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REVIEW ARTICLES

Is thoracic ultrasound a viable alternative to conventional imaging in the critical care setting?

D. T. Ashton-Cleary*

Department of Critical Care, Royal Cornwall Hospital, Truro TR1 3LJ, UK

* E-mail: daveashtoncleary@hotmail.com

Editor's key points

- There is growing enthusiasm for using ultrasound in critical care.
- This review provides evidence for the usefulness of thoracic ultrasound in critical care.
- In expert hands, ultrasound is accurate in diagnosing pleural effusions, consolidation, and pneumothorax.
- Further research is required to explore its usefulness in diagnosing other chest conditions.

Summary. Thoracic imaging is regularly performed on the majority of critical care patients. Conventionally, this uses a combination of plain radiography and computed tomography. There is growing enthusiasm for the use of ultrasound to replace much of this radiology and provide more immediate, point-of-care imaging with reduction in patient transfers, ionizing radiation exposure and cost. This article explores the diagnostic performance of thoracic ultrasound in the imaging of pleural effusion, consolidation, extra-vascular lung water (EVLW), and pneumothorax. Current evidence suggests that, in expert hands, thoracic ultrasonography has similar diagnostic accuracy to computed tomography in pleural effusion, consolidation and pneumothorax. The technique also has potential to identify the cause of increased EVLW and accurately quantify pleural effusions. More large-scale studies are required in these areas however. Ultrasonography outperforms bedside chest radiography in all cases.

Keywords: equipment, thoracic ultrasound; imaging; intensive care; lung; pulmonary oedema

Imaging of the chest is performed on the majority of critical care patients. It relies heavily on portable plain chest X-ray (CXR) (which has problems with the technical quality of images obtainable in this setting) and, to a lesser extent, computed tomography (CT).[1–5] Both rely on ionizing radiation and the time and resources of another department.

Ultrasound is already in common use within critical care, typically to guide central venous access.[6–8] Other applications such as echocardiography and abdominal scanning in trauma are also finding their way into everyday practice.[9–17] Advocates of thoracic ultrasound suggest that the majority of important pathology can be detected with relative ease, speed, and greater reliability when compared with plain radiography. It also spares ionizing radiation exposure and, in the case of CT, potentially hazardous transfer of the patient to the radiology suite.[18 19] There is also the potential for a considerable cost saving.[1 20] Despite these factors, thoracic ultrasound is not currently in widespread use within the critical care setting except in the detection of pleural effusion.[21]

As air-filled tissues such as the lung do not return ultrasound signals well, expert radiological opinion has dismissed this as a useful application of the technology.[22] However, interpretation of various indirect ultrasound artifacts generated by aerated tissue is being suggested as a means by which to image the intrathoracic contents. The aim of this review is to explore the diagnostic performance of using these artifacts to characterize key intrathoracic pathology in the critical care population and, by extension, determine if it can replace conventional imaging.

Literature review methodology

The Medline and EMBASE databases were searched seeking relevant articles in human subjects, written in the English language and published between 1995 and February 2012. Search terms included thoracic, chest, lung, ultrasound or ultrasonography, and critical or intensive care and those specific to particular pathologies, e.g. pneumothorax. The Cochrane Database of Systematic Reviews and International Standard Randomized Controlled Trial Number Register were also searched.

This initial search strategy revealed 825 articles. By review of titles and abstracts, duplicates, and non-relevant studies were removed leaving an initial 88 articles of potential relevance. These included 51 observational studies and 37 reviews, editorials and commentaries. These were refined by review of complete articles. Further relevant work was identified from the reference lists of the principal articles. There were no randomized controlled trials or relevant Cochrane reviews. Due to the relative paucity of evidence, a number of conference abstracts found in the primary search were, with caution, retained in the final literature pool.

Review

Focusing on common diagnoses which require repeated imaging to diagnose and monitor treatment allows the greatest reduction in CXR/CT to be realized from a switch to ultrasonography. This strategy should also maximize reliability of the examination by allowing critical care ultrasonography (CCUS) practitioners to focus their practice on a few common pathologies. Those suggested to fit these criteria are as follows:[23]

- Pleural effusion,
- Consolidation,
- Pulmonary oedema/extravascular lung water, and
- Pneumothorax.

