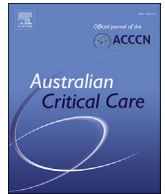




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Review paper

The role of lung ultrasound for detecting atelectasis, consolidation, and/or pneumonia in the adult cardiac surgery population: A scoping review of the literature

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ABSTRACT

Objectives: Postoperative pulmonary complications (PPCs) frequently occur after cardiac surgery and may lead to adverse patient outcomes. Traditional diagnostic tools such as auscultation or chest x-ray have inferior diagnostic accuracy compared to the gold standard (chest computed tomography). Lung ultrasound (LUS) is an emerging area of research combating these issues. However, no review has employed a formal search strategy to examine the role of LUS in identifying the specific PPCs of atelectasis, consolidation, and/or pneumonia or investigated the ability of LUS to predict these complications in this cohort. The objective of this study was to collate and present evidence for the use of LUS in the adult cardiac surgery population to specifically identify atelectasis, consolidation, and/or pneumonia.

Review method used: A scoping review of the literature was completed using predefined search terms across six databases which identified 1432 articles. One additional article was included from reviewing reference lists. Six articles met the inclusion criteria, providing sufficient data for the final analysis.

Data sources: Six databases were searched: MEDLINE, Embase, CINAHL, Scopus, CENTRAL, and PEDro. This review was not registered.

Review methods: The review followed the PRISMA Extension for Scoping Reviews.

Results: Several LUS methodologies were reported across studies. Overall, LUS outperformed all other included bedside diagnostic tools, with superior diagnostic accuracy in identifying atelectasis, consolidation, and/or pneumonia. Incidences of PPCs tended to increase with each subsequent timepoint after surgery and were better identified with LUS than all other assessments. A change in diagnosis occurred at a rate of 67% with the inclusion of LUS and transthoracic echocardiography in one study. Pre-established assessment scores were improved by substituting chest x-rays with LUS scans.

Conclusion: The results of this scoping review support the use of LUS as a diagnostic tool after cardiac surgery; however, they also highlighted a lack of consistent methodologies used. Future research is required to determine the optimal methodology for LUS in diagnosing PPCs in this cohort and to determine whether LUS possesses the ability to predict these complications and guide proactive respiratory supports after extubation.

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1. Introduction

Open-heart surgery (OHS) is associated with numerous long-term benefits, including a reduction in cardiac-related symptoms, improved quality of life, and improved life expectancy.^{1,2} Whilst demonstrating long-term benefits, this surgery is not without risk,

with reported 30-day mortality of 2–3%^{3,4} and 1-year mortality of approximately 6%.^{3,5} Common postsurgical complications include heart rhythm disturbances, delirium, and postoperative pulmonary complications (PPCs).^{6,7}

Dependent on the definition, the incidences of PPCs in patients undergoing a coronary bypass graft range from 5% to 90%⁸ and contribute significantly to increased hospital length of stay, intensive care unit length of stay, and increased morbidity and mortality.^{9–13} For patients undergoing OHS, studies have reported that approximately two-thirds of patients who develop the specific PPC of acute respiratory distress syndrome (ARDS) will die, either within hospital or within 1-month after discharge.¹⁴ Long-term survival is also affected by PPCs, with postoperative pneumonia approximately halving a patient's 5-year survival after OHS.¹⁵ PPCs also create a major economic burden on the healthcare system with healthcare costs doubling for patients undergoing cardiac surgery who develop ventilator-associated pneumonia.¹⁶ Furthermore, studies have reported that up to 85% of PPCs occur within the first 3 days following a major surgery.¹⁷ However, accurate diagnosis of PPCs in the early postoperative phase remains challenging due to the inferior diagnostic accuracy of traditional tools such as auscultation or chest x-ray (CXR) compared to the gold standard computed tomography (CT),^{18,19} which is impractical and uncommonly used after these procedures. Additionally, when CT is used, it exposes patients to significant levels of ionising radiation.²⁰

Over the past two decades, lung ultrasound (LUS) has been increasingly used by bedside clinicians in critical care settings as an imaging technique to identify lung pathology and PPCs.²¹ LUS has demonstrated excellent diagnostic accuracy for a variety of pulmonary diseases and PPCs including pneumothoraces, pleural effusions, pneumonia, and pulmonary oedema.^{22–27} In addition to the growing use of LUS in the medical profession, this technique is gaining popularity in the field of physiotherapy to improve clinical assessments and guide individualised respiratory care.^{28,29} In Australia, physiotherapists are often integrated within hospitals' multiprofessional surgical teams, providing preoperative education, early mobilisation, and respiratory management to prevent PPCs and restore function after surgery. Pulmonary complications predominantly treated by physiotherapists are more accurately diagnosed with LUS than traditional techniques. For example, LUS is more accurate than CXR or auscultation in diagnosing consolidation related to pneumonia^{26,30–32} and is more accurate than CXR for detecting atelectasis.^{33–35} However, limited access to LUS and inability to interpret LUS findings have been identified as barriers to uptake by physiotherapists as part of clinical decision-making.³⁶ Improving physiotherapists' access to LUS may allow them to identify PPCs earlier and provide timely, appropriate, and targeted respiratory management.

Emerging research is also investigating the use of LUS as a monitoring and predictive tool via lung aeration scores. For example, a 36-point aeration score has been developed that allocates a score of 0 (normal) to 3 (no aeration) across 12 defined lung zones, with lower scores indicating better aeration.^{37–39} Lung aeration scores have demonstrated promising results in patients weaning from extended mechanical ventilation (>48 h duration), with a score of >17 predictive of postextubation distress.⁴⁰ In patients with respiratory failure from coronavirus disease (COVID-19), several studies have demonstrated that higher lung aeration scores strongly correlate with the requirement for invasive mechanical ventilation.^{41–43} Despite the monitoring and predictive use of LUS in other patient cohorts, this has not yet been investigated in the cardiac surgery population.

Two reviews have previously described the broader use of LUS in this population.^{44,45} Cantinotti et al.⁴⁴ provided an overview of the existing literature for the clinical application of LUS in cardiac

surgery for identifying pulmonary complications that included pleural effusion, consolidation, pneumothoraces, diaphragmatic motion anomalies, and pulmonary oedema. Efremov et al.⁴⁵ provided a detailed methodology for LUS in the cardiac surgery population and reported the diagnostic and prognostic accuracy of LUS in identifying similar pulmonary complications, with the addition of pulmonary embolism. Both reviews highlighted the frequent occurrence of pulmonary complications following cardiac surgery and emphasised a lack of standardised protocols for LUS assessment to identify these. However, neither review included a formal search strategy to find existing literature examining the use of LUS for identifying PPCs in patients undergoing cardiac surgery. Therefore, by employing a formal search strategy, the aim of this scoping review is to collate and present evidence for the use of LUS in the adult cardiac surgery population to specifically identify atelectasis, consolidation, and/or pneumonia.

