Bedside lung ultrasound, mobile radiography and physical examination: a comparative analysis of diagnostic tools in the critically ill

Andrew J Inglis, Marek Nalos, Kwan-Hing Sue, Jan Hruby, Daniel M Campbell, Rachel M Braham, Sam R Orde

ABSTRACT

Objective: To compare lung ultrasonography (LUS), chest xray (CXR) and physical examination (Ex) for the detection of pathological abnormalities in the lungs of critically ill patients.

Design, setting and participants: A prospective cohort study of 145 patients in the intensive care unit of a tertiary teaching hospital who were undergoing echocardiography for a clinical indication.

Main outcome measures: Each patient was independently assessed by Ex, CXR and LUS on the same day. Examiners were asked to comment on the presence or absence and severity of pleural effusion, lung consolidation and alveolar interstitial syndrome (AIS). Independent expert examiners performed the LUS and an independent radiologist reported on the CXR.

Results: Ex, CXR and LUS were in fair agreement with each other in detecting a pulmonary abnormality (CXR v LUS, $\kappa = 0.31$; CXR v Ex, $\kappa = 0.29$; LUS v Ex, $\kappa = 0.22$). LUS detected more abnormalities than did CXR (16.2%; $\chi^2 = 64.1$; $P < 0.001$) or Ex (23.5%; $\chi^2 = 121.9$; $P < 0.001$). CXR detected more pleural effusions than LUS (9.3%; $\chi^2 = 7.6$; $\kappa = 0.39$), but LUS detected more pleural effusions than Ex (22.8%; $\chi^2 = 36.4$; $\kappa = 0.18$). There was no significant difference in the performance of LUS and CXR in quantifying the size of a pleural effusion ($Z = -1.2$; $P = 0.23$). Ex underestimated size compared with CXR or LUS. LUS detected more consolidation than CXR (17%; $\chi^2 = 115.9$; $P < 0.001$) and Ex (16.2%; $\chi^2 = 90.3$; $P < 0.001$). We saw no difference in performance between CXR and Ex in detecting lung consolidation (0.9%; $\chi^2 = 0.51$; $P < 0.48$). LUS detected more cases of AIS than CXR (5.5%; $\chi^2 = 7.9$; $P = 0.005$) and Ex (13%; $\chi^2 = 25.8$; $P < 0.001$).

Conclusions: There was only fair-to-moderate agreement between LUS, CXR and Ex in detecting pulmonary abnormalities, including pleural effusion, lung consolidation and AIS. The higher rate of detection from LUS, combined with its ease of use and increasing accessibility, makes for a powerful diagnostic tool in the ICU.

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Clinical examination of the respiratory system is a standard part of daily evaluation in the critically ill. Typically, physical examination (Ex) and bedside chest xray (CXR) are the mainstays of assessment, and computed tomography (CT) is considered the reference standard.[1,2] Significant limitations are associated with each of the methods. Ex is subjective and prone to inter-rater variability, and auscultation can be difficult in patients who are mechanically ventilated because transmitted sounds from the ventilator can alter pathologically significant sounds.[3,4] Portable CXR, although done at the bedside with relatively rapid acquisition of results, is often hindered by inadequate patient positioning, the necessity for anteroposterior imaging and exposing patients to harmful radiation. CT provides superior imaging resolution and diagnostic accuracy but there are significant drawbacks to this technique, such as transport of unstable patients, logistical delays and considerable radiation exposure. The use of bedside lung ultrasound (LUS) in the intensive care unit is increasing due to its ease of use, accessibility, safety profile, immediate feedback and diagnostic accuracy.[1,2,5-9]

