Use of handheld ultrasound by intensive care nurses: a restricted review

Universitetet i Stavanger

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Master in Nursing, Specialization: Intensive Care

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KEYWORDS: point-of-care ultrasound, handheld ultrasound device, focused ultrasound, nurse, non-physicians, inferior vena cava, b-lines, pleural effusion, pericardial effusion, task-shifting.

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Preface

This master thesis marks the ending and completion of a master program in intensive care nursing at the University of Stavanger. Working with this thesis has been exciting, educational and challenging, and it is satisfying to see the final product.

After working as nurses for several years, this master program and internships has given us the opportunity to explore a new and challenging work environment. It has therefore been enriching and thrilling to be able to further investigate a tool that intensive care nurses may benefit from in their daily work and thus enhance patient care.

Several people have contributed to this this master thesis. Firstly, we would like to thank our head supervisor, Ingvild Margreta Morken, for her valuable and constructive comments throughout the process. Secondly, we would also like to thank our co-supervisor Marianne Laastad Sørensen for her positive and helpful feedback.

We would also like to thank the librarian, Elisabeth Hundstad Molland, at Stavanger University Hospital for all the help conducting a proper literature search.

Finally, we would like to thank family and friends for being supportive throughout the entire study period.

Stavanger, May 2023

Celia Brotons Payá and Solveig Gil Bjordal

Sammendrag

Hensikt: Utforske om intensivsykepleiere/annet helsepersonell nøyaktig kan utføre og tolke kardiale – og pulmonale målrettede ultralydbilder, samt hva innholdet og utførelsesmetoden i opplæringsprogrammene laget for å undervise intensivsykepleiere / annet helsepersonell i å utføre og tolke målrettede ultralydbilder var.

Metode: En systematisk litteraturoversikt av ni kvantitative studier. Datamaterialet ble analysert ved bruk av tematisk analyse.

Resultat: To hovedtemaer ble identifisert fra tematisk analyse: 1) strukturen i utdannings- og opplæringsprogrammene og 2) kvalifisert og kyndig utførelse av målrettet ultralyd. Utdannings- og opplæringsprogrammene inneholdt nettbaserte forelesninger, forelesninger med oppmøte og praktisk opplæring, og varigheten på disse varierte fra 90 minutter til 4 timer. Kunnskapsnivået til deltakerne ble evaluert med muntlige tilbakemeldinger fra ekspert eller en skriftlig prøve. Ved vurdering av pleuravæske, perikardvæske og påvisning av B-linjer, viste intensivsykepleierne/annet helsepersonell høy sensitivitet og spesifisitet sammenlignet med eksperter etter en kort opplæringsperiode. Resultatene indikerer at mer opplæring er nødvendig for å øke påliteligheten og samsvar med ekspert ved vurdering av inferior vena cava.

Konklusjon: Intensivsykepleiere/annet helsepersonell kan, etter en kort opplæringsperiode, utføre og tolke kardiale – og pulmonale målrettede ultralydbilder på en akseptabel og pålitelig måte. Med et godt opplæringsprogram kan målrettet ultralyd brukes av intensivsykepleiere som et mer kontinuerlig hemodynamisk overvåkningsverktøy, og kan dermed bidra til å forbedre pasientsikkerheten og redusere komplikasjoner hos pasienten.

Nøkkelord: Målrettet ultralyd, håndhold ultralyd, fokusert ultralyd, sykepleier, annet helsepersonell, inferior vena cava, b-linjer, pleuravæske, perikardvæske, oppgaveglidning.

Abstract

Aim: To summarize information about the possibility of intensive care nurses accurately performing and interpreting point-of-care cardiac and lung images, and the content and delivery mode of the education and training programmes designed to educate intensive care nurses / non-physicians to perform and interpret point-of-care ultrasound.

Methods: A systematic restricted review of nine quantitative studies. The data were analysed by the means of thematic analysis.

Results: Two main themes were derived from thematic analysis: 1) structure of the education and training programmes, and 2) qualified and skilled performance of point-of-care ultrasound. The content of the education and training programmes was online lectures, in-person lectures and hands-on training. The duration ranged from 90 minutes to 3 hours. Participants' knowledge was evaluated with expert feedback or an evaluation test. When assessing pleural effusion, pericardial effusion and detecting B-lines, ICU nurses/non-physicians demonstrated a high sensitivity and specificity compared to expert reviewer after a short training period. Results indicate that more training is needed in inferior vena cava examinations to enhance reliability and improve the level of agreement with expert reviewer.

Conclusion: Intensive care nurses/non-physicians can, after a short training period, adequately acquire and interpret point-of-care ultrasound scans using a handheld ultrasound device in a valid and reliable way. With proper training and education point-of-care ultrasound can be used by intensive care nurses/non-physicians as a more continuous and personalized hemodynamic monitoring tool and can improve patient safety and decrease complication rates.

Keywords: point-of-care ultrasound, handheld ultrasound device, focused ultrasound, nurse, non-physicians, inferior vena cava, b-lines, pleural effusion, pericardial effusion, task-shifting.

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Abbreviations

POCUS: Point-of-care ultrasound

HUD: Handheld ultrasound device

ICU: Intensive care unit

HF: Heart failure

LV: Left ventricle

PE: Pericardial effusion

IVC: Inferior vena cava

EACVI: European Association of Cardiovascular Imaging

ACEM: Australasian College for Emergency Medicine

CCCS: Canadian Critical Care Society

TSANZ: Thoracic Society of Australia and New Zealand

MICU: Medical intensive care unit

FoCUS: focused cardiac ultrasound

WHO: World Health Organization

MR: Magnetic Resonance

SUSTAIN: Stavanger ultrasound training and innovation network

ED: Emergency department

LUS: Lung ultrasound

PLE: Pleural effusion

BLUE-protocol: bedside lung ultrasound in emergency

1. Introduction

This master thesis aims to summarize information about the possibility of intensive care nurses (ICU) nurses to accurately perform and interpret point-of-care ultrasound (POCUS). In addition, this master thesis also aims to explore the education and training needed for novice ultrasound operators, such as intensive care nurses, to acquire and interpret focused point-of-care examinations when assessing pleural effusion, pericardial effusion, detecting B-lines and inferior vena cava volume status in a reliable and valid way.

