressure [7], and quantitative measurement of extravascular lung water and natriuretic peptide levels [7,8]. The potential for incorporating lung ultrasound into clinical practice depends on how readily physicians can acquire the necessary interpretive skills. This study aimed to assess how well physicians with little training in ultrasound could detect pulmonary edema by interpreting lung ultrasound studies and chest radiographs.

Methods

Study design

This was a prospective, blinded observational study designed to assess the ability of resident physicians to independently evaluate pulmonary edema on chest radiography and lung ultrasound. The institution's Institutional Review Board approved this study (Protocol number: 2010 P-001207).

Study protocol

A convenience sample of residents in the Departments of Emergency Medicine (EM), Internal Medicine (IM), and Radiology were given the same brief tutorial on how to recognize pulmonary edema on both lung ultrasound and chest radiograph. Residents were then shown the chest

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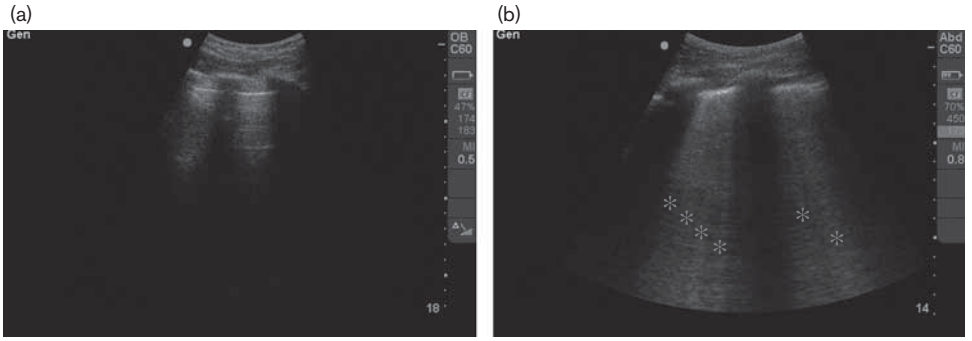
Fig. 1



(a). Image of a normal lung ultrasound, absent of B-lines. (b). Image of a lung ultrasound showing multiple B-lines (marked by asterisk) in each intercostal space.

radiographs and lung ultrasound studies from 20 patients and asked to assess whether pulmonary edema was present. Lung ultrasounds and chest radiographs were selected *a priori* from 10 patients known to have pulmonary edema as the cause of their acute dyspnea and 10 patients with alternative causes of dyspnea. Patient selection was made on the basis of chart review carried out by EM physicians certified by the American Board of Emergency Medicine. Images were obtained from an image bank created from previous research [8]. The group of 10 patients with pulmonary edema included five patients selected for positive lung ultrasounds (blinded to chest radiograph results) and five patients selected for positive chest radiographs (blinded to lung ultrasound results). The group of 10 patients with alternative causes of dyspnea included five patients selected for negative lung ultrasounds (blinded to chest radiograph results) and five patients selected for negative chest radiographs (blinded to lung ultrasound results) (Fig. 2).

Lung ultrasounds were shown as eight looped video clips playing simultaneously on a single slide. Each of the eight video clips corresponded to an anatomical zone on the chest (Fig. 3). Chest radiographs were shown as a single still image per slide and labeled as anterior–posterior or posterior–anterior depending on the type of view obtained. Ultrasound videos and chest radiographs were shown separately in an unpaired randomized order. Residents had 30 s per slide to record whether pulmonary edema was present or absent and their level of confidence (ordinal scale of 1–10) relating to each slide assessment.

Ultrasound video clips were obtained with a MicroMaxx Sonosite (SonoSite Inc., Bothell, Washington, USA) ultrasound machine using a 5–2 MHz curvilinear probe set to a depth of 18 or 22 cm. Chest radiographs were obtained using either the posterior–anterior technique (12 patients) or the portable anterior–posterior technique (eight patients). Radiograph images were digital images downloaded from the hospital's picture archiving and communication system. Images and films were projected through an LCD projector (Epson, Long Beach, CA, USA) onto a 10×10 ft white screen in conference rooms.