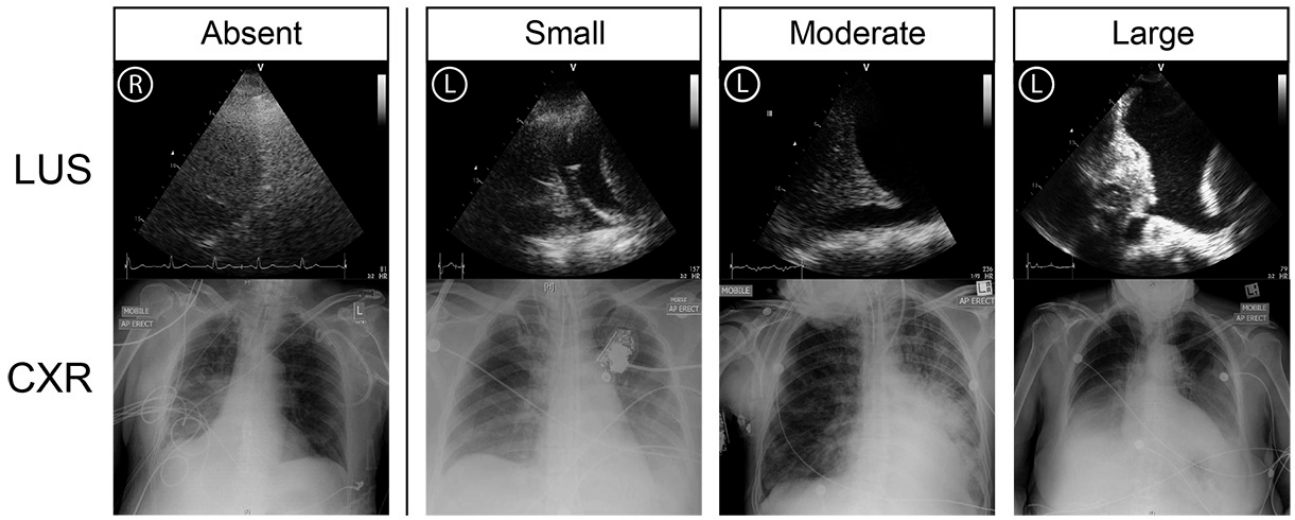
Studies to date have focused on LUS compared with reference standards such as CT, and have generally shown LUS to have a high degree of diagnostic accuracy.[4,10] We aimed to study the performance and agreement of Ex, CXR and LUS in detecting and assessing the severity of pleural effusion, alveolar interstitial syndrome (AIS) and alveolar consolidation in critically ill patients.

Methods

Patients

We prospectively included 145 adult ICU patients over a 1-year period at Nepean Hospital, Kingswood, New South Wales, Australia. Eighty-three patients were men and 62 were women, with an average age of 62 years (SD, 19 years). Sixty-three patients were mechanically ventilated. A primary respiratory condition was the most common reason for admission (37%); 19% of patients were admitted with a primary cardiovascular condition and 13% of patients were admitted for non-respiratory-related sepsis. The remainder were admitted for a variety of other indications, including seizures, acute renal failure, pancreatitis, trauma and diabetic ketoacidosis. The Nepean Blue Mountains

Figure 1. Lung ultrasound and radiological analysis of pleural effusion



LUS = lung ultrasound. CXR = chest x-ray. Absent = images of normal lungs. Small, moderate, large = volume of pleural effusion. R = right-sided LUS probe position. L = left-sided LUS probe position, in basal lung region, mid-axillary line.

Human Research Ethics Committee approved the study, and authority for consent was waived because imaging was considered standard care in our ICU. Patients were included if they were undergoing a cardiac ultrasound (US) examination during their ICU stay.

Lung ultrasonography

LUS was performed using a Vivid 7 or Vivid I echocardiography machine (GE Healthcare) by sonographers fully trained in echocardiography. The patients were positioned supine at 15–30°, with their heads up. Six lung regions were examined:

- bilateral basal regions at the mid-axillary line at the level of intercostal spaces 6–10, with a posteriocaudal orientation of the US probe after correct position was ascertained by imaging of the diaphragm
- bilateral anterior intercostal spaces 2–3 in the mid-clavicular line
- bilateral anterior intercostal space 4 in the mid-clavicular line.