2. Materials and methods

This review followed the standardised scoping review methodology from Arksey and O'Malley,⁴⁶ Levac et al.,⁴⁷ and the Joanna Briggs Institute guidance for the conduct of scoping reviews.⁴⁸ The Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR)⁵⁰ was also followed to ensure the quality of reporting. This review was not registered.

2.1. Research question

The Participants, Concept, and Context method⁵⁰ was used to formulate the following research question: "What is the role of LUS in identifying atelectasis, consolidation, and/or pneumonia in the adult cardiac surgery population?"

P (Participants): Human adults undergoing cardiac surgery.

C (Concept): LUS in identifying atelectasis, consolidation, and/or pneumonia.

C (Context): Including the following publication type: systematic reviews, prospective randomised control trials, pseudo-randomised controlled trials, and prospective cohort studies. Studies must have investigated atelectasis and/or consolidation and/or pneumonia with LUS. No limitations were placed on location of studies or publication date.

2.2. Search strategy

A comprehensive search strategy was created in collaboration with a medical librarian (JW), and an extensive literature search was conducted through the following electronic databases: MEDLINE Complete (EbscoHOST), Embase (Elsevier), CINAHL Complete (EbscoHOST), Scopus (Elsevier), CENTRAL (Wiley), and PEDro. The search strategy included subject headings and keywords relevant to 'lung ultrasound' and 'cardiac surgery' (full search strategy is provided in [Supplementary File 1](#)). Studies were not excluded by publication date; therefore, databases were searched from the earliest date of publication up to September 6, 2022. Language filters were set to English, and commentary pieces, editorials, letters, responses, and animal studies were excluded. The final search results were exported into EndNote X9, and duplicates were removed using EndNote's inbuilt duplicate locator.

2.3. Eligibility criteria

Several inclusion and exclusion parameters were created prior to the database searching and screening of articles; these can be seen in detail in [Table 1](#). Paediatric studies were excluded during

Table 1
Inclusion/exclusion criteria for review.

Inclusion criteria
Design
- Systematic reviews
- Prospective randomised controlled trials
- Pseudo-randomised controlled trials
- Prospective cohort/observational studies
Participants
- Adult patients (≥ 18 years)
- Primarily undergoing cardiac surgery (i.e., >50% of enrolled participants)
Outcome measures
- Clinical suspicion of PPCs atelectasis and/or consolidation and/or pneumonia, based on clinical features, imaging techniques (LUS, CXR, and CT), and microbiological/laboratory test
Exclusion criteria
Design
- Letters
- Editorials
- Opinion pieces
- Studies other than in English
Participants
- Animal studies
Outcome measures
- Cardiogenic pulmonary oedema
- Pleural effusions
- Pneumothoraces
- Diaphragmatic ultrasound
- Pulmonary embolism
- LUS not investigating PPCs (e.g., endotracheal tube position)

CT: computed tomography; CXR: chest x-ray; LUS: lung ultrasound; PPC: post-operative pulmonary complication.

the screening process of titles and abstracts, as were trial protocols and narrative reviews. The articles needed to report on the following primary outcomes to be included: clinical suspicion of atelectasis, consolidation, and/or pneumonia, via LUS. Two assessors (LC, PT) independently screened the titles and abstracts of the studies identified in the literature search, with a third independent assessor (OT) consulted for any disagreements. After abstract screening, selected studies were retrieved for a second-stage manuscript full-text review. Abstracts without full-text links were included if relevant data could be extracted. Where possible, authors were contacted for full-text articles of abstracts. The full detail of the article selection process is listed in Fig. 1.

2.4. Data extraction and analysis

One reviewer (LC) independently extracted the following data from each article: first author, year of publication, study design, sample size, population condition, primary outcomes, secondary outcomes (Table 2), reference standard, LUS timepoints, number of regions examined with LUS (Supplementary File 2), and key findings (Tables 3–5). Extracted data were validated by the second reviewer (PT).

3. Results

3.1. Study selection

From the 1433 articles identified, 438 were removed as duplicates, and 983 were eliminated on review of the titles and abstracts due to nonadherence to the predetermined exclusion criteria (Table 1). The remaining 12 articles were reviewed in full-text, and a further six were excluded as they did not provide data on PPCs (i.e., assessment protocol).⁵¹ used LUS in a population other than cardiac surgery patients,⁵² examined PPCs outside of predetermined inclusion/exclusion criteria,^{53,54} or were conference abstracts presenting

preliminary data of a final publication.^{55,56} After the screening was complete, a total of six articles were included in the final analysis.

3.2. Demographics and setting

General characteristics, primary and secondary outcomes, and key findings of the studies are demonstrated in Tables 2–5. The included studies were published over a 6-year period from 2014 to 2020. All studies were single-centre, prospective, observational studies, and the overall number of participants was 621 (range 51–177).