Statistical methods

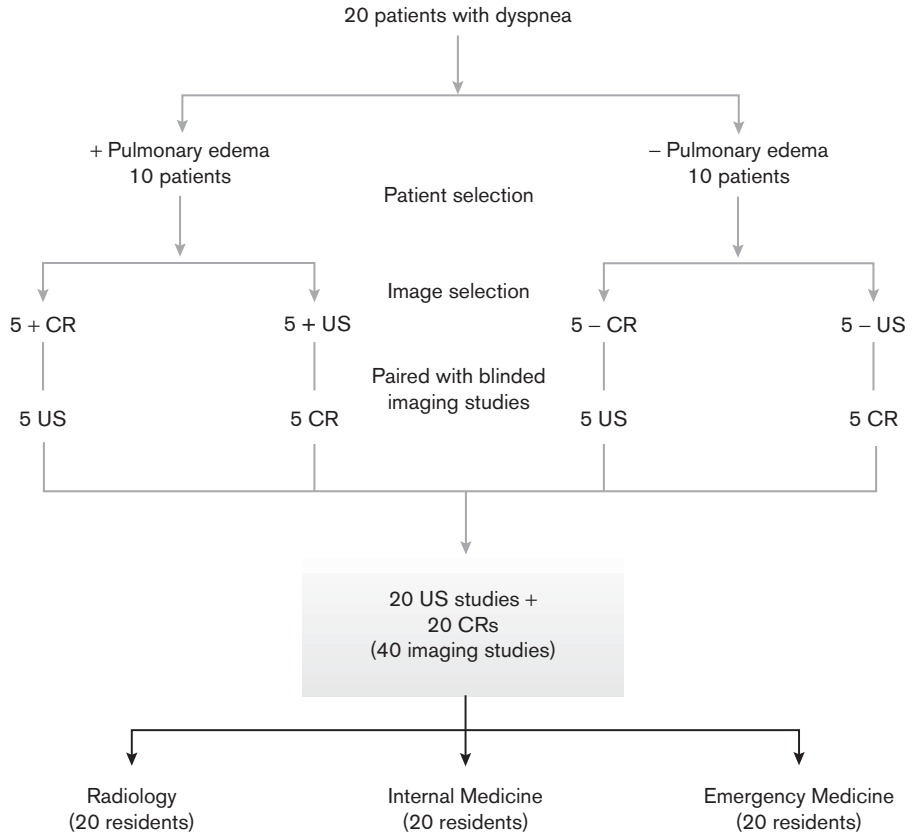
Resident interpretations of ultrasounds and chest radiographs were recorded and compared with gold standard interpretations. The gold standard for ultrasound interpretation was interpretation by an EM physician fellowship-trained in emergency ultrasound and credentialed by the American Registry for Diagnostic Medical Sonography. This is a not-for-profit organization that offers credentialing in sonography. Certification represents a standard of competence in sonography recognized among various specialties in the USA, including EM. Interpretation by a board-certified attending radiologist served as the gold standard for radiographs. Cohen's κ was used to determine the agreement between resident and gold standard interpretations.

One-way analysis of variance was used to determine a statistically significant difference among the mean levels of postgraduate medical education. Fischer exact tests with two-tailed *P*-values were used to compare the performance between the two imaging modalities and to compare the performance between different residency types. Standard *t*-tests with two-tailed *P*-values were used to compare the mean confidence levels between the two imaging modalities. A *P*-value less than 0.05 was considered to be significant.

Results

Sixty resident physicians (20 from each training program) carried out a total of 2398 assessments of the presence or absence of pulmonary edema on lung ultrasound and chest radiographs. The majority of participating residents

Fig. 2



Patient, image, and subject selection. CR, chest radiograph; US, ultrasound.

were in their second year of postgraduate training (Table 1). There was no statistical difference in the level of training among the different residency groups ($P = 0.186$).

The overall accuracy in identifying pulmonary edema on lung ultrasound [74%, $\kappa = 0.51$, 95% confidence interval (CI) 0.46–0.55] was greater than that on chest radiographs (58%, $\kappa = 0.25$, 95% CI 0.20–0.30) ($P < 0.0001$) (Table 2). This is despite residents having an overall higher confidence level in chest radiograph interpretation (6.76, 95% CI 6.65–6.78) than in lung ultrasound interpretation (6.30, 95% CI 6.18–6.41) ($P < 0.0001$). The interpretation of negative lung ultrasounds was more accurate (61%) than the interpretation of negative chest radiographs (32%).