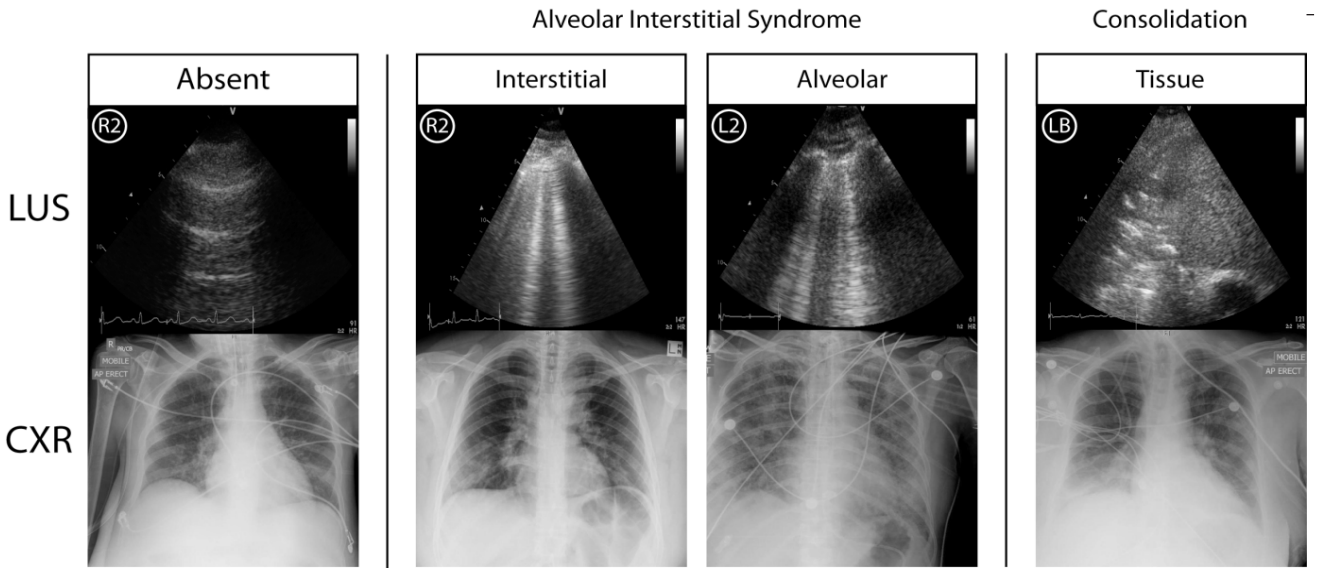
Normal lung was defined as equidistant horizontal artefact lines (A-lines) being present, with no pathological changes seen, which represent reverberation artefact signals originating from the multiple reflections of the US signal between the pleural surface and the US transducer. The presence or absence of pleural effusion was recorded and, if present, the size of the effusions was recorded as small (maximal diameter, < 2 cm), moderate (maximal diameter, 2–4 cm) or large (maximal diameter, > 4 cm).

Figure 1 compares the normal LUS and CXR examinations with pleural effusion of varying severity. An increasing hypoechoic signal on LUS corresponds to fluid accumulation in the pleural cavity.[11-13] The presence or absence of lung consolidation in each region was also recorded, indicated by a liver-like or "tissue" appearance of the lung (known as sonographic hepatisation), with air bronchograms sometimes seen (Figure 2).[14,15] AIS was defined by the presence of B-lines or "lung rockets".[6,16] These sonographic artefacts represent increased extravascular lung fluid. They take the appearance of hyperechoic beams resembling searchlights or the fire trail of an ascending rocket. These artefacts traverse the entire sonographic image. The presence of three to five B-lines was considered to represent interstitial accumulation of extravascular lung fluid. The presence of more than five B-lines was considered to represent consistent alveolar pulmonary oedema (see Figure 2).

Chest radiography

An independent radiologist (K-H S), blinded to the Ex or LUS findings, reviewed all routine portable CXR images taken in erect or semi-erect position. The lung zones were described as upper lung, mid-lung or lower lung fields, based on the upper and lower hilar line. The presence of pleural effusion was diagnosed when homogeneous opacification in the lower lung or mid-lung fields was present, with signs of typical gravity dependence. Pleural effusion was quantified based on estimated volumes (using meniscus position on imaging): small (< 400 mL), moderate (400–800 mL) or large

Figure 2. Lung ultrasound and radiological analysis of consolidation and alveolar interstitial syndrome



LUS = lung ultrasound. CXR = chest x-ray. Absent = images of normal lungs. LUS probe positions: R2 = right second intercostal space, mid-clavicular line; L2 = left second intercostal space, mid-clavicular line; LB = left basal lung region, mid-axillary line.

