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A Pilot Assessment of 3 Point-of-Care Strategies for Diagnosis of Perioperative Lung Pathology

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BACKGROUND: Lung ultrasonography is superior to clinical examination and chest X-ray (CXR) in diagnosis of acute respiratory pathology in the emergency and critical care setting and after cardiothoracic surgery in intensive care. Lung ultrasound may be useful before cardiothoracic surgery and after discharge from intensive care, but the proportion of significant respiratory pathology in this setting is unknown and may be too low to justify its routine use. The aim of this study was to determine the proportion of clinically significant respiratory pathology detectable with CXR, clinical examination, and lung ultrasound in patients on the ward before and after cardiothoracic surgery.
METHODS: In this prospective observational study, patients undergoing elective cardiothoracic surgery who received a CXR as part of standard care preoperatively or after discharge from the intensive care unit received a standardized clinical assessment and then a lung ultrasound examination within 24 hours of the CXR by 2 clinicians. The incidence of collapse/atelectasis, consolidation, alveolar-interstitial syndrome, pleural effusion, and pneumothorax were compared between clinical examination, CXR, and lung ultrasound (reference method) based on predefined diagnostic criteria in 3 zones of each lung.
RESULTS: In 78 participants included, presence of any pathology was detected in 56% of the cohort by lung ultrasound; 24% preoperatively and 94% postoperatively. With lung ultrasound as a reference, the sensitivity of the 5 different pathologies ranged from 7% to 69% (CXR), 7% to 76% (clinical examination), and 14% to 94% (combined); the specificity of the 5 different pathologies ranged from 91% to 98% (CXR), from 90% to 99% (clinical examination), and from 82% to 97% (combined). For clinical examination and lung ultrasound, intraobserver agreements beyond chance ranged from 0.28 to 0.70 and from 0.84 to 0.97, respectively. The agreements beyond chance of pathologic diagnoses between modalities ranged from 0.11 to 0.64 (CXR and lung ultrasound), from 0.08 to 0.7 (CXR and lung ultrasound), and from 0 to 0.58 (clinical examination and CXR).
CONCLUSIONS: Clinically important respiratory pathology is detectable by lung ultrasound in a substantial number of noncritically ill, pre or postoperative cardiothoracic surgery participants with high estimate of interobserver agreement beyond that expected by chance, and we showed clinically significant diagnoses may be missed by the contemporary practice of clinical examination and CXR. (Anesth Analg 2017;124:734–42)

Lung ultrasonography is an emerging tool in emergency and critical care medicine to guide decision-making in real time. In broad terms, lung ultrasound is performed by the treating physician at the time and place of the clinical assessment and often is limited in scope, being confined to an assessment relevant to the clinical situation.[1] Thereby, lung ultrasound can provide a rapid, noninvasive assessment of the respiratory state without exposing patient or staff to ionizing radiation and without requiring transportation of the patient.[1–3]

In critical care, the use of lung ultrasound has been shown to decrease the number of chest X-rays (CXRs) and computed tomography (CT) scans, reducing radiation exposure as well as the cost of care,[4] and despite percussion note and auscultation forming key components of clinical examination, poor reliability has been described.[5,6] Generally, the diagnostic performance of lung ultrasound has been shown to approach CT scans and to be superior to clinical examination and CXR.[7] Nevertheless, in perioperative care, clinical examination and CXR have remained the modalities of choice for routine assessment of respiratory pathology, although missed pathology can result in poor outcomes and delayed recovery.[2] Importantly, however, because these patients are rarely in a critical state, the proportion of clinically meaningful respiratory pathology may be too low to justify the cost of implementing lung ultrasound into routine clinical practice.

Therefore, the primary aim of this prospective observational study was to assess the proportion of clinically important respiratory pathology detectable with CXR, clinical examination, and lung ultrasound in patients undergoing cardiac surgery. Secondary end points included the evaluation of the sensitivity and specificity of CXR and clinical

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examination of clinically significant respiratory pathology compared with lung ultrasound as the reference method.

METHODS

The local institutional ethical review board from the Melbourne Health Human Research Ethics Committee approved the study, which conforms to the ethical guidelines of the 1975 Declaration of Helsinki. Written informed consent was obtained from all patients. This manuscript adheres to the applicable Equator guidelines.

Design and Study Participants

In a prospective, observational pilot study, patients were enrolled at the Royal Melbourne Hospital, Melbourne, Australia. The study was conducted as a pilot study to evaluate feasibility before performance of a full-scaled, randomized trial to investigate whether lung ultrasound can improve clinical outcomes. Inclusion criteria were patients aged 18 years or older undergoing cardiac or thoracic surgery who received a CXR as part of standard care either preoperatively or postoperatively after discharge from the intensive care unit. Clinical examination and lung ultrasound were performed after and within 24 hours of the CXR.

Within 24 hours of the CXR, a standardized focused clinical examination and a lung ultrasound examination were performed by 2 independent observers. With respect to lung ultrasound, the observers were novice examiners with approximately 25 hours of training experience, but, if necessary, the scan was reviewed by an expert as per the observer's discretion. Observers were blinded to all radiologic findings but otherwise aware of the patient's previous medical history.