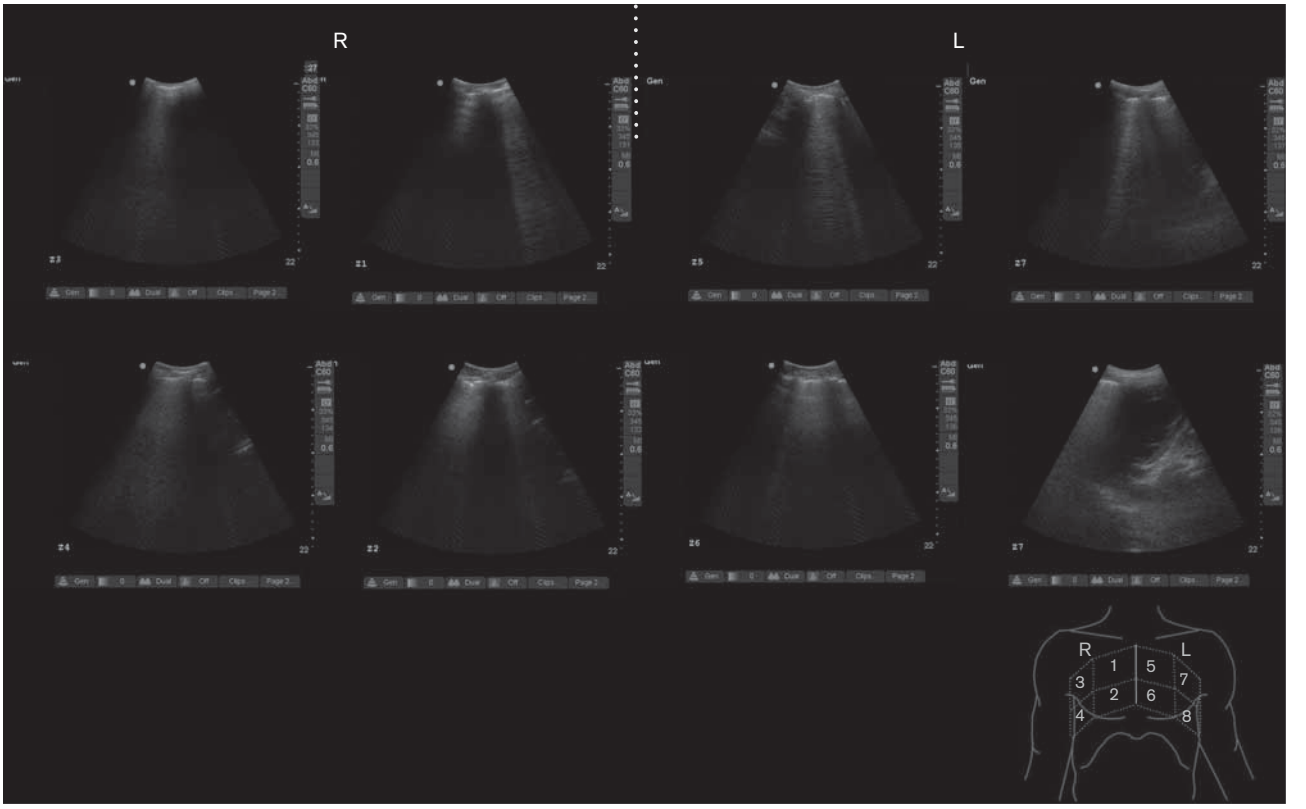
Radiology residents interpreted chest radiographs with greater accuracy (67%) than did EM (56%, $P = 0.003$) and IM (52%, $P < 0.0001$) residents (Table 3). EM residents interpreted lung ultrasound with greater accuracy (79%) than did IM residents (69%, $P = 0.002$), but not radiology residents (74%, $P = 0.08$). Radiology and IM residents were more confident in the assessment of chest radiographs than in their assessment of lung ultrasound.

Discussion

The presence of pathologic B-lines in multiple lung zones can help to identify diffuse pulmonary edema in acute respiratory distress syndrome [9], fluid overload from end-stage renal disease [10,11], and decompensated congestive heart failure [3,4,7,8]. Studies evaluating lung ultrasound in diagnosing pulmonary edema are largely based on image interpretation by one or more highly trained sonographers. The ability of physicians with minimal training in ultrasound to detect pulmonary edema on lung ultrasound has not, to our knowledge, been characterized.

Our study showed that residents across different specialties were reliably able to identify whether pulmonary edema was present or absent on lung ultrasound. Residents were able to interpret negative ultrasounds more accurately than negative chest radiographs perhaps owing to fewer visual artifacts on lung ultrasound that might be mistaken for signs of pulmonary edema. Residents were

Fig. 3



Images taken from lung ultrasound video clips, as they were shown to residents. Videos were continuously looped 3 to 4-s clips.