(> 800 mL).[17] Alveolar consolidation was defined as lung-zone opacification with air bronchograms present. One or more of the following findings defined AIS: heterogeneous or patchy lung field opacification, septal (Kerley-B) lines and reticulonodular pattern.

Physical examination

We performed Ex by auscultation with the patient in the supine or semi-erect position (head of bed at 30° elevation) and classified results as normal, pleural effusion, consolidation or AIS, corresponding to the suggested definitions of Loudon and Murphy,[18] as have been used in previous studies.[4] Anterior, lateral and posterior lung regions on either side were systematically examined, with each region divided into an upper and lower region. A normal Ex result was defined as the presence of vesicular breath sounds and the absence of any adventitious sounds. Pleural effusion was defined as the absence of normal vesicular breath sounds.

We asked the clinical examiner to estimate whether the pleural effusion was small, moderate or large, and this was largely subjective, based on the examiner's experience. The examiner also recorded the number of regions in which clinical signs were elucidated. Alveolar consolidation was identified by bronchial breath sounds, and AIS was identified by inspiratory crepitations or crackles. Fine crackles and coarse crackles were interpreted as low-severity and high-severity AIS, respectively. All modalities of assessment were completed as soon as practical, and always within 12 hours of each other.

Statistical analysis

We used SPSS Statistics, version 20 (IBM) for our statistical analysis. We collected all data in an ordinal format and tested measures of agreement using kappa analysis. When data were non-dichotomous, we used the weighted kappa statistic. Differences in the dichotomous data were analysed with McNemar analysis, using $P < 0.05$ to indicate statistical significance. The Wilcoxon rank–sum test was used to compare differences in non-dichotomous data. We used a Bonferroni adjustment for the three-way comparison, hence $P = 0.017$ was used as the cut-off in determining statistical significance.

Results

Normal v abnormal

A total of 870 lung regions were examined by LUS, CXR and Ex. Out of 145 patients, LUS identified 125 patients (86%) with some abnormality. Similarly, CXR identified 120 patients (83%) with an abnormality, and Ex identified 84 patients (60%) with an abnormality. CXR and LUS agreed 65% of the time that an abnormality was present; CXR and Ex 70% of the time, and LUS and Ex 61% of the time. Table 1 outlines the performance of each of the diagnostic modalities as a three-way comparison of each of their abilities in detecting an abnormality (pleural effusion, consolidation or AIS). Each of CXR, LUS and Ex showed fair agreement with each other, but LUS detected more

Table 1. Comparison of lung ultrasound, chest x-ray and physical examination for detecting any abnormality in critically ill patients

	Abnormality detected (*n*)			Statistic used	
Abnormality detected	No	Yes	Total	κ (*P*)	χ^2 (*P*)
CXR		LUS			
No	354	221	575		
Yes	80	215	295		
Total	434	436	870	0.31 (< 0.001)	64.1 (< 0.001)
CXR		Examination			
No	475	100	575		
Yes	163	132	295		
Total	638	232	870	0.29 (< 0.001)	14.6 (< 0.001)
LUS		Examination			
No	367	67	434		
Yes	271	165	436		
Total	638	232	870	0.22 (< 0.001)	121.9 (< 0.001)

CXR = chest x-ray. LUS = lung ultrasound. κ = kappa statistic. χ^2 = McNemar test statistic.

Table 2. Comparison of lung ultrasound, chest x-ray and physical examination for detecting pleural effusion in critically ill patients

	PE detected (*n*)			Statistic used	
PE detected	No	Yes	Total	κ (*P*)	χ^2 (*P*)
CXR		LUS			
No	94	31	125		
Yes	58	107	165		
Total	152	138	290	0.39 (< 0.001)	7.6 (0.006)
CXR		Examination			
No	106	19	125		
Yes	112	53	165		
Total	218	72	290	0.16 (< 0.001)	64.6 (< 0.001)
LUS		Examination			
No	127	25	152		
Yes	91	47	138		
Total	218	72	290	0.18 (< 0.001)	36.4 (<0.001)

PE = pleural effusion. CXR = chest x-ray. LUS = lung ultrasound. κ = kappa statistic. χ^2 = McNemar test statistic.

abnormalities than CXR (436 v 295), which in turn detected more abnormalities than Ex (295 v 232). The difference in the percentage of lung regions that had abnormalities detected by LUS compared with CXR was 16.2% (95% CI, 12.5%–20%). The corresponding values for CXR v Ex and LUS v Ex were 7.2% (95% CI, 3.6%–10.9%) and 23.5% (95% CI, 19.6%–27.3%), respectively.