For comparison between ultrasound and clinical assessment, the lung was divided into 3 anatomical zones: (1) the anterior zone, defined by the sternum anteriorly and the mid-axillary line posteriorly; (2) the upper posterior zone, defined by the mid-axillary line anteriorly, the spinous processes of the thoracic spine posteriorly, and the inferior tip of the scapular inferiorly; and (3) the lower posterior zone, defined by the mid-axillary line anteriorly, the spinous processes of the thoracic spine posteriorly, and the inferior tip of the scapula superiorly.[8] On CXR, the lung was divided into 2 anatomical zones: an upper and a lower zone defined by the reporting radiologist.

Five common pathological entities were explored for each of the 3 methods: (1) collapse/atelectasis, (2) consolidation, (3) alveolar-interstitial syndrome, (4) pleural effusion, and (5) pneumothorax. The definitions for these are explained in the sections to follow.

Chest X-Ray

A CXR was performed only when ordered by the treating team in accordance with therapeutic local guidelines. The examinations were either erect posterior-anterior and lateral studies, or supine, semi-erect or erect anterior-posterior mobile studies for patients unable to be transported to the radiology department.

The consult radiologist was blinded to any lung ultrasound findings, and the results were reported electronically. Findings suggestive of pulmonary edema or interstitial disease were recorded as alveolar-interstitial syndrome, and if pleural effusion was reported, its corresponding size estimation was recorded as small, moderate, or large. The terminology used in reports was interpreted using the recommendations made by the Nomenclature Committee of the Fleischner Society.[9]

Clinical Examination

A comprehensive clinical examination, which followed standard local protocols and teaching, was performed in a systematic manner, and comprised inspection, percussion, and auscultation. The patient was examined in a seated position, and the examination was performed on all 3 anatomical zones as defined previously. Results for each observer were recorded on a standardized form.

A normal lung was defined as standard percussion note, vesicular breath sounds, no added sounds, and normal vocal resonance in the and absence of any of the 4 specified lung pathologies: *Collapse/atelectasis* was defined as a dulled percussion note, absent or reduced breath sounds, no added sounds, and decreased or increased vocal resonance. *Consolidation* was defined as a dulled percussion note, bronchial breath sounds, presence of crackles, and increased vocal resonance. *Alveolar-interstitial syndrome* was defined as the presence of fine pan-inspiratory crackles. *Pleural effusion* was defined as stony dulled percussion note and absent breath sounds over the effusion. Additional supporting signs included bronchial breathing at upper border of effusion, possible pleural rub, and reduced vocal resonance. When detected, the size of the effusion was estimated based on the clinical reasoning and categorized as small, moderate, or large. *Pneumothorax* was defined as hyper-resonant percussion note, absent or reduced breath sounds, no added sounds, and decreased vocal resonance.

Lung Ultrasound

A lung ultrasound was performed immediately after the clinical examination with a Sonosite X-PORTE portable ultrasound device (Fujifilm, Bothell, WA), with a 1–5 MHz transthoracic and a 6–13 MHz linear array of transducers. The procedure was standardized and followed the iLungScan protocol as established by The University of Melbourne, Ultrasound Education Group.[10] Patients were in a supine position for the examination, which was performed on all 3 anatomical zones. All images were stored and the results for each observer were recorded on a standardized form. See online complemental digital content for example of a lung ultrasound examination (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Supine+lungscan.mp4) (video is reproduced with permission of the University of Melbourne).

A normal lung pattern was identified by the presence of normal lung sliding or lung pulse, reverberation artifacts from the pleura, and absence of any of the following pathologies (Figure 1)[8]: Collapse or atelectasis pattern was defined as a loss of lung volume, increased tissue density, and hyperechoic static air bronchograms.[11] Consolidation was defined as a tissue-like pattern or "hepatization" with minimal volume loss and the presence of dynamic