1.1. Structure of the master thesis

This master thesis comprises six chapters. The introductory chapter briefly describe the background for the chosen theme, followed by the aims of the thesis. Chapter 2 explains concepts, previous and present literature which constitutes the theoretical framework. Chapter 3 describes the methodological approaches applied in the review and chapter 4 presents the results. In chapter 5, the findings are discussed in the light of earlier research and relevant theories which is followed by a methodological consideration related to the review. Finally, chapter 6 provides the conclusion, including implications for the clinical practice and suggestions for further research.

1.2. Background

Ultrasound is an imaging method used to assess structures of the human body and can be an essential tool when operated by different professions in various clinical settings (Cardim et al., 2018; Gillman & Kirkpatrick, 2012). In the past decades, the use of ultrasound has expanded from only being performed by health care professionals in specialized departments to being an essential tool when assessing the patient bedside (Gillman & Kirkpatrick, 2012). Point-of-care ultrasound (POCUS) is defined as "a goal-directed, bedside ultrasound examination performed by a health care professional to answer a specific diagnostic question" (Soni et al., 2015). With the development of handheld ultrasound devices (HUDs) which are smaller, faster, easy to use and ultra-portable, POCUS has become a standard tool for advanced hemodynamic monitoring of the critically ill patient in the intensive care unit (ICU) (Barjaktarevic et al., 2021; Brunhoeber et al., 2018; Díaz-Gómez et al., 2021).

Simultaneously, the responsibility and functions of nurse practitioners in the ICUs has increased with demonstration of efficacy and quality care in the setting of an intensivist shortage and resident hour restrictions (Brunhoeber et al., 2018; Landsperger et al., 2016). Nurses are a consistent work force and are available, especially after hours, when sonographers or POCUS qualified physicians are not (Bowra et al., 2010; Mumoli et al., 2016; Steinwandel et al., 2018). Being constantly bedside and providing critical care makes nurses suitable for the use of POCUS as a continuous hemodynamic monitoring tool (Tulleken et al., 2019). Several studies show that non-radiologists and non-cardiologists, such as nurses, accurately can acquire and interpret heart and lung ultrasound images and become competent in the performance of POCUS (Brunhoeber et al., 2018; Díaz-Gómez et al., 2021; J. K. Donovan et al., 2022; Steinwandel et al., 2018; Swamy et al., 2019; Tulleken et al., 2019). Some clinical applications regarding POCUS that are relevant for nurse management and patient care are: 1) cardiac function and volume status assessment in critically ill patients admitted to the ICU, 2) decompensated heart failure (HF) management and HF follow-up addressing left ventricle (LV) function and volume status, 3) pericardial effusion (PE) in the setting of invasive cardiac procedures, 4) right atrial pressure estimation by measuring size and collapsibility of the inferior vena cava (IVC), 5) B-lines assessment (Chamsi-Pasha et al., 2017; J. K. Donovan et al., 2022).

POCUS relies not only on skilled operator availability, but also on dedicated training in acquisition and interpretation of images to acquire and maintain competency, especially when the handheld ultrasound examination is performed by non-physicians (Chamsi-Pasha et al., 2017; Mayo et al., 2017). Currently, there are no standardized or validated programmes on how to educate and train nurses and non-physicians in the use of HUDs (Australasian College for Emergency Medicine, 2021; Cardim et al., 2018; Galusko et al., 2017). Studies regarding teaching, certification and training programmes is still limited (Galusko et al., 2017). However, the European Association of Cardiovascular Imaging (EACVI), the Australasian College for Emergency Medicine (ACEM) and the Canadian Critical Care Society (CCCS) have published their guidelines and recommendations for critical care ultrasound training and competency. These guidelines include minimum criteria appropriate to achieve competence in imaging acquisition and interpretation, as well as specific education and training in HUDs (Arntfield et al., 2014; Australasian College for Emergency Medicine, 2021; Neskovic et al., 2014).

In our opinion, implementing and educating bedside working ICU nurses in POCUS can improve patient safety and decrease complication rates. In addition, POCUS can be used as a more continuous and personalised hemodynamic monitoring since changes in vital signs frequently precede deterioration in patient's condition. POCUS performed by nurses permits a quick detection of physiological changes as well as goal-directed treatment and management (Díaz-Gómez et al., 2021; Tulleken et al., 2019). Therefore, it is imperative to evaluate ICU nurses' performance of this skill and define the appropriate use to guarantee that ICU nurses have the necessary training and competence to use POCUS in a correct and safe manner (Brunhoeber et al., 2018; Moore & Copel, 2011).

1.3. Choice of theme

ICU nurses work in a high-technological environment where they are supposed to manage and understand the technical equipment being used. During our internships at the ICU and the medical intensive care unit (MICU), we have seen medical doctors and ICU nurses perform POCUS on critically ill patients. We have also had laboratory training about HUDs where we were able to understand the possibilities that POCUS offers to ICU nurses, such as assessing patients, independent decision-making and patient safety improvement.

When deciding on a theme for our master thesis we got inspiration from Marianne Laastad Sørensen, a professional development nurse working at MICU and who is responsible for training nurses in the use of HUDs and POCUS at the MICU. Sørensen wrote about ICU nurses performing point-of-care ultrasounds in her master thesis in 2019 and her newly published article "Point-of-care examinations using handheld ultrasound devices performed by ICU in a cardiac intensive care unit". ICU nurses are not always able to rely on vital signs due to ongoing treatment and medication can mask these signs. As recent graduate ICU nurses we would like to explore other reliable approaches to evaluate the patient's condition, such as POCUS.