Pleural effusion

We examined 290 lung regions for pleural effusion (bilateral basal regions in each of 145 patients). Of the 145 patients, LUS identified 98 patients (68%), CXR identified 104 patients (72%) and Ex identified 48 patients (33%) with pleural effusion. LUS and CXR agreed in 69% of cases that a pleural effusion was present; CXR and Ex agreed in 55% of cases; and LUS agreed with Ex in 60% of cases (Table 2). CXR had moderate agreement with LUS and slight agreement with Ex findings. LUS had slight agreement with Ex findings. CXR was interpreted as positive for pleural effusion more often (165/290 regions) than each of LUS (138/290 regions) and Ex (138/290 regions). The difference in the percentage of lung regions identified as having effusion, as detected by CXR and LUS, was 9.3% (95% CI, 3%–15.6%). Similarly, for CXR v Ex, the proportion difference was 32% (95% CI, 25.3%–38.9%), and for LUS v Ex, the corresponding value was 22.8% (95% CI, 16%–29.6%).

LUS is considered equal to CT for diagnosis of pleural effusion and can be considered the gold standard. The diagnostic performance of CXR was calculated as: sensitivity, 0.76; specificity, 0.62; and diagnostic accuracy, 0.69. We determined the sensitivity of Ex to be 0.34; specificity, 0.84; and diagnostic accuracy, 0.60.

For quantifying the size of pleural effusion, exact agreement was achieved in 54% of cases between CXR and LUS; 49% of cases between CXR and Ex; and 52% of cases between LUS and Ex. There was moderate agreement between CXR and LUS, slight agreement between CXR and Ex, and slight agreement between LUS and Ex (Table 3). However, according to Wilcoxon rank–sum analysis, there was no significant difference between LUS and CXR in quantification of pleural effusions. Conversely, there was a significant difference in the quantification of pleural effusion between CXR and Ex, with Ex underestimating severity compared with CXR. Similarly, Ex underestimated size of pleural effusion when compared with LUS.

Lung consolidation

Of 145 patients examined, LUS identified 102 patients with lung consolidation (70%), CXR identified 38 patients (26%) and Ex identified 26 patients (18%). With examination for presence or absence of consolidation, there was agreement between LUS and CXR in 78% of cases, between CXR and Ex in 89% of cases, and between LUS and Ex in 75% of cases. There was only slight statistical agreement between each of the three modalities (Table 4). LUS detected more

Table 3. Comparison of lung ultrasound (LUS), chest x-ray (CXR) and physical examination (Ex) in quantifying the volume of pleural effusion (PE) in critically ill patients

		Volume of PE					Statistic used	
		Absent	Small	Medium	Large	Total	κ	Wilcoxon
Examination	Volume of PE	LUS						
CXR	Absent	94	25	4	2	125	0.35	LUS < CXR, 64
	Small	51	57	26	11	145	($P < 0.001$)	LUS > CXR, 70
	Medium	6	5	4	2	17		LUS = CXR, 156
	Large	1	0	1	1	3		Z = –1.2
	Total	152	87	35	16	290		$P = 0.23$
		Examination						
CXR	Absent	106	17	2	0	125	0.16	Ex < CXR, 116
	Small	100	33	11	1	145	($P = 0.001$)	Ex > CXR, 31
	Medium	11	4	2	0	17		Ex = CXR, 143
	Large	1	0	0	2	3		Z = –6.7
	Total	218	54	15	3	290		$P < 0.001$
		Examination						
LUS	Absent	127	20	4	1	152	0.18	Ex < LUS, 109
	Small	64	19	3	1	87	($P = 0.002$)	Ex > LUS, 29
	Medium	21	9	5	0	35		Ex = LUS, 152
	Large	6	6	3	1	16		Z = –6.6
	Total	218	54	15	3	290		$P = 0.001$

consolidation than either of CXR and Ex. Compared with LUS, differences in the proportion of the study population with positive results for CXR were 17% (95% CI, 14.2%–20%) and, for Ex, 16.2% (95% CI, 13.1%–19.3%). There was no significant difference between CXR and Ex in detecting consolidation, with a proportion difference of 0.9% (95% CI, –1.3% to 3.1%). Compared with LUS, the sensitivity of CXR was 0.17; specificity, 0.97; and diagnostic accuracy, 0.78. Compared with LUS, the sensitivity of Ex was calculated as 0.12; specificity, 0.94; and diagnostic accuracy, 0.75.