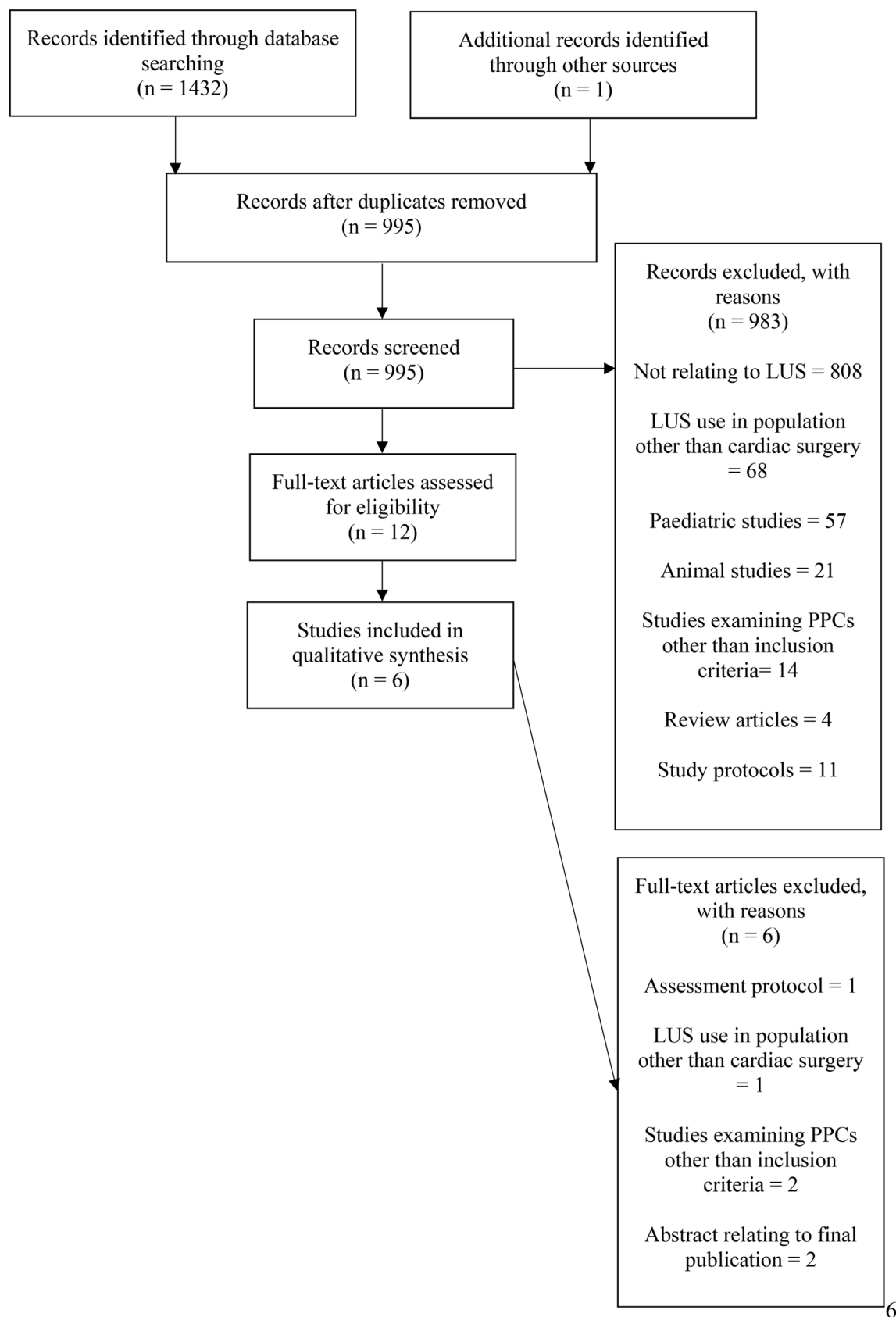
3.3. Intervention methodology

There was variation in the LUS timepoints, number of thoracic regions examined, reference standards, ultrasound probes, and ultrasound frequencies used across the studies to diagnose atelectasis, consolidation, and/or pneumonia (Supplementary File 2). Two studies included both preoperative and postoperative scans^{57,58}; the remaining four studies included postoperative scans only.^{19,59–61} Postoperative LUS timepoints utilised within studies ranged from 1 h after surgery up to the point of discharge from a medical ward (inclusive of days 2 and 3 of intensive care unit admission). LUS scanning techniques and number of thoracic regions examined varied between studies. Four studies used between six and 10 regions,^{57–60} one study used the same regions of the thorax that were evaluated by auscultation and CXR,¹⁹ and one study did not report this.⁶¹

A variety of LUS frequencies were reported, ranging from 1 to 13 MHz, and three different LUS probes were utilised (phased array, linear, and transthoracic). Only two studies reported the LUS mode (colour doppler⁶¹ and “lung ultrasound” preset⁵⁷), and only three studies reported the patient position for LUS assessment (supine^{57,58} or semirecumbent⁶⁰). Several reference standards were utilised within studies to determine sensitivity and specificity for LUS including the following: the consensus of three blinded physicians based on post hoc review of clinical, radiological, and microbiological evidence,⁶¹ CXR,¹⁹ and clinically relevant PPCs (requiring treatment as per physician).⁵⁹ The three remaining studies did not examine sensitivity or specificity.

3.4. Current evidence for LUS use in adults undergoing cardiac surgery to identify pulmonary atelectasis, consolidation, and/or pneumonia

LUS was compared to several key reference points that reflected a diagnosis of atelectasis, consolidation, and/or pneumonia (Supplementary File 2). Dureau et al.⁶¹ demonstrated improved diagnostic accuracy in detecting pneumonia using the simplified clinical pulmonary infection score (sCPIS) assessment when substituting CXR for LUS (LUS-sCPIS area under the receiver operating curve [AUC]: 0.80 [0.69 to 0.91] vs CXR-sCPIS AUC: 0.59 [0.47 to 0.71], $p = 0.00077$). Vezzani et al.¹⁹ compared LUS versus auscultation for identifying consolidation and demonstrated higher diagnostic accuracy for LUS (sensitivity and specificity: 86% and 99% for LUS versus 21% and 98% for auscultation). Touw et al.⁵⁹ demonstrated that the detection of PPCs and clinically relevant PPCs (requiring treatment as per physician) was higher with LUS than CXR at all assessed time points. Detection of consolidation at admission, day 2, and day 3 post-surgery were LUS (7.9%) vs CXR (0%) ($p =$ not reported), LUS (16.2%) vs CXR (2%) ($p = <0.001$), and LUS (27.6%) vs CXR (0%) ($p =$ not reported), respectively. Detection of atelectasis at admission, day 2, and day 3 after surgery were LUS (87%) vs CXR (40.6%) ($p = <0.001$), LUS (84.4%) vs CXR (65.7%) ($p = 0.002$), and LUS (98.3.6%) vs CXR (67.8%) ($p = <0.001$),



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Fig. 1. Flow diagram for study identification and selection (as per the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews guidelines) with reasoning for exclusions.

Table 2
Summary of study characteristics.

Author, year	Design	Sample size	Population condition	Primary outcomes	Secondary outcomes
Dureau et al. 2019	Single-centre, prospective, observational study.	N = 51	Adult patients (≥ 18 years) with acute respiratory failure within 72 h of cardiac surgery.	Diagnostic accuracy of LUS-sCPIS vs sCPIS alone in the detection of pneumonia.	
Vezzani et al. 2014	Single-centre, prospective, observational study.	N = 151	Adult patients (≥ 18 years) undergoing cardiac surgery.	Sensitivity, specificity, PPV and NPV of LUS vs auscultation for detecting consolidation, alveolar–interstitial syndrome, posterolateral alveolar and/or pleural syndrome, pleural effusion, pneumothorax, pericardial effusion, and endotracheal tube malposition.	Interobserver variability.
Emperador et al. 2020	Single-centre, prospective, observational study.	N = 73	Adult patients (≥ 18 years) undergoing cardiac surgery.	Extravascular lung water and the effect on oxygenation and time of extubation.	Extubation time, cardiopulmonary bypass time, aortic cross-clamp time, fluid balance, pleural effusion, and consolidation.
Touw et al. 2018	Single-centre, prospective, observational study.	N = 177	Adult patients (≥ 18 years) undergoing cardiac surgery.	Incidence of PPCs detected by LUS vs CXR, and sensitivity, specificity, PPV, NPV, and diagnostic accuracy of LUS and CXR for the detection of clinically relevant PPCs (requiring treatment).	LUS interobserver agreement, time to complete LUS scan, and time to detection of clinically relevant PPCs.
Ford et al. 2017	Single-centre, prospective, observational study.	N = 78	Adult patients (≥ 18 years) undergoing cardiac or thoracic surgery who received a CXR as part of standard care.	Incidence of clinically important respiratory pathology.	Sensitivity and specificity of CXR and clinical examination compared to LUS.
Alsaddique et al. 2016	Single-centre, prospective, observational study.	N = 91	Adult patients (≥ 18 years) undergoing cardiac surgery.	Change in diagnosis after TTE and LUS vs clinical examination.	TTE image quality and number of abnormalities detected by ultrasound that were missed on clinical examination.