1.4. Aim

Nurses performing point-of-care ultrasound is a relatively new domain. Therefore, the aim of this restricted review is to summarize information about the possibility of ICU nurses to accurately perform and interpret POCUS cardiac and lung images, and the content and delivery mode of the education and training programmes designed to educate ICU nurses / non-physicians to perform and interpret POCUS.

Our research questions were as follows:

1) What are the content and delivery modes of the education and training programmes designed to educate ICU nurses/non-physicians to perform and interpret point-of-care ultrasound?
2) Can ICU nurses / non-physicians acquire and interpret point-of-care ultrasound using a handheld ultrasound device to assess cardiac and lung ultrasound (B-lines identification) and assessment of inferior vena cava in in-hospital or outpatient settings?
3) Can ICU nurses / non-physicians acquire and interpret a cardiac and lung ultrasound scan using a handheld ultrasound device in a valid and reliable way?

2. Theoretical Framework

This chapter contains the theoretical framework of our study. The first part of this section includes concepts of patient safety, quality of healthcare and knowledge-based practice. Further, task shifting and ICU nurses' role and scope of practice are being described. Additionally, POCUS, focused cardiac ultrasound (FoCUS) and lung ultrasound concepts are being clarified.

2.1. Patient safety, quality of healthcare and knowledge-based practice

The World Health Organization (WHO) defines patient safety as protection against unnecessary damage as a result of the health service's benefits or lack of benefits and aims to prevent and reduce risks, errors and harm that occur to patients during provision of health care (Helsedirektoratet, 2018; World Health Organization, 2019). Patient safety may be enhanced by expansion of the ICU nurses' competence with a tool such as focused ultrasound. This could help detecting physiological signs of deterioration and prevent possible complications. The use of ultrasound could therefore contribute to increased patient comfort, shorter length of stay and in consequence increase the quality of treatment and patient safety (Brunhoeber et al., 2018; Geer, 2021; Mitchell, 2018). A systematic review from 2018, indicated that nurses could obtain adequate ultrasound images and thus improve the safety and successfully perform different procedures, such as venous catheter insertion, nasogastric placement and measurements of the vena cava inferior (Varndell et al., 2018). Nurse's use of ultrasound makes important patient information available to the attending physician, improves the efficiency and effectiveness of nursing-based procedures, and minimizes intrahospital transfers (ie. chest X-rays or magnetic resonance (MR)) and consequently, contributes to increased patient safety (Geer, 2021). These benefits derived from nurses performing POCUS are in line with the WHO's definition of patient safety (World Health Organization, 2019).

The Norwegian Department of Health have developed laws and regulations relating to the management and quality improvement in the healthcare system (Helsedirektoratet, 2018). These laws and regulations state that, to be successful with change and improvement, the workplace must guarantee that the necessary competence is recruited and sufficient training is given. In addition, the employees must ensure that they have sufficient knowledge and competence to perform their job. Ensuring the necessary competence in performing POCUS should be based on reliable knowledge of the effect of measures and should be based on the best and most up-to-date knowledge (Meld. St. 10, 2012-2013). Knowledge-based practise is, in Norway, defined as making decisions based on systematically acquired research-based knowledge, experience-based knowledge and the patient's wishes and needs in a given situation (Helsedirektoratet, 2018). Critical care nursing is knowledge-based and ICU and ICU nurses are expected to build competence, improve quality and develop new evidence with the use of advanced medical technology (Brunhoeber et al., 2018; Norwegian Nurses Organisation, 2017; Stubberud, 2020).

Nowadays, POCUS is only performed by a few ICU nurses in Norway (Mitchell, 2018). However, the use of POCUS by nurses and non-physicians in other countries varies in terms of training and education. In Norway, teaching in the use of ultrasound is not included in basic nursing education, nor in most specialist education at master's level. Some hospitals in Norway have local projects where nurses and specialized nurses are trained to perform ultrasound examinations (Mitchell, 2018). For example, Levanger Hospital developed a certification programme called "Levangermodellen" in 2016 and have since then trained nurses at the heart failure outpatient clinic, MICU and cardiac department to perform focused transthoracic echocardiography to assess fluid status (Jørgensen & Gundersen, 2017). Additionally, Stavanger ultrasound training and innovation network (SUSTAIN), a group formed at the University of Stavanger, works to introduce ultrasound as a new diagnostic tool in selected master's studies in specialist nursing (Universitetet i Stavanger, 2021).

2.2. ICU nurses' role and scope of practice and task shifting

ICU nurses have an ethical and legal responsibility to be up-to-date professionally in order to care for patients in a safe and high quality manner (Helsepersonelloven, 1999; Norwegian Nurses Organisation, 2017). Indeed, ICU nurses must be able to handle complex technical devices and safely utilize them within critical care (European Federation of Critical Care Nursing Associations, 2013). In addition, ICU nurses have to titrate medications according to prescription parameters and are responsible for administering advanced medical treatment according to the increasingly advanced medical developments in terms of technical equipment and drug treatment (European Federation of Critical Care Nursing Associations, 2013; Norwegian Nurses Organisation, 2017).

In our experience, ICU nurses not only work as part of a team, but also make independent decisions taking into account physiological changes and patient status. Therefore, both professional and technological development allows health care professionals to take over other areas of responsibility, such as performing POCUS (Leonardsen & Østfold, 2020). Task shifting is a well-known phenomenon in the health care system, both nationally and internationally. It is defined as "a delegation where tasks are moved from highly specialized workforces to less specialized health workers" (Leonardsen & Østfold, 2020).