Alveolar interstitial syndrome

Of the 145 patients, 90 (62%) were identified as having AIS using LUS, 62 (43%) were identified with AIS using CXR, and 52 (36%) were identified with AIS using Ex. Analysis for the presence or absence of AIS showed that CXR agreed with LUS in 68% of cases and with Ex in 77% of cases. There was agreement between LUS and Ex in 67% of cases. Statistical agreement was slight, at best, between CXR and each of Ex and LUS, and there was no statistical agreement between LUS and Ex. LUS detected more cases of AIS than CXR (5.5%; 95% CI, 1.8%–9.3%) and Ex (13%; 95% CI, 8.1%–17.8%). CXR was shown to detect more AIS than Ex (4.5%; 95% CI, 1.3%–7.7%). Table 5 shows these comparisons.

Absolute agreement between LUS and CXR in quantifying the severity of AIS was 65%. The corresponding value for comparison of CXR with Ex was 73%, and for LUS with Ex was 65%. Again, statistical agreement was only slight. Ex underestimated the severity of AIS compared with CXR and LUS; although CXR tended to underestimate AIS severity when compared with LUS, the difference was not significant (Table 6). The sensitivity of CXR was calculated as 0.25; specificity, 0.82; and diagnostic accuracy, 0.68. The sensitivity of Ex was calculated as 0.14; specificity, 0.85; and diagnostic accuracy, 0.67.

Discussion

We compared findings from bedside LUS, portable CXR and Ex in critically ill adult patients undergoing a transthoracic echocardiogram. We measured the ability of LUS, CXR and Ex to detect pleural effusion, lung consolidation and AIS. LUS detected substantially more abnormalities than CXR or Ex. Agreements between CXR and LUS, and between CXR and Ex, were fair at best. The numbers of abnormalities detected by CXR and Ex were more comparable. Given that there were consistently more abnormalities detected by LUS, our data suggest that the cases in which LUS and CXR are in agreement are different from the cases in which CXR and Ex are in agreement, which further highlights the potential

Table 4. Comparison of lung ultrasound, chest x-ray and physical examination in assessing the presence or absence of lung consolidation in critically ill patients

	Consolidation detected (*n*)			Statistic used	
Consolidation detected	No	Yes	Total	κ (*P*)	χ^2 (*P*)
CXR		LUS			
No	646	169	815		
Yes	20	35	55		
Total	666	204	870	0.19 (< 0.001)	115.9 (< 0.001)
CXR		Examination			
No	763	52	815		
Yes	44	11	55		
Total	807	63	870	0.13 (< 0.001)	0.51 (0.48)
LUS		Examination			
No	628	38	666		
Yes	179	25	204		
Total	807	63	870	0.09 (0.002)	90.3 (< 0.001)

CXR = chest x-ray. LUS = lung ultrasound. κ = kappa statistic. χ^2 = McNemar test statistic.

Table 5. Comparison of lung ultrasound, chest x-ray and physical examination in assessing the presence or absence of alveolar interstitial syndrome in critically ill patients

	AIS detected (*n*)			Statistic used	
AIS detected	No	Yes	Total	κ (*P*)	χ^2 (*P*)
CXR		LUS			
No	538	163	701		
Yes	115	54	169		
Total	653	217	870	0.01 (0.019)	7.9 (0.005)
CXR		Examination			
No	619	82	701		
Yes	121	48	169		
Total	740	130	870	0.18 (< 0.001)	7.1 (0.008)
LUS		Examination			
No	553	100	653		
Yes	187	30	217		
Total	740	130	870	–0.02 (0.6)	25.8 (< 0.001)