LUS: lung ultrasound; NPV: negative predictive value; PPCs: postoperative pulmonary complications; PPV: positive predictive value; sCPIS: simplified clinical pulmonary infection score; TTE: transthoracic echocardiogram.

respectively. The diagnostic accuracy of LUS was also higher than that of CXR in detecting atelectasis at admission. Results included sensitivity and specificity, LUS (82% and 13%, respectively) vs CXR (45% and 59%, respectively) and positive predictive value and negative predictive value, LUS (91% and 6%, respectively) vs CXR (94% and 7%, respectively). The data for days 2 and 3 were not recorded. The diagnostic accuracy of LUS in detecting consolidation was not reported in this study.

Ford et al.⁵⁸ investigated the proportion of clinically important respiratory pathology (preoperatively and postoperatively) detectable with CXR, clinical examination, and LUS. The diagnostic accuracy of CXR and clinical examination were also examined using LUS as the reference standard. Respiratory pathology was detected by LUS in 56% of the cohort (24% preoperatively and 94% postoperatively in the ward). The detection of atelectasis and consolidation was found at much greater rates in the lower zones of the chest than in the upper zones. Overall, LUS outperformed CXR, clinical examination, and combined CXR and clinical examination in the detection of atelectasis and consolidation, although some values were lower for consolidation with LUS (full details Table 5).

Alsaddique et al.⁶¹ investigated the number of changes in diagnosis of clinically important cardiac and respiratory abnormalities between clinical examination and ultrasound (transthoracic echocardiography and LUS). After ultrasound, a change in diagnosis occurred at a rate of 67% compared to the original clinical examination.

Overall, the studies investigating the incidence or detection of atelectasis, consolidation, and/or pneumonia at multiple time points with LUS demonstrated increased rates of PPCs from the first time point to the last time point, up to 72 h.^{57–60} However, the incidence of PPCs detected by LUS that were deemed clinically relevant (requiring active treatment) did not increase over time.⁵⁹

4. Discussion

By using the PRISMA-ScR framework,⁴⁹ we have systematically reported on the peer-reviewed literature for the role of LUS in detecting atelectasis, consolidation, and/or pneumonia in the cardiac surgery population. All studies included were single-centre, prospective, observational studies, and all were published within the last decade, highlighting this as an area of emerging research and clinical interest.

The characteristics of LUS technique, frequencies, and time points varied widely across the six studies, further highlighting a universal lack of standardised assessment protocols previously reported in reviews.^{21,44,45} LUS performed by critical care clinicians has a steep learning curve for obtaining the minimum standards for proficiency^{62,63} and has been shown to be feasible for nonmedical professions such as physiotherapists,⁶⁴ paramedics,^{65,66} and nurses.⁶⁷ However, the diagnostic accuracy of LUS differs significantly between novice users and advanced clinicians,⁶⁸ with the use of differing probes potentially influencing accuracy further.⁶⁹

The widespread variation in LUS methodology has been addressed by authors in the latest *International Guidelines and Consensus on the Use of Lung Ultrasound*.⁷⁰ The authors highlighted that different LUS protocols have been adopted to suit the acuity of patient conditions (e.g., rapid differential diagnosis in acute respiratory failure (six scan points⁷¹)) versus assessment of fluid overload in dialysis patients (28 scan points⁷²). Demi et al.⁷² proposed that for the specific condition of COVID-19, a 12 scan-point protocol was the most optimal in balancing accuracy with rapid diagnosis, in contrast to more or fewer scan points.⁷³ This demonstrates that studies that explore the diagnostic accuracy and clinical feasibility of different LUS protocols are possible in single-patient conditions; however, the results might not be generalisable to other patient

Table 3

Summary of key findings grouped by diagnostic accuracy.

Author, year	PPC investigated	Key findings			
Vezzani et al. 2014	Consolidation		LUS	Auscultation	
		Sensitivity	86%	21%	
		Specificity	99%	98%	
		PPV	86%	50%	
		NPV	99%	92%	
Touw et al. 2018	Clinically relevant PPC (atelectasis) at admission *(Days 2 and 3 not recorded)		LUS	CXR	
		Sensitivity	82%	45%	
		Specificity	13%	59%	
		PPV	91%	94%	
		NPV	6%	7%	

LUS: lung ultrasound; NPV: negative predictive value; PPC: postoperative pulmonary complication; PPV: positive predictive value.

cohorts/clinical conditions. Previous studies have investigated the diagnostic accuracy of LUS for respiratory complications in critically ill patients, using chest CT as the gold standard; however, these studies did not compare multiple LUS approaches and/or scan points.^{74,75} Therefore, to develop a standardised LUS protocol for diagnosing atelectasis, consolidation, and/or pneumonia in patients with critical illness, we recommend that studies be completed that explore different LUS approaches, using chest CT as the gold standard, to determine the most optimal methodology.

Despite the different methodologies of LUS scans in the included studies, similarities were observed across the key findings. Firstly, when comparing the diagnostic accuracy of LUS against CXR, auscultation, clinical examination, or CXR combined with clinical examination, overall, LUS outperformed all other techniques in detecting atelectasis, consolidation, and/or pneumonia. Improved diagnostic accuracy was demonstrated for detecting postoperative pneumonia with sCPIS assessments when CXRs were substituted with LUS scans.⁶¹ Furthermore, when compared to clinical examinations alone, a change in diagnosis occurred at a rate of 67% with the addition of LUS and transthoracic echocardiography.⁶⁰ These findings align with previous literature demonstrating the superior diagnostic accuracy of LUS versus other currently used techniques for detecting consolidation across patient populations, approaching the accuracy of chest CT (the gold standard).^{26,30,31,76–78} The findings also add to promising data demonstrating a higher diagnostic accuracy of LUS versus CXR in diagnosing atelectasis.^{33–35}

Table 4

Frequency of postoperative pulmonary complication detection at separate time points within studies.