In all the studies discussed, the ultrasonography was performed by physicians who were described explicitly or implicitly as having training and experience in the skill. However, a lack of an agreed credentialing system makes direct comparisons of operator skill between studies difficult.

Pleural effusion

This is the typical indication for thoracic ultrasonography and has the potential ability to identify, as well as characterize, quantify, and guide the drainage of fluid.[24 25] Studies have focused either on the ability to detect effusions or the ability to quantify the fluid volume.

Several well-conducted studies have compared the ability of CCUS to detect effusions against that of CXR, using CT as a reference standard.[1 26 27] All demonstrated high sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy (DA) for CCUS whereas CXR was notably weaker, particularly in terms of sensitivity, NPV and DA (Table 1). Chest auscultation alone seems slightly superior to CXR.[1] Overall, this body of evidence suffers from a degree of heterogeneity as some restricted patient selection to those with a pre-existing diagnosis of ARDS or thoracic trauma.[1 27]

Further studies have investigated attempts to determine effusion volume and the need for insertion of a drain, evaluating performance against actual drained volume (Table 2). One involved volumetric modelling by scanning and measurement of the effusion in several planes.[28] This method compared well with similar models constructed with CT scans but from a practical point of view is complex.

Other investigators have used a more simple approach determining the value of a single measurement which would predict an effusion of a certain volume.[29–32] This has the potential to guide clinical decision making as to whether to insert a drain or not. One group using such a method also demonstrated the clinical effectiveness of this cut-off; Roch and colleagues[29] investigated the depth of effusion beneath the lung base as a means to predict a drained volume greater than or less than 500 ml and demonstrated a moderate correlation (r=0.5, P<0.01) between volume drained and improvement in $Pa_{O_2}:FI_{O_2}$ ratio over the following 12 h for those patients with >500 ml drained. In this particular study however, only 20 of the 44 patients included had effusions >500 ml on which the principal study conclusions were founded.

Of note, asymmetry in CCUS performance with left-sided estimation consistently performing slightly worse has been noted in these studies.[30 31] The authors[31] suggest the presence of the heart in the left chest accounts for this and the greater interobserver variability seen in measurements of the left hemithorax. Meanwhile, differing levels of PEEP appear to have no significant effect on these models although, to date, this has only been determined through *post hoc* analysis. Parallel analysis of CXR performance produced disappointing results with moderate sensitivity and poor specificity.[31]

In summary, CCUS can reliably identify simple effusions and should be the method of choice over CXR. There is also compelling evidence that accurate and clinically useful estimations of effusion volume may also be derived by CCUS. Further studies of one single, simple method of volume estimation would add valuable homogeneity to the evidence.

Table 1 Pleural effusion, qualitative studies. Drained Vol, drained volume; NPV, negative predictive value; PPV, positive predictive value; DA, diagnostic accuracy. *n/N* =number affected/number in study; **n/N* in terms of lung regions or hemithoraces rather than patients

Paper	Reference test	Modality/comparison	*n/N*	Sensitivity	Specificity	PPV	NPV	DA
Xirouchaki[26]	CT	CCUS	63/84*	100.0	100.0	100.0	100.0	100.0
		CXR		65.1	81.0	91.1	43.6	69.0
Rocco[27]	CT	CCUS—post-drain	38/180*	92.0	95.0	–	–	94.0
		CCUS—48 h post-drain	33/180*	94.0	99.0	–	–	98.0
		CXR—post-drain		23.0	94.0	–	–	81.0
		CXR—48 h post-drain		42.0	97.0	–	–	87.0
Vignon[30]	Drained Vol >800 ml	CCUS-right	49/97	94.0	76.0	–	–	–
		CCUS-left		100.0	67.0	–	–	–
		CXR		75.6	50.9	67.8	60.4	90.7
Roch[29]	Drained Vol >500 ml	CCUS	20/44	83.0	90.0	91.0	82.0	86.0
Lichtenstein[1]	CT	CCUS	100/384*	92.0	93.0	–	–	93.0
		CXR		39.0	85.0	–	–	47.0
		Auscultation		42.0	90.0	–	–	61.0