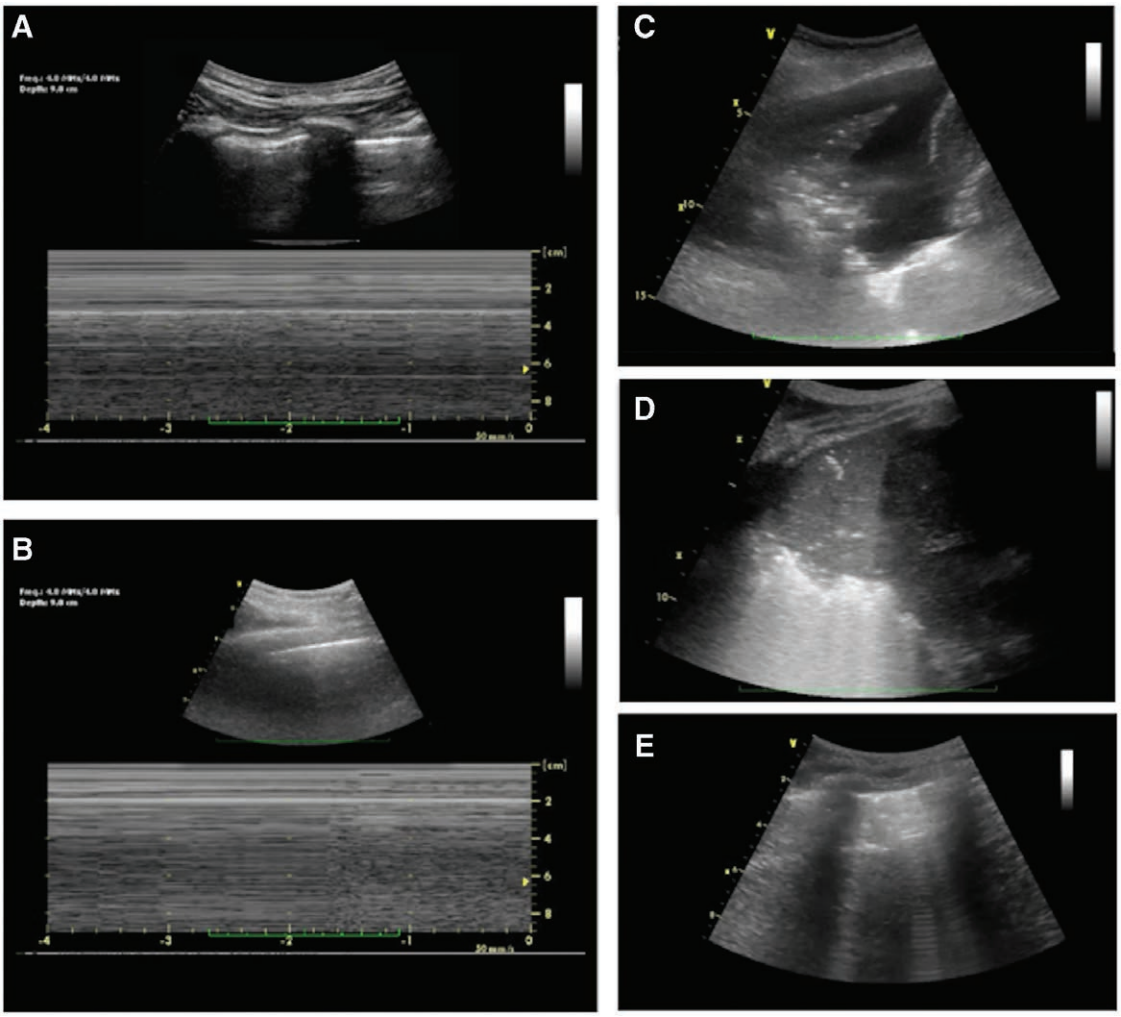

Figure 1. Ultrasound images of normal lung and the defined respiratory pathology. A, 2-dimensional (2D) image (top) and M-mode image (bottom) showing a normal lung pattern. The 2D image shows the main hallmarks, including ribs and reverberation artifacts from the pleura, whereas the M-mode image illustrates lung sliding. B, 2D image (top) and M-mode image (bottom) showing a pneumothorax. Both images show normal lung pattern to the left and absence of lung sliding and lung pulse to the right. C, 2D image showing and hypoechoic pleural effusion with collapsed/atelectatic lung pattern with increased tissue density and hyperechoic static air bronchograms. D, 2D image showing consolidation with tissue-like pattern and dynamic air bronchograms. E, 2D image demonstrating alveolar-interstitial syndrome with hyperechoic, vertical artifacts arising from the pleural line and reaching the bottom of the screen without fading (B-lines).
See online complemental digital content for examples of normal lung sliding (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Lung+sliding.mp4), pneumothorax (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/No+lung+sliding.mp4), pleural effusion (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Pleural+effusion+2.mov), and B-lines (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/B-lines.mp4). All videos are reproduced with permission of the University of Melbourne.

air bronchograms in affected lung.[2,12] Alveolar-interstitial syndrome was defined as 3 or more B-lines in a single rib space.[2,13] B-lines were defined strictly as hyperechoic, vertical artifacts arising from the pleural line and reaching the bottom of the screen without fading. In addition, B-lines should move with lung sliding and lung pulse, ablate reverberation artifacts from the pleura, but while typically laser-like in appearance, multiple B-lines can coalesce.[14] Pleural effusion was defined as an anechoic space between the parietal and visceral pleura with movement with the respiratory cycle (sinusoid sign).[2,7,15] When detected, the volume in milliliters (mL) of a nonloculated pleural effusion was estimated by measuring the maximal perpendicular intrapleural distance in centimeters and multiplying this by 200 mL/cm.[16] Pneumothorax was defined as the absence of lung sliding and lung pulse.[2,13,17] For confirmation of the absence, the linear array probe was used to obtain a high-resolution view of the parietal and visceral pleura.[18]

Outcomes

The primary end point was the incidence of clinically important respiratory pathology detectable by CXR, clinical examination, and lung ultrasound in patients undergoing cardiothoracic surgery. Secondary end points included the sensitivity and specificity of CXR and clinical examination compared with lung ultrasound as the reference method.