In Norway, the Health Personnel Act allows task shifting as the health care professionals are evaluated according to their professional qualifications, not their profession (Helsepersonelloven, 1999). Task shifting can be a way for the health care system to meet future challenges, and it can increase patient safety, when done in a regulated and responsible way (Baugstø, 2022; Leonardsen & Østfold, 2020). However, task shifting might threaten existing hierarchies and artificial restrictions on what some health care professionals can do, and this often relates to maintaining the dominance of one group rather than the welfare of the patient (European Commission, 2019; Leonardsen & Østfold, 2020). As stated in the literature, the ultrasound performed by nurses should not replace the conventional ultrasound examination performed by doctors (Chamsi-Pasha et al., 2017; Mitchell, 2018).

2.3. Point-of-care ultrasound

Point-of-care ultrasound (POCUS) is commonly used, and is increasingly popular, in intensive care settings to rapidly assess patients' hemodynamic and respiratory status and as a monitoring tool at the ICU to monitor critically ill patients (Brunhoeber et al., 2018). POCUS is safe, cost effective and a goal-directed examination compared to a formal ultrasound where all the anatomic aspects of the organ system gets evaluated (Brunhoeber et al., 2018; Chamsi-Pasha et al., 2017). Performing POCUS is not limited to one speciality and it provides the treating clinician with real-time diagnostic and monitoring information and can be used to enhance the safety of standard ultrasound-guided procedures (Díaz-Gómez et al., 2021).

Focused cardiac ultrasound (FoCUS) refers to a point-of-care ultrasound examination that is goal oriented in a specific clinical setting to supplement the physical examination and it can be used on stable and unstable patients (Chamsi-Pasha et al., 2017; Savino & Ambrosio, 2019). FoCUS can extend the physical examination and one can achieve rapid diagnosis, early treatment and basic monitoring of some cardiac diseases (Savino & Ambrosio, 2019). The findings on these goal-directed examinations aid in early cardiac triage and management with great utility when used in ICUs and emergency departments (ED) settings where echocardiography may not be readily available (Chamsi-Pasha et al., 2017). Other additive values are short time acquisition (<5 minutes), rapid diagnosis in symptomatic patients, and detection of clinically significant pathologies in asymptomatic individuals (Fuster, 2016; Spencer et al., 2013).

The need for evaluating cardiac function and volume status in critically ill patients is crucial in patient management (Chamsi-Pasha et al., 2017), especially for nurses that continuously monitor changes in physiological vitals and adjust treatment accordingly. Several studies show the superiority of handheld echocardiography in helping manage patients with decompensated HF (Goonewardena et al., 2008; Lucas et al., 2011; Wiley et al., 2022). Additionally, the size and collapsibility of the IVC is a valuable measure to assess volume status in critically ill patients and patients with HF (Goonewardena et al., 2010; Razi et al., 2011; Zengin et al., 2013).

The measurement of IVC respiration variability and diameter can help assess fluid status and hemodynamic, which makes POCUS examination an alternative or supplement to invasive hemodynamic measurements (Busse et al., 2013; Mikkelsen et al., 2022; Yanagawa et al., 2007). In their cross-sectional interrater pilot study, Steinwandel et al. (2018) concluded that a renal nurse could reliably perform ultrasound of the IVC in haemodialysis patients, obtaining high quality scans for volume assessment. Gundersen et al. (2016) concluded that focused ultrasound examinations of the pleural cavities and IVC among HF patients performed by nurses significantly predicted dose adjustments of diuretics compared to standard care, and Brunhoeber et al. (2018) concluded that ICU nurses could accurately acquire and interpret POCUS images of IVC. Additionally, a recent literature review by Meissner (2022) explored the use of lung ultrasound for detection of fluid overload in patients on dialysis, including its applicability to routine nursing practice. A strong association between the B-lines detected through LUS and fluid overload was demonstrated, which meant that LUS was superior in detecting lung congestion and fluid overload compared to standardized assessment.

Lung ultrasound (LUS) is carried out to look for lung sliding, B-lines, pleural effusion (PLE), empyema, atelectasis or pneumothorax (Nielsen et al., 2019). It is also used to verify endotracheal tube position (Saga, 2021; Sağlam et al., 2022) and it can be used in mechanically ventilated patients to guide positive end-expiratory pressure setting, assess the efficacy of treatments, monitor the evolution of the respiratory disorder, and as a predictor during weaning from mechanical ventilator support (Mayo et al., 2016; Mojoli et al., 2018). LUS signs, either alone or combined with other POCUS techniques, are helpful in the diagnostic approach to patients with acute respiratory failure, circulatory shock, or cardiac arrest (Mojoli et al., 2018).

The BLUE-protocol (bedside lung ultrasound in emergency) is used for the immediate diagnosis of acute respiratory failure (Lichtenstein, 2015), for example, lung sliding with lung rockets define the B-profile and usually indicate hemodynamic pulmonary oedema. This examination is currently carried out by anaesthesiologists in the ICU in Norway, though in Italy, nurses perform LUS to identify causes of acute cardiogenic pulmonary congestion with good accuracy in combination with serum brain natriuretic peptide levels (Mumoli et al., 2016) and in a recent scoping review by (J. K. Donovan et al., 2022), paramedics demonstrated the feasibility of LUS in the out-of-hospital environment.

In their observational study, Zisis et al. (2022) determined that nurses that work with heart failure patients could obtain images and provide diagnostics reports performing LUS and IVC assessment (LUICA) that are predictive of acute decompensated heart failure outcomes. Both Zisis et al. (2022) and Meissner (2022) stated that to achieve an effective application of POCUS performance, non-experts delivering POCUS need routine use and protocols.