Author, year	PPC investigated	Frequency of PPC detection								
Emperor et al. 2020	Consolidation		Preoperatively	Admission to the ICU	1 h postoperatively	Day 1	Day 2	Day 3	Postoperatively in ward	Before discharge
Touw et al. 2018	Consolidation	LUS	11%	—	39%	50%	—	—	—	—
		LUS	—	7.9%	—	—	16.2%	27.6%	—	—
		CXR	—	0%	—	—	2%	0%	—	—
		p-value	—	NR	—	—	<0.001	NR	—	—
		LUS	—	87%	—	—	84.4%	98.3%	—	—
	Atelectasis	CXR	—	40.6%	—	—	65.7%	67.8%	—	—
		LUS vs CXR p-value	—	<0.001	—	—	p = 0.002	<0.001	—	—
		Overall	—	0%	—	—	1%	1.7%	—	—
		Overall	—	6.2%	—	—	4.0%	0%	—	—
		Overall	—	0%	—	—	1%	1.7%	—	—
Ford et al. 2017	Respiratory pathology ^a	LUS	—	17%	—	—	NR	NR	—	—
		CXR	—	58%	—	—	NR	NR	—	—
		LUS	24% ^b	—	—	—	—	—	94% ^b	—
		LUS	—	—	—	1%	—	—	—	NR
Alsaddique et al. 2016	Consolidation missed on clinical examination	LUS	—	—	—	1%	—	—	—	NR

CXR: chest x-ray; ICU: intensive care unit; LUS: lung ultrasound; NR: not recorded; PPC: postoperative pulmonary complication.

^a Pathology included: collapse/atelectasis, consolidation, alveolar–interstitial syndrome, pleural effusion, and pneumothorax.

^b Values calculated from 56% (n = 44) of total cohort (n = 78) with positive respiratory pathology.

Table 5

Summary of key findings grouped by postoperative pulmonary complication detection in different lung zones.

Author, year	PPC investigated	Key findings					
Ford et al. 2017	Collapse/atelectasis		Upper zones		Lower zones		
			Left	Right	Left	Right	
		LUS	3%	0%	39%	37%	
		CXR	1%	0%	17%	15%	
		CE	1%	0%	28%	24%	
	Consolidation	CE + CXR	3%	0%	35%	29%	
			Upper zones		Lower zones		
			Left	Right	Left	Right	
		LUS	1%	0%	10%	15%	
		CXR	0%	0%	18%	9%	
Ford et al. 2017	Consolidation	CE	2%	1%	3%	3%	
		CE + CXR	3%	1%	21%	12%	

CE: clinical examination; CXR: chest x-ray; LUS: lung ultrasound; PPC: postoperative pulmonary complication.

A key finding from this review is that in general, the incidence of atelectasis, consolidation, and/or pneumonia was reported to increase across sequential postoperative time points up to 72 h.^{57–60} One study completed LUS scans beyond 72 h (before discharge from a medical ward); however, it did not detect any additional consolidation compared to clinical examination at this point.⁶⁰ As previously stated, it is well documented that pulmonary complications are common after cardiac surgery (up to 90%, depending on the definition),⁸ which lead to increased morbidity and mortality^{9–13,15,79} and create a major economic burden on the healthcare system.¹⁶ Up to 85% of these complications occur within the first 3 days following a major surgery,¹⁷ and approximately 40% of reintubations within the cardiac surgery population occur within the first 3 days after surgery.⁸⁰ This highlights the need for medical, nursing, and allied health staff to perform thorough respiratory assessments, not only on Day 1 postoperatively, but also as rigorously on Days 2 and 3. Early detection or prediction of PPCs in this population may enable earlier, targeted treatments to improve these outcomes. The results from this review suggest that LUS is an important component of any screening, due to its high sensitivity and specificity to detect lung pathology.

As previously stated, emerging research is now investigating LUS as a monitoring and predictive tool via lung aeration scores in

non-cardiac surgery patient populations. Lung aeration scores can monitor PPCs and treatment response,^{37,38} potentially predict which patients require invasive mechanical ventilation in the event of deterioration,^{41–43} predict postextubation distress after weaning from extended mechanical ventilation,⁴⁰ and potentially predict the need for increased breathing supports in patients with acute respiratory failure.³⁹ Despite these promising results, there is currently no published data for the use of LUS to predict who is likely to require extra respiratory support or further invasive mechanical ventilation after cardiac surgery, based on accurate and early detection of PPCs. We believe this gap in literature warrants investigation through robust studies on this topic.

Finally, the findings of this review align with previous literature demonstrating the superiority of LUS over traditional techniques for diagnosing pulmonary complications predominantly treated by physiotherapists.^{26,30–35} Whilst countries such as the United Kingdom (UK) have displayed a rapid rise in physiotherapy-led LUS assessments, the application of this skill by physiotherapists in Australia remains in its infancy.²⁹ Currently, the number of physiotherapists formally accredited to perform LUS within Australia is very low ($n = 4$), compared to a notably higher number reported in the UK ($n = 111$).²⁹ Although introductory training is available, many physiotherapists report that they lack time to complete training and implement LUS.³⁶ Within Australia, greater access to formal education pathways for physiotherapists to gain LUS credentialing is required, and frameworks are needed to support its safe and effective use within hospital settings.

4.1. Limitations

Articles included in this scoping review were limited to the English language, potentially restricting the inclusion of additional data for the role of LUS in the cardiac surgery population in other languages. This review solely focused on pulmonary complications predominantly treated by physiotherapists i.e., atelectasis, consolidation, and/or pneumonia. Despite the excellent diagnostic accuracy of LUS in detecting several lung pathologies, physiotherapists report low utilisation of this skill in clinical decision-making.³⁶ Therefore, this review sought to highlight the scope and diagnostic accuracy of LUS in diagnosing PPCs specifically amenable to physiotherapy treatments in the cardiac surgery population. The authors acknowledge that this limited a broader overview of the literature investigating the diagnostic accuracy of LUS for other PPCs that this population may encounter such as pleural effusions, pulmonary oedema, and pneumothoraces.

5. Conclusion

Overall, within the cardiac surgery population, LUS demonstrated a higher diagnostic accuracy for detecting atelectasis, consolidation, and/or pneumonia when compared to other diagnostic tools/tests (CXR, auscultation, clinical examination, or CXR combined with clinical examination). The addition of LUS to previously established assessment protocols or techniques also resulted in an improved diagnostic accuracy and a change in diagnosis in approximately two-thirds of patients. Additionally, the incidence of atelectasis, consolidation, and/or pneumonia detected by LUS increased across sequential time points for up to 72 h after surgery.