Statistical Analyses

Continuous data are presented as mean ± SD, and binary data are presented as percentages of patients or lung zones.

The proportion of patients with respiratory pathology was compared with an expected level of 20% of patients via a χ^2 test. Sensitivity and specificity are both presented as percentages with 95% confidence intervals (binomial exact). To assess estimates of agreement between the 3 modalities beyond that expected by chance, and to assess interobserver agreements beyond chance for clinical examination and lung ultrasound, Cohen's kappa (k) statistics was used. Values of $k < 0.20$ indicated poor strength of agreement, $k = 0.21$–0.4 fair strength of agreement, $k = 0.41$–0.60 moderate strength of agreement, $k = 0.61$–0.80 good strength of agreement, and $k = 0.81$–1.0 very good strength of agreement. P-values <.05 were considered statistically significant on our primary outcome, whereas only P-values <.01 were considered statistically significant on our secondary end points to adjust for multiple comparisons, all P-values are 2-sided.

We included a convenience sample of patients with no previous sample size calculation, wherefore the sample size was determined by the number of patients eligible within the inclusion period. With the given sample size of 78 patients, a significance level of 5%, and a statistical power of 90%, we were able to detect a 16% greater proportion of patients with respiratory pathology than our expected proportion of 20% of patients. Descriptive data were stored in Microsoft Excel 2016 (Microsoft Corp., Redmond, CA) and for statistical analyses we used Stata/IC 12.1 for Mac (Stata Corp., College Station, TX).

RESULTS

We included a total of 78 patients in the period from March to May 2015, of which 42 patients were preoperative and 36 patients were postoperative on the ward. The mean age was 62 ± 16 years, 82% were male, and the surgical procedures were as follows: coronary artery bypass graft surgery (40%), video-assisted thoracoscopic surgery (28%), valve replacement (17%), combined coronary artery bypass graft surgery and valve replacement (6%), and other (9%). A total of 468 lung zones were examined during the course of the study.

Respiratory Pathology Detected

Respiratory pathology was detected by lung ultrasound in 56% of the cohort; preoperatively 24% of the patients had pathology and postoperatively on the ward 94% had pathology. The proportion of patients with respiratory pathology (56%) was greater than the proportion expected (20%), $P < .01$. Pleural effusion was the most commonly detected pathology in preoperative as well as postoperative patients. There was no difference between cardiac and thoracic surgical patients in terms of pathology detected, neither the overall proportion of pathology nor any of the 5 different pathologies.

The proportions of defined respiratory pathology detected by CXR, clinical examination, and lung ultrasound in each lung zone are displayed in Table 1. Not surprisingly, respiratory pathology was not distributed uniformly within the lung; collapse, consolidation, alveolar interstitial syndrome, and pleural effusion were found at much greater rates in the lower zones of the chest, in comparison with upper zones of the chest. In contrast, pneumothorax was found more frequently in the upper zones of the lungs compared with the lower zones.

Diagnostic Performance of CXR and Clinical Examination

Sensitivity and specificity of CXR and clinical examination with lung ultrasound as the reference method are summarized in Table 2. Sensitivity of the different pathologies ranged from 7% to 69% (CXR), 7%–76% (clinical examination), and 14%–94% (combined). For both modalities as well as the combination, sensitivity was lowest in the detection of alveolar-interstitial syndrome and highest in detecting pleural effusion. The specificity of the different pathologies ranged from 91% to 98% (CXR), from 90% to 99% (clinical examination), and from 82% to 97% (combined).

Interobserver agreements beyond chance of clinical examination and lung ultrasound are displayed in Table 3, including observed and expected agreements. As seen, the agreement beyond chance of clinical examination ranged from 0.28 to 0.70, whereas agreements beyond chance were much greater when it came to lung ultrasound ranging from 0.84 to 0.97. In both modalities, there were statistically significant relationships between the observers for all the pathologies and in both modalities, consolidation had the lowest agreement beyond chance and collapse/atelectasis had the highest.

A description of patients in which pathology was missed by CXR and clinical examination by each of the 2 observers is displayed in Table 4. The greatest number of patients with no additional pathology was described in terms of alveolar-interstitial syndrome; the pathology with lowest sensitivity in both modalities. In terms of pleural effusion, the pathology with highest sensitivity in both modalities, the lowest number of patients with no additional pathology was found. Of the patients with pleural effusion missed by CXR, all had additional collapse/atelectasis, and of the patients with pleural effusion missed by clinical examination, all except one had additional collapse/atelectasis detected by ultrasound.

Agreements beyond chance between the 3 modalities are displayed in Table 5, including observed and expected agreements. The agreements beyond chance of pathologic diagnoses between CXR and lung ultrasound ranged from 0.11 to 0.64 across the 5 pathologies and 2 observers, whereas agreements beyond chance of pathologic diagnoses between clinical examination and lung ultrasound ranged from 0.08 to 0.71. Between clinical examination and CRX agreements, beyond chance of pathologic diagnoses ranged from 0 to 0.58, and there was no statistically significant agreement beyond chance of diagnosis of consolidation or alveolar-interstitial syndrome. All the remaining agreements beyond chance were statistically significant.