3. Methods

Cochrane Rapid Reviews Method Group define a rapid review as "a form of knowledge synthesis that accelerates the process of conducting a traditional systematic review through streamlining or omitting specific methods to produce evidence for stakeholders in a resource-efficient manner" (Garritty et al., 2020). Due to the characteristics of this master thesis project, the limited experience of the authors and time limitation, a systematic restricted review was seen as a suitable method (Plüddemann et al., 2018). Plüddemann et al. (2018) conclude that if restricted or rapid reviews are conducted well, the information obtained could be used by clinicians in decision-making about healthcare interventions. A restricted review consists of core steps that are minimum requirements for systematic reviews. The framework comprises six core steps: (1) literature search, (2) study selection, (3) data extraction, (4) critical assessment of the included studies, (5) data synthesis, and (6) publication (Plüddemann et al., 2018).

3.1. Step 1: Literature search and research terms

The use of handhold ultrasound by ICU nurses is relatively a new procedure and has not been implemented in many hospitals yet. For this reason, different information sources were included to identify potentially relevant documents, map the research already done in this area, as well as to identify any existing gaps in knowledge.

The following bibliographic databases were searched: EMBASE, MEDLINE, CINAHL and British Nursing Index. Polit and Beck (2021) suggest searching for primary studies in multiple bibliographic databases and “snowball sampling”, that is, actively screening the reference list of the included articles for other relevant studies.

The search strategies were checked by an experienced librarian at University of Stavanger. It was further refined through team discussion and supervised by the project tutors. The research questions were based on a PI(c)O-chart (Thomas et al., 2022) and the search terms used in the data base search are described in Table 1. Documentation of the search strategy and search terms is presented in APPENDIX 1. The final searches were performed from December 2022 to January 2023. EMBASE was inaccessible from December 31st 2022 because the Norwegian Electronic Health Library did not extend their subscription to the database.

Table 1. Search terms

Search terms
Nurse, non-physician, paramedic
Ultrasonography, sonography, echocardiography, echocardiograph, point-of-care, POCUS
Heart, cardiac, cardiovascular, pericardium, lung, pulmo, pleura, vena cava, cava vein, venae cavae
Competence, education, certification, training, learning, simulation, teach, program development, program evaluation

3.1.1. Eligibility criteria

Eligibility criteria is summarized in Table 2. To ensure that our results reflect current conditions, this restricted review was limited to data published between 2012 and 2022 in English, Spanish, French or Scandinavian language.

In many studies nurses are described as non-physicians or operators with different backgrounds. Therefore, non-physicians and paramedics are also included as inclusion criteria in addition to nurses.

Table 2. Eligibility criteria

Inclusion criteria	Exclusion criteria
- Handheld ultrasound interventions - **Participants**: Nurses / ICU nurses / Non-physicians / Paramedics - **Patient population**: Adults >18 years old - **Study designs**: Experimental, cross-sectional, longitudinal, cohort - **Setting**: Intensive care unit, outpatient clinic, emergency unit, medical intensive care unit, prehospital care - Peer-reviewed studies - **Published** in English, French, Spanish or Scandinavian language.	- Tele-ultrasonography - Obstetrics & paediatrics - Full text not available - Review studies, study protocols, book chapters, and conference contributions, abstracts and thesis