AIS = alveolar interstitial syndrome. CXR = chest x-ray. LUS = lung ultrasound. κ = kappa statistic. χ^2 = McNemar test statistic.

errors in interpretation of CXR images and Ex findings. It should be noted that although LUS detected substantially more abnormalities than CXR, the numbers of patients detected with an abnormality using these techniques were comparable (86% using LUS, and 83% using CXR). The likelihood that some patients had pathological changes in multiple lung regions may explain this. For example, a patient in whom four lung regions were identified as having pathological changes according to LUS, but only two lung regions were identified as having pathological changes according to CXR, would show that LUS would detect more abnormalities, on a lung-region basis, while CXR still identified the patient as having an abnormality.

Pleural effusions were detected using each of the three techniques explored in this study. We found significant association between LUS, CXR and Ex in the detection and quantification of pleural effusions. LUS and CXR had moderate agreement for detection and quantification of the size of pleural effusions. When the two imaging modalities were compared with Ex, agreement was substantially smaller. LUS detected considerably more pleural effusions than CXR or Ex, and we believe this reflects the previously reported accuracy and superiority of the technique.[4,19,20]

Lung consolidation was detected by LUS with much greater frequency than by CXR or Ex. This is shown in the absolute number of cases detected and supported by the large statistical differences we determined with the McNemar test (Table 4). Additionally, no difference was observed in the cases determined to be either positive or negative for lung consolidation using the CXR and Ex techniques.

Except for the slight agreement between CXR and Ex in detection of AIS, agreement between these techniques and LUS failed to reach a level beyond that due to chance alone. However, the McNemar test revealed there was a significant difference between the number of cases of AIS detected by LUS when compared with CXR and Ex. Quantification of AIS showed modest agreement between the techniques.

There have been several studies published that evaluate the performance of LUS against other diagnostic techniques.[19,21-29] Essentially, these studies have repeatedly shown that LUS has superior sensitivity and diagnostic accuracy in detecting various pulmonary pathological changes, compared with CXR. Lichtenstein and colleagues directly compared LUS with CXR, auscultation and the gold standard CT,[4] but this study was designed to look at only the techniques themselves; a single clinician examining all patients with auscultation, a single operator acquiring and interpreting all images by LUS, a single radiologist interpreting CT data and another radiologist interpreting plain CXR films. Furthermore, the patients included in the study had already been diagnosed with, and were being treated for, acute respiratory distress syndrome. It was a well designed study but did not necessarily reflect how

Table 6. Comparison of lung ultrasound, chest x-ray and physical examination in assessing the severity of alveolar interstitial syndrome in critically ill patients

		AIS severity (*n*)				Statistic used	
		Nil	Low	High	Total	κ (*P*)	Wilcoxon
Examination	AIS level	LUS					
CXR	Nil	538	50	65	653	0.07	CXR < LUS, 178
	Low	81	16	9	106	(0.012)	CXR > LUS, 124
	High	82	15	14	111		CXR = LUS, 568
	Total	701	81	88	870		Z = –2.3
							P = 0.021
CXR		Examination					
	Nil	619	51	70	740	0.14	CXR < Ex, 99
	Low	38	13	12	63	(< 0.001)	CXR > Ex, 133
	High	44	17	6	67		CXR = Ex, 638
	Total	701	81	88	870		Z = –2.5
							P = 0.011
LUS		Examination					
	Nil	553	94	93	740	–0.015	LUS < Ex, 109
	Low	50	3	10	63	(0.301)	LUS > Ex, 197
	High	50	8	8	67		LUS = Ex 564
	Total	653	106	111	870		Z = –4.6
							P < 0.001

AIS = alveolar interstitial syndrome. CXR = chest x-ray. LUS = lung ultrasound. κ = kappa statistic. χ^2 = McNemar test statistic.

patients are assessed in an ICU. Typically, multiple clinicians are involved in patient assessment and interpretation of diagnostic imaging. It would therefore be useful to see how LUS, CXR and Ex agree with each other in daily practice. In other words, how well do the three diagnostic methods agree with each other given that, in reality, interobserver variability is not excluded?