The categorization of pleural effusion size by CXR and clinical examination was compared with the calculated volume from lung ultrasound. In terms of CXR, effusions categorized as small had a mean volume of 362 mL for observer I and 329 mL for observer II, effusions categorized as moderate had a mean volume of 714 mL for observer I and 779 mL for observer II, and effusions categorized as large had a mean volume of 938 mL for observer I and 890 mL for observer II. Likewise, in terms of clinical examination, effusions categorized as small had a mean volume of 400 mL for observer I and 420 mL for observer II, according to lung ultrasound quantification; the effusions categorized as

Table 1. Overview of Pathology Detected by Chest X-Ray, Clinical Examination, and Lung Ultrasound for Each Lung Zone

Pathology	Chest X-Ray (%)	Clinical Examination (%)	Chest X-Ray and Clinical Examination (%)	Lung Ultrasound (%)
Left upper zone (n = 78)				
Normal	95	92	90	88
Collapse/atelectasis	1	1	3	3
Consolidation	0	2	3	1
Alveolar-interstitial syndrome	0	2	3	8
Pleural effusion	0	2	3	3
Pneumothorax	4	1	5	1
Left lower zone (n = 78)				
Normal	59	63	54	56
Collapse/atelectasis	17	28	35	39
Consolidation	18	3	21	10
Alveolar-interstitial syndrome	3	2	5	6
Pleural effusion	27	28	38	30
Pneumothorax	1	0	1	1
Left anterior zone (n = 78)				
Normal	–	99	–	92
Collapse/atelectasis	–	0	–	0
Consolidation	–	0	–	0
Alveolar-interstitial syndrome	–	1	–	4
Pleural effusion	–	0	–	2
Pneumothorax	–	1	–	3
Right upper zone (n = 78)				
Normal	95	97	92	92
Collapse/atelectasis	0	0	0	0
Consolidation	0	1	1	0
Alveolar-interstitial syndrome	0	2	3	4
Pleural effusion	0	1	1	0
Pneumothorax	5	0	5	4
Right lower zone (n = 78)				
Normal	68	63	55	56
Collapse/atelectasis	15	24	29	37
Consolidation	9	3	12	15
Alveolar-interstitial syndrome	3	2	5	8
Pleural effusion	22	24	32	27
Pneumothorax	0	0	0	1
Right anterior zone (n = 78)				
Normal	–	98	–	88
Collapse/atelectasis	–	0	–	0
Consolidation	–	1	–	0
Alveolar-interstitial syndrome	–	1	–	5
Pleural effusion	–	1	–	0
Pneumothorax	–	0	–	8

Data presented as percentages of patients and reported as means between the 2 observers.
–, pathology not detectable in the respective lung zone.

moderate had a mean volume of 414 mL for observer I and 713 mL for observer II; and effusions categorized as large had a mean volume of 1152 mL for observer I and 1480 mL for observer II.

DISCUSSION

In this prospective, observational pilot study, we demonstrated a high proportion of clinically important respiratory pathology in noncritically ill patients before and after cardiothoracic surgery, with the majority occurring after surgery. Furthermore, we showed that the conventionally used assessment tools, clinical examination, CXR, and the combination of the two, have poor diagnostic performances, whereas lung ultrasound, in contrast, had high estimate of interobserver agreement beyond that expected by chance even in novice examiners. Routine use of lung ultrasound in these settings may result in fewer missed diagnosis of clinically important respiratory pathology. Because missed pathology may lead to poor clinical outcome, our results suggest that lung ultrasound may become an important part of the perioperative assessment in the future. Importantly, this study suggests the need for randomized, controlled trials to determine whether lung ultrasound can change diagnoses and improve clinical outcomes.

In emergency and critical care medicine, numerous studies have investigated the comparative diagnostic performance of lung ultrasound[3,7,19] and, consistently, lung ultrasound is reported to be more sensitive and more specific in the detection of common respiratory pathology including consolidation,[7,12] pleural effusion,[20,21] alveolar-interstitial syndrome,[22,23] and pneumothorax[18] than conventional CXR. Although CT scan is indeed the gold standard, we, therefore, established lung ultrasound as the reference method to evaluate whether the proportion of clinically

Table 2. Sensitivity and Specificity of Chest X-Ray and Clinical Examination in Patients With Pathology Detected by Lung Ultrasound

Pathology	Modality	Sensitivity (95% CI)	Specificity (95% CI)
Collapse/atelectasis		(n = 35)	(n = 43)
	Chest X-ray	43 (26–61)	91 (79–98)
	Clinical examination	63 (45–78)	92 (81–98)
	Combined	71 (54–85)	89 (86–96)
Consolidation		(n = 13)	(n = 65)
	Chest X-ray	37 (13–66)	84 (75–93)
	Clinical examination	15 (2–45)	96 (89–100)
	Combined	52 (24–79)	82 (71–91)
Alveolar-interstitial syndrome		(n = 14)	(n = 64)
	Chest X-ray	7 (0–34)	98 (92–100)
	Clinical examination	7 (1–33)	98 (91–100)
	Combined	14 (3–42)	97 (90–100)
Pleural effusion		(n = 32)	(n = 46)
	Chest X-ray	69 (50–84)	91 (80–98)
	Clinical examination	78 (60–91)	90 (80–97)
	Combined	94 (79–99)	86 (75–95)
Pneumothorax		(n = 8)	(n = 70)
	Chest X-ray	29 (5–68)	94 (86–98)
	Clinical examination	6 (0–42)	99 (94–100)
	Combined	33 (8–72)	93 (86–98)

Data presented as percentages with 95% confidence intervals and reported as means between the 2 observers.
Abbreviation: CI, confidence interval.