The results of this scoping review support the use of LUS in the cardiac surgery population; however, they also highlighted a lack of consistent LUS methodologies in diagnosing atelectasis, consolidation, and/or pneumonia. Future research is required to determine the most optimal methodology for diagnosing these PPCs and determining whether LUS possesses the ability to predict PPCs and early adverse respiratory outcomes in this population, to help guide

proactive respiratory supports after extubation and assist in reducing pulmonary complications.

Data availability statement

Not applicable.

Study registration

Not registered.

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CRediT authorship contribution statement

Luke Churchill: Conceptualisation, methodology, investigation, writing – original draft; **Oystein Tronstad:** Conceptualisation, methodology, writing – review and editing; **Allison Madrusiak:** Conceptualisation, methodology, writing – review and editing; **Jana Waldmann:** Conceptualisation, methodology, investigation, writing – review and editing; **Peter Thomas:** Conceptualisation, methodology, investigation, validation, writing – original draft, writing – review and editing.

Conflicts of interest

The authors do not have any competing interests to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.aucc.2023.08.002>.

References

- [1] Knuuti J, Wijns W, Saraste A, Capodanno D, Barbato E, Funck-Brentano C, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes: the Task Force for the diagnosis and management of chronic coronary syndromes of the European Society of Cardiology (ESC). *Eur Heart J* 2020;41(3):407–77.
- [2] Windecker S, Stortecky S, Stefanini GG, Rutjes AW, Di Nisio M, Silettta MG, et al. Revascularisation versus medical treatment in patients with stable coronary artery disease: network meta-analysis. *BMJ* 2014;348.
- [3] Siregar S, Groenwold RH, de Mol BA, Speekenbrink RG, Versteegh MI, Brandon Bravo Bruinsma GJ, et al. Evaluation of cardiac surgery mortality rates: 30-day mortality or longer follow-up? *Eur J Cardiothorac Surg* 2013;44(5):875–83.
- [4] Billah B, Reid CM, Shardey GC, Smith JA. A preoperative risk prediction model for 30-day mortality following cardiac surgery in an Australian cohort. *Eur J Cardiothorac Surg* 2010;37(5):1086–92.
- [5] Hansen LS, Hjortdal VE, Andreassen JJ, Mortensen PE, Jakobsen C-J. 30-day mortality after coronary artery bypass grafting and valve surgery has greatly improved over the last decade, but the 1-year mortality remains constant. *Ann Card Anaesth* 2015;18(2):138.
- [6] Montrieff T, Koyfman A, Long B. Coronary artery bypass graft surgery complications: a review for emergency clinicians. *Am J Emerg Med* 2018;36(12):2289–97.
- [7] Li H-C, Chen Y-S, Chiu M-J, Fu M-C, Huang G-H, Chen CC-H. Delirium, sub-syndromal delirium, and cognitive changes in individuals undergoing elective coronary artery bypass graft surgery. *J Cardiovasc Nurs* 2015;30(4):340–5.
- [8] Jensen L, Yang L. Risk factors for postoperative pulmonary complications in coronary artery bypass graft surgery patients. *Eur J Cardiovasc Nurs* 2007;6(3):241–6.
- [9] do Carmo TG, Santana RF, de Oliveira Lopes MV, Nunes MM, Diniz CM, Rabelo-Silva ER, et al. Prognostic indicators of delayed surgical recovery in patients undergoing cardiac surgery. *J Nurs Scholarsh* 2021;53(4):428–38.