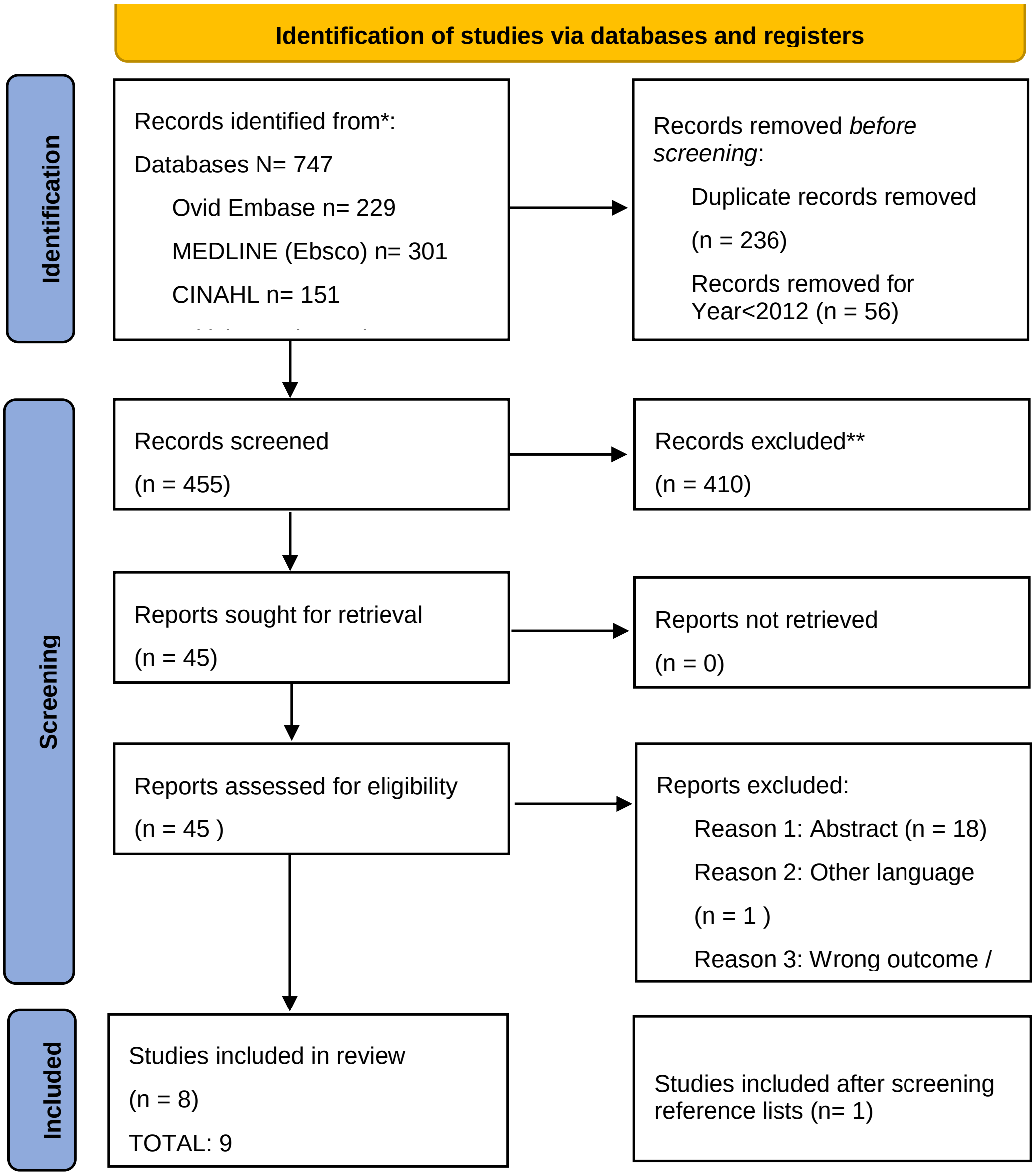
3.2. Step 2: Study selection

The literature search process is outlined in APPENDIX 1. The search yielded a total of 747 references; after the removal of 236 (32%) duplicates by using Endnote (Clarivate) and 56 (8%) articles being excluded because they were published before 2012, 455 (61%) titles and abstracts were assessed for inclusion. Both authors of this restricted review (SGB and CBP) carried out an initial broad review of all included titles and abstracts using the Rayyan Systematic Review Screening Software (Rayyan). This software allows reviewers to, blinded to one another, screen all of the references and select include, exclude or maybe for each article. Reviewers being blinded to one another reduces potential bias and enhance objectivity (Polit & Beck, 2021). Of the 455 titles and abstracts, 45 (9%) were evaluated for eligibility in full text. After independently reading titles and abstracts, any conflicts were discussed, and the articles were included or excluded based on consensus and inclusion criteria (Table 2). Subsequently, a new file with the selected articles was created in Rayyan, and a full text revision was carried out. Both authors conducted the full text revision by reading articles independently and any disagreements on study selection were resolved by consensus. The supervisors (IMM and

MLS) were also involved as expertise in the field. After full text revision, 8 (2%) articles met all inclusion criteria and were included. Screening the reference lists of the included studies identified additionally one study (Pietersen et al., 2021). Finally, this review included 9 studies.

The results of the data search and selection process are displayed in a PRISMA (preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart Figure 1 (Page et al., 2021).

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow chart of the study selection process



3.3. Step 3: Data extraction

A data-charting form was jointly developed by the authors using Excel (Microsoft Corp) to ensure consistent data extraction from the included articles as recommended by Li et al. (2022). The data-charting form was divided in 6 sections: (1) basic data information, (2) methodologic information, (3) sample and participants, (4) point-of-care ultrasound, (5) training programme, and (6) quality appraisal results (MMAT assessment).

Data extraction and coding of data from the articles was completed by the authors (CBP & SGB) to allow for an assessment of interrater agreement, and monitoring to reduce extraction errors which is a common problem in systematic reviews (Mathes et al., 2017; Polit & Beck, 2021).

3.4. Step 4: Critical assessment of included studies

The Mix Methods Appraisal Tool (MMAT) aims to appraise the methodological quality of included studies in systematic reviews by systematically assessing and interpreting evidence, its validity, results and relevance to the context (Hong, Pluye, et al., 2018). MMAT assesses the trustworthiness, relevance and results, in addition to minimizing bias, assessing internal validity of the included studies, risk of bias and potential conflicts of interest (Polit & Beck, 2021).

For this review, checklists for quantitative non-randomized studies and quantitative descriptive studies were used. Each checklist is initiated with 2 screening questions to allow for further assessment, and each list contains 5 questions about assessment criteria to be answered with “Yes”, “No” and “Can’t tell”. A total score of 5 constitutes a “Yes” response to the screening and assessment criteria (Hong, Gonzalez-Reyes, et al., 2018). The developers recommend that MMAT should only be used to describe the study quality and to avoid excluding studies based on total scores (Hong, Gonzalez-Reyes, et al., 2018).

The authors (CBP and SGB) independently assessed each primary study using the MMAT version 2018. One supervisor (IMM) independently appraised three of the articles to enhance objectivity and reduce bias. Disagreements were resolved by consensus or in meetings with the supervisors.

All the included articles were published in recognized and peer-reviewed journals. Identification of study designs in Dalen et al. (2015) and Gustafsson et al. (2015) was not clear after reviewing the study's methods section. It was therefore discussed with the supervisors to ensure that further quality assessment was carried out with the right quality appraisal tool.

The quality assessment is presented in Table 3 and Table 4. Seven articles were assessed as high quality (ie, of the 5 criteria, 4 were answered with "*Yes*") and one was assessed as moderate quality (score 3). Guy et al. (2019) scored 2 points due to a small paramedic sample which was recruited by convenience sampling, as well as it was not possible to identify if all the participants completed the online training. No studies were excluded based on this data evaluation rating system.

Patient sample was recruited by consecutive sampling in all of the studies and most of the studies included a sample over 50 patients, except for Pietersen et al. (2021) and J. Donovan et al. (2022) where sample size was not registered. Guy et al. (2019) did not include patients in their study. Nurses and paramedics were recruited through convenience sampling and the sample size was small in most of the studies (range 2 – 100). As bias in the population is concerned, in two of the studies one of the nurses performed 58% and one paramedic performed 34% of the ultrasound examinations (J. Donovan et al., 2022; Gustafsson et al., 2015). In addition, some of the studies cannot relate how many ultrasounds were performed per nurse or paramedic (Graven et al., 2015; Pietersen et al., 2021; Schoeneck et al., 2021). Three studies included participants with and without prior experience (J. Donovan et al., 2022; Guy et al., 2019; Schoeneck et al., 2021).