Table 3. Estimates of Interobserver Agreement Between Clinical Examination and Lung Ultrasound Beyond That Expected by Chance

		Collapse/ Atelectasis	Consolidation	Alveolar-Interstitial Syndrome	Pleural Effusion	Pneumothorax
Clinical examination	Observed agreement	0.86	0.94	0.94	0.84	0.98
	Expected agreement	0.57	0.90	0.94	0.54	0.98
	Cohen's kappa	0.70	0.28	–	0.68	–
	(95% confidence interval)	(0.58–0.82)	(0.0–0.59)		(0.56–0.80)	
		$P < .0005$	$P < .0005$		$P < .0005$	
Lung ultrasound	Observed agreement	1.00	0.96	0.98	1.00	0.99
	Expected agreement	0.51	0.72	0.71	0.52	0.81
	Cohen's kappa	0.97	0.84	0.92	0.94	0.93
	(95% confidence interval)	(0.94–1.0)	(0.72–0.96)	(0.84–1.0)	(0.89–0.99)	(0.83–1.0)
		$P < 0.001$	$P < .001$	$P < .001$	$P < .001$	$P < .001$

Data presented as observed agreements, expected agreements, and Cohen's kappa coefficients reported with 95% confidence intervals and corresponding *P* values.
–, not calculated as observer II did not detect alveolar-interstitial syndrome or pneumothorax in any lung zones.

significant respiratory pathology in patients undergoing cardiothoracic surgery can justify the cost of implementing lung ultrasound into clinical practice, including training, equipment, and quality assurance. We found that clinically important respiratory pathology was detected in more than one quarter of cardiothoracic surgery patients before surgery and in almost all patients after surgery. Furthermore, in a substantial proportion of patients, respiratory pathology was not detected with CXR or clinical assessment, which could lead to poor outcome if left undiagnosed.

The most commonly detected pathology with lung ultrasound in this study was collapse/atelectasis, which was frequently missed by CXR, clinical examination, and the two in combination; a condition that has different etiology and management to consolidation. This is not surprising in the context of cardiac surgery, whereby there is a major chest incision, postoperative pain and reduced tidal volume, use of cardiopulmonary bypass, and frequently compromised cardiac function. Importantly, although most literature does not explicitly report collapse as a separate entity to consolidation, ultrasound enables successful differentiation of the 2 conditions.[11] The low sensitivity of CXR and clinical examination for atelectasis may be due to the detected collapse/atelectasis almost consistently being accompanied by a pleural effusion as it was demonstrated, which makes the diagnosis difficult by clinical examination. After cardiac surgery a radiologist may have an innate bias to report the pleural effusion and to ignore atelectasis. For consolidation, sensitivities of CXR and clinical examination were even lower than that of atelectasis, and the interobserver agreement beyond chance of clinical examination was poor. Consolidation was accompanied uniformly by pleural effusion. Notably, although our study included percussion and vocal resonance in the diagnostic criteria, and not only bronchial breathing, the low sensitivity of clinical examination is consistent with previous findings.[7,19]

Our data on the diagnostic performance of CXR and clinical examination are in line with previous experiences in the intensive care setting.[24,25] The recommendations from The American College of Radiology state that CXR should only

Table 4. Description of Patients With Missed Pathology by Chest X-Ray and Clinical Examination