- [10] Almashrafi A, Vanderbloemen L. Quantifying the effect of complications on patient flow, costs and surgical throughputs. *BMC Med Inform Decis Mak* 2016;16(1):1–15.
- [11] Engelman DT, Ali WB, Williams JB, Perrault LP, Reddy VS, Arora RC, et al. Guidelines for perioperative care in cardiac surgery: enhanced recovery after surgery society recommendations. *JAMA Surg* 2019;154(8):755–66.
- [12] Pimentel MF, Soares MJF, Murad JA, Oliveira MABd, Faria FL, Faveri VZ, et al. Predictive factors of long-term stay in the ICU after cardiac surgery: logistic CASUS score, serum bilirubin dosage and extracorporeal circulation time. *Braz J Cardiovasc Surg* 2017;32:367–71.
- [13] Quintana JF, Kalil RAK. Heart surgery: feeling of patient before and after surgery. *Psicol Hosp* 2012;10(2):17–32.
- [14] Al-Qubati FAA, Damag A, Noman T. Incidence and outcome of pulmonary complications after open cardiac surgery, Thowra Hospital, Cardiac center, Sana'a, Yemen. *Egypt J Chest Dis Tuberc* 2013;62(4):775–80.
- [15] Pahwa S, Bernabei A, Schaff H, Stulak J, Greason K, Pochettino A, et al. Impact of postoperative complications after cardiac surgery on long-term survival. *J Card Surg* 2021;36(6):2045–52.
- [16] Luckraz H, Manga Nn, Senanayake EL, Abdelaziz M, Gopal S, Charman SC, et al. Cost of treating ventilator-associated pneumonia post cardiac surgery in the National Health Service: results from a propensity-matched cohort study. *J Intensive Care Soc* 2018;19(2):94–100.
- [17] Neto AS, Hemmes SN, Barbas CS, Beiderlinden M, Fernandez-Bustamante A, Futier E, et al. Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis. *Lancet Respir Med* 2014;2(12):1007–15.
- [18] Woodring JH. Determining the cause of pulmonary atelectasis: a comparison of plain radiography and CT. *AJR Am J Roentgenol* 1988;150(4):757–63.
- [19] Vezzani A, Manca T, Benassi F, Galligani A, Spaggiari I, Brusasco C, et al. Diagnostic value of chest ultrasound after cardiac surgery: a comparison with chest X-ray and auscultation. *J Cardiothorac Vasc Anesth* 2014;18(1):1–182.
- [20] Armao D, Smith JK. The health risks of ionizing radiation from computed tomography. *N C Med J* 2014;75(2):126–31.
- [21] Pietersen PI, Madsen KR, Graumann O, Konge L, Nielsen BU, Laursen CB. Lung ultrasound training: a systematic review of published literature in clinical lung ultrasound training. *Crit Ultrasound J* 2018;10(1):1–15.
- [22] Grimberg A, Shigueoka DC, Atallah AN, Ajzen S, Iared W. Diagnostic accuracy of sonography for pleural effusion: systematic review. *Sao Paulo Med J* 2010;128:90–5.
- [23] Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care* 2013;17(5):1–8.
- [24] Laursen CB, Sloth E, Lassen AT, Christensen Rd, Lambrechtsen J, Madsen PH, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. *Lancet Respir Med* 2014;2(8):638–46.
- [25] Pivetta E, Goffi A, Lupia E, Tizzani M, Porrino G, Ferreri E, et al. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED. *Chest* 2015;148(1):202–10.
- [26] Alzahrani SA, Al-Salamah MA, Al-Madani WH, Elbarbary MA. Systematic review and meta-analysis for the use of ultrasound versus radiology in diagnosing of pneumonia. *Crit Ultrasound J* 2017;9(1):1–11.
- [27] Long L, Zhao H-T, Zhang Z-Y, Wang G-Y, Zhao H-L. Lung ultrasound for the diagnosis of pneumonia in adults: a meta-analysis. *Medicine* 2017;96(3).
- [28] Whittaker JL, Ellis R, Hodges PW, O'Sullivan C, Hides J, Fernandez-Carnero S, et al. Imaging with ultrasound in physical therapy: what is the PT's scope of practice? A competency-based educational model and training recommendations. *Br J Sports Med* 2019;53(23):1447–53.
- [29] Lockstone J, Brain M, Zalucki N, Ntoumenopoulos G. Implementation of physiotherapy-led lung ultrasound in the intensive care unit. *Aust Health Rev* 2023. Epub ahead of print.
- [30] Chavez MA, Shams N, Ellington LE, Naithani N, Gilman RH, Steinhoff MC, et al. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res* 2014;15(1):1–9.
- [31] Ye X, Xiao H, Chen B, Zhang S. Accuracy of lung ultrasonography versus chest radiography for the diagnosis of adult community-acquired pneumonia: review of the literature and meta-analysis. *PLoS One* 2015;10(6):e0130066.
- [32] Tasci O, Hatipoglu ON, Cagli B, Ermiş V. Sonography of the chest using linear-array versus sector transducers: correlation with auscultation, chest radiography, and computed tomography. *J Clin Ultrasound* 2016;44(6):383–9.
- [33] Tierney DM, Huelster JS, Overgaard JD, Plunkett MB, Boland LL, St Hill CA, et al. Comparative performance of pulmonary ultrasound, chest radiograph, and CT among patients with acute respiratory failure. *Crit Care Med* 2020;48(2):151–7.
- [34] Cantinotti M, Ait Ali L, Scalese M, Giordano R, Melo M, Remoli E, et al. Lung ultrasound reclassification of chest X-ray data after pediatric cardiac surgery. *Paediatr Anaesth* 2018;28(5):421–7.
- [35] Liu J, Chen S-W, Liu F, Li Q-P, Kong X-Y, Feng Z-C. The diagnosis of neonatal pulmonary atelectasis using lung ultrasonography. *Chest* 2015;147(4):1013–9.
- [36] Hansell L, Milross M, Delaney A, Tian DH, Rajamani A, Ntoumenopoulos G. Barriers and facilitators to achieving competence in lung ultrasound: a survey of physiotherapists following a lung ultrasound training course. *Aust Crit Care* 2023;36(4):573–8.
- [37] Bouhemad B, Liu Z-H, Arbelot C, Zhang M, Ferarri F, Le-Guen M, et al. Ultra-sonid assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. *Crit Care Med* 2010;38(1):84.
- [38] Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. *Minerva Anestesiol* 2012;78(11):1282–96.
- [39] Nobile L, Beccaria P, Zambon M, Cabrini L, Landoni G, Zangrillo A. Lung ultrasound reaeration score: a useful tool to predict non-invasive ventilation effectiveness. *Crit Care* 2014;18(1):1–182.
- [40] Soummer A, Perbet S, Brisson H, Arbelot C, Constantin J-M, Lu Q, et al. Ultra-sonid assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. *Crit Care Med* 2012;40(7):2064–72.
- [41] Seiler C, Klingberg C, Hårdstedt M. Lung ultrasound for identification of patients requiring invasive mechanical ventilation in COVID-19. *J Ultrasound Med* 2021;40(11):2339–51.
- [42] Lichter Y, Topilsky Y, Taieb P, Banai A, Hochstadt A, Merdler I, et al. Lung ultrasound predicts clinical course and outcomes in COVID-19 patients. *Intensive Care Med* 2020;46(10):1873–83.
- [43] de Alencar JCG, Marchini JFM, Marino LO, da Costa Ribeiro SC, Bueno CG, da Cunha VP, et al. Lung ultrasound score predicts outcomes in COVID-19 patients admitted to the emergency department. *Ann Intensive Care* 2021;11(1):1–8.
- [44] Cantinotti M, Giordano R, Volpicelli G, Kutty S, Murzi B, Assanta N, et al. Lung ultrasound in adult and paediatric cardiac surgery: is it time for routine use? *Interact Cardiovasc Thorac Surg* 2016;22(2):208–15.
- [45] Efremov SM, Kuzkov VV, Fot EV, Kirov MY, Ponomarev DN, Lakhin RE, et al. Lung ultrasonography and cardiac surgery: a narrative review. *J Cardiothorac Vasc Anesth* 2020;34(11):3113–24.
- [46] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol* 2005;8(1):19–32.
- [47] Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci* 2010;5(1):1–9.
- [48] Peters MD, Marnie C, Tricco AC, Pollock D, Munn Z, Alexander L, et al. Updated methodological guidance for the conduct of scoping reviews. *JBIM Evid Synth* 2020;18(10):2119–26.
- [49] Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 2018;169(7):467–73.
- [50] Peters M, Godfrey C, McInerney P, Baldini Soards C, Khalil H, Parker D. Methodology for JBI scoping reviews. The Joanna Briggs Institute reviewers' manual. The Joanna Briggs Institute; 2015.
- [51] Garduño-López J, García-Cruz E, Baranda-Tovar FM. Cardiac, cerebral, renal, optic nerve, and lung ultrasound study (CCROSS) protocol. *Arch Cardiol Mex* 2019;89(2):126–37.
- [52] Silva S, Ait Aissa D, Cocquet P, Hoarau L, Ruiz J, Ferre F, et al. Combined thoracic ultrasound assessment during a successful weaning trial predicts postextubation distress. *Anesthesiology* 2017;127(4):666–74.
- [53] Edrich T, Dünser MW, Lux M, Schaubmair H, Bacher B, Butturini E, et al. CASE 11–2015: intraoperative transthoracic cardiac and pulmonary ultrasonography. *J Cardiothorac Vasc Anesth* 2015;29(6):1702–11.
- [54] Corradi F, Brusasco C, Vezzani A, Santori G, Manca T, Ball L, et al. Computer-aided quantitative ultrasonography for detection of pulmonary edema in mechanically ventilated cardiac surgery patients. *Chest* 2016;150(3):640–51.
- [55] Parlevliet KL, Touw HRW, Beerepoot M, Boer C, Elbers PWG, Tuinman PR. Lung ultrasound detects pulmonary complications earlier than chest x-ray in patients after cardiac surgery: a prospective single centre observational study. In: Intensive care medicine experimental conference: 29th annual congress of the European society of intensive care medicine, ESICM 2016 Italy, vol. 4; 2016 (no pagination).
- [56] Royse A, Ford J, Brennan A, Royse C. Point-of-care lung ultrasound for cardiothoracic surgery patients. *Heart Lung Circ* 2016;25(8):e100–1.
- [57] Emperador IVF, Bennett SR, Gonzalez J, Saati A, Alsaywid BS, Fernandez JA. Extravascular lung water and effect on oxygenation assessed by lung ultrasound in adult cardiac surgery. *Cureus* 2020;12(8).
- [58] Ford JW, Heiberg J, Brennan AP, Royse CF, Canty DJ, El-Ansary D, et al. A pilot assessment of 3 point-of-care strategies for diagnosis of perioperative lung pathology. *Anesth Analg* 2017;124(3):734–42.
- [59] Touw H, Parlevliet KL, Beerepoot M, Schober P, Vonk A, Twisk JW, et al. Lung ultrasound compared with chest x-ray in diagnosing postoperative pulmonary complications following cardiothoracic surgery: a prospective observational study. *Anaesthesia* 2018;73(8):946–54.
- [60] Alsaddique A, Royse AG, Royse CF, Mobeirek A, El Shaer F, AlBackr H, et al. Repeated monitoring with transthoracic echocardiography and lung ultrasound after cardiac surgery: feasibility and impact on diagnosis. *J Cardiothorac Vasc Anesth* 2016;30(2):406–12.
- [61] Dureau P, Bouglé A, Melac AT, Hamou NA, Arbelot C, Hassen KB, et al. Colour Doppler ultrasound after major cardiac surgery improves diagnostic accuracy of the pulmonary infection score in acute respiratory failure: a prospective observational study. *Eur J Anaesthesiol* 2019;36(9):676–82.
- [62] House DR, Amatya Y, Nti B, Russell FM. Lung ultrasound training and evaluation for proficiency among physicians in a low-resource setting. *Ultrasound J* 2021;13(1):1–6.
- [63] Russell FM, Ferre R, Ehrman RR, Noble V, Gargani L, Collins SP, et al. What are the minimum requirements to establish proficiency in lung ultrasound training for quantifying B-lines? *ESC Heart Fail* 2020;7(5):2941–7.