Table 3. Critical appraisal of quantitative non-randomized studies

MMAT	Screening questions (for all types)		Category of study design: 3) Quantitative non-randomized studies					Results
Study (Year)	**1**	**2**	**1**	**2**	**3**	**4**	**5**	**Score**
Ünlüer, EE (2014)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Gustafsson, M (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Dalen, H (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Graven, T (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Schoeneck, JH (2021)	Yes	Yes	Yes	Yes	No	Yes	No	3
Pietersen, PI (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Sørensen, ML (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	5
Donovan, JK (2022)	Yes	Yes	Yes	Yes	Can't tell	Yes	Yes	4

Screening questions: 1) Are there clear research questions?; 2) Do the collected data allow to address the research questions?
Category of study design questions: 1) Are the participants representative of the target population?, 2) Are measurements appropriate regarding both the outcome and intervention (or exposure)?, 3) Are there complete outcome data?, 4) Are the confounders accounted for in the design and analysis?, 5) During the study period, is the intervention administered (or exposure occurred) as intended?

Table 4. Critical appraisal of quantitative descriptive studies

MMAT	Screening questions (for all types)		Category of study design: 3) Quantitative non-randomized studies					Results
Study (Year)	**1**	**2**	**1**	**2**	**3**	**4**	**5**	**Score**
Guy A, (2019)	Yes	Yes	No	No	Yes	No	Yes	2

Screening questions: 1) Are there clear research questions? 2) Do the collected data allow to address the research questions?
Category of study design questions: 1) Is the sampling strategy relevant to address the research question?, 2) Is the sample representative of the target population?, 3) Are the measurements appropriate?, 4) Is the risk of nonresponse bias low?, 5) Is the statistical analysis appropriate to answer the research question?

3.5. Step 5: Data synthesis

Due to the heterogeneity of the study designs, participants, and outcome measures, meta-analysis was not recommended (Polit & Beck, 2021). Thus, the effects of POCUS performance and training programme outcomes were reviewed and reported narratively as suggested by Whittemore and Knafl (2005). The integrative review method suggested by Whittemore and Knafl allows for the combination of diverse methodologies and has the potential to play a greater role in evidence-based practice for nursing. The findings on education and training programmes outcomes and POCUS performed by nurses or non-physicians were systematically analysed by using thematic analysis as well as searching for patterns, themes and categories across studies.

3.6. Step 6: Publication

The results from this restricted review will be published, including all appendices and added data. In addition, the study's findings will be disseminated in relevant clinical settings and websites.

3.7. Ethical considerations

According to literature, ethical considerations is a topic that should not be evaluated due to the characteristics of a restricted review, which normally has a very limited timeframe (Garritty et al., 2020; O'Leary et al., 2017; Plüddemann et al., 2018). Neither does a restricted review require an institutional ethics approval before commencing. However, the authors are aware of the role that restricted reviews play in influencing policies, providing relevant evidence to make informed decisions about health care systems, further research and public perception, as well as analysis of cost-effectiveness (O'Leary et al., 2017; Suri, 2020; Tricco et al., 2017). Therefore, it's important to consider and acknowledge ethical challenges and responsibilities that could arise during the research process.

In addition, the potential benefits of the research to various groups (health care systems, nurses and patients) was taken into account (Suri, 2020). Methodological bias and ethical considerations that could arise from the individual studies included in this restricted review were critically reflected upon and analysed using MMAT.

The authors have taken into account any potential conflicts of interest and the review does not contain plagiarized material.

4. Results

4.1. Overview

The study selection process is outlined in Figure 1. The search yielded a total of 747 references; after the removal of 236 (32%) duplicates, 455 (61%) titles and abstracts were assessed for inclusion. Of the 455 titles and abstracts, 45 (9%) titles pertaining to POCUS performed by nurses / non-physicians and POCUS education and training programmes were screened for eligibility. Of the 45 studies evaluated for eligibility in full text, 8 (2%) met all inclusion criteria and were included. Screening the reference lists of the included studies identified a further study. Finally, this review included 9 studies.

In this section, results from the systematic restricted review are narratively described, and a visual model of the thematic analysis is presented in Figure 2.

Figure 2. Visual model of the thematic analysis

The black circles containing "Structure of the education and training programme" and "Performance of POCUS" represent the two main subjects in the research questions of this study. This model presents the two themes that emerged from the thematic analysis and are represented as circles arising from the main themes. The subthemes derived from the main themes are represented in smaller circles.

4.2. Study characteristics

Detailed characteristics of the included studies are displayed in Table 5. All studies were published between 2014 and 2022. Of the nine studies, five (56%) were performed in Scandinavian countries, and two (22%) in USA/Canada. The predominant study design was prospective observational (44%) and prospective cross-sectional (44%). Of the included studies, 44% were pilot studies.

In five (56%) of the studies B-lines were evaluated, and in six (67%) of the studies pleural effusion (PLE) and/or PE were assessed. The collapsibility and diameter of IVC was assessed in three of the studies (33%). The duration of the studies was from 1 – 26 months.

The study participants in five (56%) of the studies were nurses or specialised nurses and in four (44%) of the studies the participants were paramedics. In the 44% of the studies, the participants had no prior experience in the use of HUDs or POCUS. Dalen et al. (2015) only included participants with prior experience in ultrasound whereas, Ünlüer et al. (2014) did not register participant's previous experience with HUDs.

Regarding patient recruitment, approximately one third of the studies recruited patients in pre-hospital settings, and one third of the studies recruited patients in the emergency room or ICU, and in twenty-two percent of the studies patients were recruited in out-patient-clinics. The diagnosis criteria for including patients in the studies were: dyspnoea 56%, HF patients 22%, and post-cardiac surgery 11%. Guy et al. (2019) did not include patients for their study.