Pathology (No. Patients Detected by Lung Ultrasound)	Modality (No. Patients With Missed Diagnosis)	Description of Patients With Missed Diagnosis (No. Patients With Additional Diagnoses Detected by Lung Ultrasound)
Observer I		
Collapse/atelectasis (n = 35)	Chest X-ray (n = 19)	Pleural effusion (n = 16), consolidation (n = 8), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 4), no additional (n = 2)
	Clinical examination (n = 14)	Pleural effusion (n = 12), consolidation (n = 4), alveolar-interstitial syndrome (n = 4), pneumothorax (n = 2), no additional (n = 1)
Consolidation (n = 15)	Chest X-ray (n = 9)	Collapse/atelectasis (n = 9), pleural effusion (n = 9), alveolar-interstitial syndrome (n = 1)
	Clinical examination (n = 13)	Collapse/atelectasis (n = 13), pleural effusion (n = 12), alveolar-interstitial syndrome (n = 2)
Alveolar-interstitial syndrome (n = 14)	Chest X-ray (n = 13)	Collapse/atelectasis (n = 7), no additional (n = 5), pleural effusion (n = 5), pneumothorax (n = 4), consolidation (n = 2)
	Clinical examination (n = 12)	Collapse/atelectasis (n = 6), no additional (n = 5), pleural effusion (n = 4), pneumothorax (n = 4), consolidation (n = 2)
Pleural effusion (n = 32)	Chest X-ray (n = 10)	Collapse/atelectasis (n = 10), alveolar-interstitial syndrome (n = 4), pneumothorax (n = 3), consolidation (n = 3)
	Clinical examination (n = 6)	Collapse/atelectasis (n = 5), consolidation (n = 1), no additional (n = 1)
Pneumothorax (n = 9)	Chest X-ray (n = 6)	Collapse/atelectasis (n = 3), alveolar-interstitial syndrome (n = 3), pleural effusion (n = 2), no additional (n = 1)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 6), pleural effusion (n = 5), alveolar-interstitial syndrome (n = 4)
Observer II		
Collapse/atelectasis (n = 35)	Chest X-ray (n = 20)	Pleural effusion (n = 16), consolidation (n = 6), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 3), no additional (n = 2)
	Clinical examination (n = 12)	Pleural effusion (n = 10), consolidation (n = 4), alveolar-interstitial syndrome (n = 3), pneumothorax (n = 2), no additional (n = 1)
Consolidation (n = 12)	Chest X-ray (n = 8)	Collapse/atelectasis (n = 8), pleural effusion (n = 8), alveolar-interstitial syndrome (n = 1)
	Clinical examination (n = 10)	Collapse/atelectasis (n = 10), pleural effusion (n = 9), alveolar-interstitial syndrome (n = 2)
Alveolar-interstitial syndrome (n = 14)	Chest X-ray (n = 13)	Collapse/atelectasis (n = 8), pleural effusion (n = 6), no additional (n = 4), pneumothorax (n = 4), consolidation (n = 2)
	Clinical examination (n = 14)	Collapse/atelectasis (n = 8), pleural effusion (n = 6), no additional (n = 5), pneumothorax (n = 4), consolidation (n = 2)
Pleural effusion (n = 32)	Chest X-ray (n =10)	Collapse/atelectasis (n = 10), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 3), consolidation (n = 2)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 7), alveolar-interstitial syndrome (n = 2), consolidation (n = 1), no additional (n = 1)
Pneumothorax (n = 8)	Chest X-ray (n = 6)	Collapse/atelectasis (n = 3), alveolar-interstitial syndrome (n = 3), pleural effusion (n = 2), no additional (n = 1)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 5), alveolar-interstitial syndrome (n = 4), pleural effusion (n = 4)

Data presented as absolute numbers of patients.

be performed for specific clinical indications after initial admission to the intensive care unit.[26] Others have shown than clinical examination is not sufficiently sensitive to replace CXR in the first 24 hours after cardiac surgery.[27] Lung ultrasound, however, is accurate, noninvasive, portable, and does not emit ionizing radiation and may therefore substitute CXR in this setting, although may not be as efficient as CXR at identifying positions of invasive catheters and tubes.

In this study, we demonstrated that conventional methods of assessment of respiratory pathology in nonventilated patients before and after cardiothoracic surgery have poor diagnostic performance and repeatability representing a significant area for improvement. We believe that lung ultrasound, being easily repeated and generally superior as a diagnostic tool,[7] has the potential to improve the perioperative assessment of patients in this setting.

For critical care physicians, learning to perform lung ultrasound has been reported to have a steep learning curve, but with knowledge of only a few ultrasound findings, a novice can effectively improve diagnostic accuracy of several clinically important respiratory pathologies.[2,14] The researchers who performed lung ultrasound in this study had no prior experience in lung ultrasound and received training in lung ultrasound before commencement of the study. They required 50 mentored scans to achieve a flat learning curve, and the inter-observer agreements beyond chance between the 2 observers were very strong (0.84–0.97), similar to previous reports.[19] The theoretical knowledge required for lung ultrasound is not excessive and is available widely. The time taken to perform the lung ultrasound typically is less than 5 minutes.[23] From a practical point of view, it is relatively simple for anesthetists, cardiac surgeons, or physiotherapists to incorporate lung ultrasound into their assessment because ultrasound equipment is available widely and many already perform ultrasound-guided vascular access and/or focused echocardiography. Nevertheless, before lung ultrasound is implemented as a part of standard care, randomized trials are warranted to assess whether lung ultrasound can change diagnoses and subsequently improve clinical outcomes.