Our study did not make use of the gold standard CT technique, so agreement or disagreement between LUS, CXR and Ex can only be used as measures of consistency. However, Lichtenstein and colleagues have shown LUS to perform extremely well when compared with CT in detecting effusion, consolidation and AIS.[4] Therefore, if one were to use LUS as a surrogate standard for each of these pathological states, it can be shown that the LUS technique outperforms both CXR and Ex.

A possible explanation may come from an understanding of the differences between the three pathological conditions examined in our study. Pleural effusion, lung consolidation and AIS all involve excess extravascular fluid within the chest cavity, and a factor to consider is the distribution of that fluid. Hence, it makes sense to define a ratio of volume:volume-of-distribution. In an appropriately positioned patient, the volume of fluid in pleural effusion accumulates in the most dependent space in the pleural cavity. AIS and lung consolidation involve excess extravascular fluid within the lung tissue. It can be argued that, in AIS, this extra fluid is distributed over a wider area, meaning its appearance on CXR is less defined. In AIS, adventitious sounds heard on auscultation are also less defined and more likely to be masked by noises from a mechanical ventilator. Furthermore, the position of a patient may influence clinical signs of excess extravascular fluid. In pleural effusion, changes in the position of a patient will influence the regions in which clinical signs of excess fluid may be detected, as the fluid shifts with repositioning.[30] It was partly for this reason that we tried to maintain a consistent patient position for evaluation of respiratory pathological conditions.

Gazon and colleagues have also performed an agreement analysis, comparing detection of each of the above pathological conditions with CXR and LUS.[28] In their study of 50 patients, they performed independent interpretation of the LUS and CXR images. Only moderate agreement between the two examination modalities was observed, similar to our findings. The selection criteria for Gazon and colleagues' study included any patient whose clinical examination warranted further exploration for lung disease. Based on their screening, we would expect the prevalence of lung abnormality to be higher than in randomly selected patients, as was the case for our patients.

For the elements of Gazon and colleagues' study that parallel ours (ie, CXR v LUS), the determined measure of agreement (kappa) is comparable to that of our study for overall abnormality detection of CXR v LUS (0.42 v 0.31), pleural effusion (0.46 v 0.39) and alveolar consolidation (0.24 v 0.19); but kappa is not comparable for AIS (0.49 v 0.01). This can be readily explained by the effect of prevalence on the determination of kappa.

In the absence of a gold standard of reference, our data, and those of Gazon and colleagues, rely on the observed marginal total values of the contingency tables. These may serve as surrogates for prevalence.[31] The observed marginal total affects kappa in much the same way as prevalence affects positive predictive values.[31] Our observed marginal frequencies for each of total abnormalities, pleural effusion and alveolar consolidation were comparable, but for AIS they were not. In the population we studied, AIS is a less common occurrence than in the population studied by Gazon and colleagues (98/200 patients were AIS-positive using LUS in their study, compared with 217/870 AIS-positive patients using LUS in our study).

Our study was affected by several limitations, the largest of which was the lack of comparison with CT imaging, regarded as the gold standard. We found that the number of patients who also had CT imaging (independently of our study) would not have contributed enough to our data for our population studied. Similar to the work of Lichtenstein and colleagues,[4] inclusion of comparison with CT imaging would have allowed us to derive sensitivity and specificity data. That data would have allowed us to more objectively compare the performance of the three other diagnostic modalities. However, as discussed above, CT has disadvantages that preclude its more routine use, and it is instructive to know how consistently CXR, LUS and Ex agree with each other in the diagnostic assessment of a patient. Given the already high sensitivity and specificity of LUS for many lung conditions (including those dealt with here), our current data show that LUS largely outperforms CXR and Ex in detecting and quantifying the severity of some of the more common pulmonary conditions that occur in the ICU.

Conclusion

LUS has a growing reputation for being a highly sensitive and specific diagnostic test for pulmonary conditions in hospitalised patients, including the critically ill. Our study shows the real-world performance of LUS compared with bedside CXR and Ex. The ability of LUS to detect more abnormalities than the other two techniques makes it an attractive diagnostic tool for the treating physician. Future studies on interobserver variability of CXR, Ex and LUS would further aid in comparing how well each technique performs in diagnostic evaluation of critically ill patients in daily practice.

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Competing interests

None declared.

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