- [64] Hayward S, Janssen J. Use of thoracic ultrasound by physiotherapists: a scoping review of the literature. *Physiotherapy* 2018;104(4):367–75.
- [65] Pietersen PI, Mikkelsen S, Lassen AT, Helmerik S, Jørgensen G, Nadim G, et al. Quality of focused thoracic ultrasound performed by emergency medical technicians and paramedics in a prehospital setting: a feasibility study. *Scand J Trauma Resusc Emerg Med* 2021;29(1):1–9.
- [66] O'Dochartaigh D, Douma M, MacKenzie M. Five-year retrospective review of physician and non-physician performed ultrasound in a Canadian critical care helicopter emergency medical service. *Prehosp Emerg Care* 2017;21(1):24–31.
- [67] Swamy V, Brainin P, Biering-Sørensen T, Platz E. Ability of non-physicians to perform and interpret lung ultrasound: a systematic review. *Eur J Cardiovasc Nurs* 2019;18(6):474–83.
- [68] Tsou PY, Chen KP, Wang YH, Fische J, Gillon J, Lee CC, et al. Diagnostic accuracy of lung ultrasound performed by novice versus advanced sonographers for pneumonia in children: a systematic review and meta-analysis. *Acad Emerg Med* 2019;26(9):1074–88.
- [69] Gomond-Le Goff C, Vivalda L, Foligno S, Loi B, Yousef N, De Luca D. Effect of different probes and expertise on the interpretation reliability of point-of-care lung ultrasound. *Chest* 2020;157(4):924–31.
- [70] Demi L, Wolfram F, Klersy C, De Silvestri A, Ferretti VV, Muller M, et al. New international guidelines and consensus on the use of lung ultrasound. *J Ultrasound Med* 2022;42(2):309–44.
- [71] Lichtenstein DA. BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill. *Chest* 2015;147(6):1659–70.
- [72] Torino C, Gargani L, Sicari R, Letachowicz K, Ekart R, Fliser D, et al. The agreement between auscultation and lung ultrasound in hemodialysis patients: the LUST study. *Clin J Am Soc Nephrol* 2016;11(11):2005–11.
- [73] Demi L, Mento F, Di Sabatino A, Fiengo A, Sabatini U, Macioce VN, et al. Lung ultrasound in COVID-19 and post-COVID-19 patients, an evidence-based approach. *J Ultrasound Med* 2022;41(9):2203–15.
- [74] Lichtenstein DA, Lascols N, Mezière G, Gepner A. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med* 2004;30:276–81.
- [75] Xirouchaki N, Magkanas E, Vaporidi K, Kondili E, Plataki M, Patrianakos A, et al. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. *Intensive Care Med* 2011;37:1488–93.
- [76] Hew M, Corcoran JP, Harriss EK, Rahman NM, Mallett S. The diagnostic accuracy of chest ultrasound for CT-detected radiographic consolidation in hospitalised adults with acute respiratory failure: a systematic review. *BMJ Open* 2015;5(5):e007838.
- [77] Llamas-Alvarez AM, Tenza-Lozano EM, Latour-Perez J. Accuracy of lung ultrasonography in the diagnosis of pneumonia in adults: systematic review and meta-analysis. *Chest* 2017;151(2):374–82.
- [78] Hansell L, Milross M, Delaney A, Tian DH, Ntoumenopoulos G. Lung ultrasound has greater accuracy than conventional respiratory assessment tools for the diagnosis of pleural effusion, lung consolidation and collapse: a systematic review. *J Physiother* 2021;67(1):41–8.
- [79] Khuri SF, Henderson WG, DePalma RG, Mosca C, Healey NA, Kumbhani DJ. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. *Ann Surg* 2005;242(3):326.
- [80] Beverly A, Brovman EY, Malapero RJ, Lekowski RW, Urman RD. Unplanned reintubation following cardiac surgery: incidence, timing, risk factors, and outcomes. *J Cardiothorac Vasc Anesth* 2016;30(6):1523–9.