Table 5. Estimates of Intraobserver Agreement Between Chest X-Ray, Clinical Examination, and Lung Ultrasound Beyond that Expected by Chance

		Collapse/ Atelectasis	Consolidation	Alveolar-Interstitial Syndrome	Pleural Effusion	Pneumothorax
Observer I						
Chest X-ray	Observed agreement	0.70	0.78	0.83	0.83	0.88
versus	Expected agreement	0.54	0.70	0.81	0.54	0.82
lung ultrasound	Cohen's kappa	0.40	0.44	0.12	0.50	0.16
	(95% confidence interval)	(0.27–0.53)	(0.31–0.57)	(0.0–0.28)	(0.34–0.66)	(0.00–0.38)
		P < .001	*P* < .001	*P* < .001	*P* < .001	*P* < .001
Clinical examination	Observed agreement	0.79	0.80	0.82	0.85	0.89
versus	Expected agreement	0.53	0.78	0.79	0.52	0.87
lung ultrasound	Cohen's kappa	0.55	0.16	0.27	0.70	0.23
	(95% confidence interval)	(0.43–0.67)	(0.0–0.34)	(0.08–0.46)	(0.59–0.81)	(0.00–0.49)
		P < .001	*P* < 0.001	*P* < .001	*P* < .001	*P* < .001
Clinical examination	Observed agreement	0.79	0.78	0.94	0.80	0.91
versus	Expected agreement	0.61	0.78	0.92	0.54	0.89
chest X-ray	Cohen's kappa	0.40	0.04	0.00	0.58	0.17
	(95% confidence interval)	(0.24–0.56)	(0.00–0.16)	(0.00–0.01)	(0.45–0.71)	(0.00–0.47)
		P < .001	*P* = .395	*P* = .724	*P* < .001	*P* < .001
Observer II						
Chest X-ray	Observed agreement	0.70	0.77	0.83	0.83	0.86
versus	Expected agreement	0.54	0.72	0.81	0.54	0.83
lung ultrasound	Cohen's kappa	0.40	0.22	0.11	0.64	0.16
	(95% confidence interval)	(0.27–0.53)	(0.03–0.41)	(0.0–0.26)	(0.52–0.76)	(0.00–0.38)
		P < .001	*P* < .001	*P* < .001	*P* < .001	*P* < .001
	Observed agreement	0.80	0.85	0.83	0.86	0.90
	Expected agreement	0.52	0.82	0.83	0.54	0.90
Clinical examination	Cohen's kappa	0.67	0.08	–	0.71	–
versus	(95% confidence interval)	(0.56–0.78)	(0.00–0.24)		(0.60–0.82)	
lung ultrasound		*P* < .001	*P* = .027		*P* < .001	
	Observed agreement	0.83	0.77	0.98	0.77	0.91
	Expected agreement	0.59	0.78	0.98	0.56	0.91
Clinical examination	Cohen's kappa	0.47	0.00	–	0.50	–
versus	(95% confidence interval)	(0.32–0.62)	(0.00–0.01)		(0.35–0.65)	
chest X-ray		*P* < .001	*P* = .663		*P* < .001	

Data presented as observed agreements, expected agreements, and Cohen's kappa coefficients reported with 95% confidence intervals and corresponding *P* values.

–, not calculated as observer II did not detect alveolar-interstitial syndrome or pneumothorax in any lung zones.

Limitations

First, this study was designed as a pilot study to assess different strategies for diagnosis of perioperative lung pathology; therefore, we included only a convenience sample of patients. Consequently, larger-scale studies are needed to reproduce our findings as well as to explore potential correlations between lung pathology and clinical outcomes. Second, the sensitivity of CXR was lower than expected, which may result from the radiologists not being supplied with a standardized form for their findings, and thus we cannot preclude that abnormalities were detected but for some reason not reported. Third, no conclusions can be drawn in terms of alveolar-interstitial syndrome and pneumothorax because their proportions were low and the second observer did not detect either pneumothorax or alveolar-interstitial syndrome on clinical examination. Thus, we were unable to complete the calculations of agreements beyond chance between modalities for observer II and interobserver agreements beyond chance for these 2 pathologies. Fourth, our ultrasound definition of pneumothorax was absence of lung sliding and lung pulse but not including demonstration of lung point. Even though this might reduce the specificity of this ultrasound diagnosis, the intention was to be able to investigate each of the 3 lung zones independently keeping in mind that the lung point might be found in another lung zone than the absence of lung sliding and lung pulse. Hence, the superiority of lung ultrasound compared with clinical assessment and CXR are weaker than for the other respiratory pathologies. Fifth, we chose to perform each of the assessments in the most optimal patient position, and hence, the positions were different for the 3 modalities. Obviously, this might have altered the distribution of pathologies between different lung zones and estimation of effusion sizes, but suboptimal patient position would clearly have impaired the external validity of our findings. Lastly, we are well-aware that CT scan is the gold standard in detection of respiratory pathology. Nevertheless, in this clinical setting, CT scan is often challenging due to, for instance, costs and time consumption; therefore, we chose lung ultrasound as the reference method for this study.

CONCLUSIONS

We showed that the detection of clinically important respiratory pathology is improved with lung ultrasound compared with conventional methods of assessment (CXR, clinical examination, and the 2 in combination) in a significant number of nonventilated and noncritically ill patients before and after cardiothoracic surgery. We demonstrated high estimate of interobserver agreement beyond that expected by chance for lung ultrasound even in novice examiners. Routine use

of lung ultrasound may be an important tool for perioperative assessment in this setting. ■

DISCLOSURES

Name: John W. Ford, MD.
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Name: Johan Heiberg, PhD.
Contribution: This author helped analyze the statistics, interpret the data, graphic illustrations, and draft the manuscript.
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