Table 1 Participant training level in postgraduate medical education

Year	All	EM	IM	Radiology
1	11	6	5	NA[a]
2	32	8	11	13
3	11	2	4	5
4	6	4	NA[b]	2
Mean	2.2	2.2	1.95	2.45

EM, Emergency Medicine; IM, Internal Medicine; NA, not available.
[a]The radiology residency program starts after a preliminary year of postgraduate medical education has been completed.
[b]The IM residency program is a 3-year program.

less discriminant in their determinations of pulmonary edema on chest radiographs, showing a tendency to overcall pulmonary edema. Portable technique and anteroposterior projection may have contributed to the decreased specificity in diagnosing pulmonary edema. The interobserver agreement of plain radiograph interpretation by radiologists has previously shown to be only fair ($\kappa = 0.31$) when radiographs are viewed without accompanying clinical information [12].

EM residents performed better than IM residents in the interpretation of pulmonary edema on lung ultrasound. EM residents are exposed to this imaging modality in the first year of training. Radiology residents performed better than EM and IM residents in chest radiograph interpretation, likely given their greater didactic instruction and clinical training in this area. Despite less confidence in lung ultrasound interpretation, radiology and medicine residents detected pulmonary edema more accurately with this imaging tool.

This study is limited in several ways. It was not designed to assess the test characteristics of the two imaging modalities in patients with undifferentiated dyspnea. An equal number of lung ultrasounds and chest radiographs were selected to be positive in patients diagnosed with pulmonary edema and negative in patients without pulmonary edema to ensure some balance in the opportunity to assess positive and negative studies using each imaging modality. This prevents us from being able to accurately quantify the sensitivity and specificity of imaging tests for the diagnosis of pulmonary edema.

Both portable anterior–posterior and standard posterior–anterior radiographs were included in the assessment tool. However, residents were informed of the view, and in clinical practice, physicians must interpret radiographs

Table 2 Comparison of ultrasound and chest radiograph interpretation

Test characteristics and statistics	All	EM	IM	Radiology
US				
Sensitivity (%)	99	99	98	98
Specificity (%)	61	68	54	60
Accuracy (%)	74	79	69	74
κ (95% CI)	0.51 (0.46–0.55)	0.59 (0.51–0.67)	0.43 (0.35–0.52)	0.50 (0.42–0.58)
Self-rated confidence (1–10) [mean (95% CI)]	6.30 (6.18–6.41)	6.64 (6.45–6.82)	6.05 (5.85–6.25)	6.21 (6.02–6.40)
CR				
Sensitivity (%)	97	99	96	97
Specificity (%)	32	28	22	47
Accuracy (%)	58	56	52	67
κ (95% CI)	0.25 (0.20–0.02)	0.23 (0.14–0.31)	0.15 (0.06–0.24)	0.39 (0.30–0.47)
Self-rated confidence (1–10) [mean (95% CI)]	6.76 (6.65–6.87)	6.77 (6.58–6.96)	6.65 (6.47–6.84)	6.86 (6.67–7.04)
US versus CR accuracy (*P*-values)	<0.0001	<0.0001	<0.0001	0.04
US versus CR confidence (*P*-values)	<0.0001	0.303	<0.0001	<0.0001

CI, confidence interval; CR, chest radiograph; EM, Emergency Medicine; IM, Internal Medicine; US, ultrasound.

Table 3 Novice reads compared with clinical gold standard of pulmonary edema

Residency	Ultrasound (% correct)	CR (% correct)	*P*-values
EM	81	61	<0.0001
IM	75	57	<0.0001
Radiology	77	67	0.04
Overall	77	62	<0.0001

CR, chest radiograph; EM, Emergency Medicine; IM, Internal Medicine; US, ultrasound.

obtained by both techniques. Accession of lung ultrasound video clips could have been better standardized if all video clips had been obtained at the standard 18-cm depth. The criterion standard of chest radiograph interpretation used in this study was imperfect. Attending radiologists may have used relevant clinical data to modify their image interpretation. They may have also used a patient's previous radiographic studies for comparison. Access to previous studies with similar radiographic findings may have contributed toward the number of negative gold standard reads and, subsequently, the observed frequency of overdiagnosing pulmonary edema on chest radiograph by resident physicians. Because the purpose of this study was to assess image interpretation, residents were not provided with any clinical data associated with the ultrasound and radiographic studies.

Conclusion

Despite these limitations, our study shows that physicians with minimal exposure to lung ultrasound can assess pulmonary edema using this imaging modality. Interpretation of lung ultrasound may even be more accurate in diagnosing pulmonary edema than interpretation of chest radiographs. There is potential to incorporate lung ultrasound into the evaluation of patients with acute dyspnea, but more research is required to better define how best to do so.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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