Table 5. Characteristics of the included studies

Basic data information	**Methodologic information**				**Results**	**Quality appraisal**
Study (year) (country)	**Design**	**Sample size (N)**	**Characteristics of study participants**	**Characteristics of the patients**	**Main finding**	**MMAT score**
Ünlüer, EE (2014) Turkey	Prospective cross-sectional cohort study: pilot study	2	**Profession**: EN* **Years of experience**: At least 5 **Prior experience w/US**: Not registered	**Patient size:** 96 **Age**: 70,6 **Sex:** Male 62,2%, Female 37,8%	ENs can perform BLUS in hospital EDs with a high degree of accuracy to dyspnoeic patients	5
Gustafsson, M (2015) Sweden	Cross-sectional study with comparative design	4	**Profession**: Nurse **Years of experience**: >10 years **Prior experience w/US**: No prior experience	**Patient size:** 104 **Age**: 72 years **Sex:** Male 72%, Female 28%,	After four hours of training in a PSUD, HF nurses were able to obtain information on the assessment and detection of pulmonary congestion and pleural effusion.	5

Dalen, H (2015) Norway	Cross-sectional study with comparative design	2	**Profession**: ICN* and cardiovascular nurses **Years of experience**: Not registered. **Prior experience w/US**: Variable (>200 focused US prior to the dedicated training)	**Patient size:** 62 **Age**: 74 ± 12 **Sex:** Male 52%, Female 48%,	Specialized nurses were, after dedicated training, able to reliably classify volume state in HF patients by assessing both the pleural cavities and the dimension and collapsibility of the IVC with a good agreement with high-end ultrasound examinations performed by cardiologists.	5
Graven, T (2015) Norway	Prospective single- centre observational study	2	**Profession**: Nurses specialized in cardiology **Years of experience**: Not registered. **Prior experience w/US**: No previous experience with diagnostic US.	**Patient size:** 62 **Age**: 67 (35-86) **Sex:** Male 66%, Female 34%,	After tailored training, nurses were able to perform focused US with HUD and reliable detect and quantify PE and PLE in patients in the early phase after cardiac surgery. The US examinations performed by the nurses were superior to chest x-ray to detect and quantify PLE.	5
Guy A, (2019) Canada	Prospective observational cohort study	17	**Profession**: CCP* **Years of experience**: at least 5 years **Prior experience w/US**: 1 had previous US experience (did not involve formal training)	Not applicable	A multimodal education strategy using novel FOAMed resources for prereading and continuing education combined with traditional didactic and hands-on components was effective in this group.	2
Schoeneck, JH (2021) USA	Prospective observational study: pilot study	22	**Profession**: PMs* **Years of experience**: Not registered **Prior experience w/US**: 60 reported no prior experience and 11 reported prior ultrasound experience.	**Patient size:** 69 **Age**: 64 ± 17 **Sex:** Male 57%, Female 43%,	There was good agreement with the expert sonologist review for the presence of any B-lines, although notably this assessment was limited by poor compliance with image archival for review.	3

Pietersen, PI (2021) Denmark	Retrospective quality-control study with prospective gathering of data	100	**Profession**: EMT* or PM* **Years of experience**: >1 year **Prior experience w/US**: No prior experience with US	Not registered	It is possible for EMTs and PMs to perform focused thoracic ultrasound examinations with a high feasibility and image quality sufficient to determine if pathology is present or not.	5
Sørensen, ML (2022) Norway	Single-centre observational study using a comparative cross-sectional design	8	**Profession**: ICN* **Years of experience**: 4 months - 26 years **Prior experience w/US**: Little or no prior training in US	**Patient size:** 50 **Age**: 75 ± 13 **Sex:** Female 42%, Male 58%	After a brief training in POCUS, intensive care nurses using HUDs can perform examinations of the IVC and pleural and pericardial cavities, with outcomes ranging from moderate to almost perfect agreement with conventional ultrasound examinations performed by a physician.	5
Donovan, JK (2022) Australia	Prospective observational pilot study	44	**Profession**: ICPs* **Years of experience**: 15 years (IQR 11-21) **Prior experience w/US**: 6 participants reported previous ultrasound experience.	Not registered	ICPs with minimal training and education were able to apply a modified BLUE scan using a handheld POCUS device for patients with non-traumatic respiratory distress.	4

EN: Emergency nurses; ICN: Intensive care nurses; EMT; Emergency medical technician; PM: paramedics; CCP; Critical care paramedics; ICP: intensive care paramedicsBLUS: Bedside lung ultrasound; IVC: inferior vena cava; US: ultrasound; PE: pericardial effusion; PLE: pleural effusion; HUD: handheld ultrasound device; FOAMed: Fee open-access medical education; POCUS: point-of-care ultrasound; BLUE: bedside lung ultrasound in emergency

4.3. Themes derived from data analysis

Two main themes derived from thematic analysis: (1) structure of the education and training programmes, and (2) qualified and skilled performance of point-of-care ultrasound.

4.3.1. Structure of the education and training programmes

For the thematic analysis of the education and training programmes, all nine articles were included and details regarding these programmes are provided in Table 6. From the main theme "Structure of the education and training programmes" arises the subtheme "content and delivery modes of the education and training programmes". This subtheme is divided into *content and delivery mode*, *duration* and *feedback of the training programmes*.

(1) Content and delivery mode of the education and training programmes.

The *content and delivery modes* identified in the studies included three types: I) online, II) in-person lectures, and III) hands-on training. The first delivery mode, online lectures, were used as an introductory or pre-reading module in two of the studies (J. Donovan et al., 2022; Guy et al., 2019). The second mode, in-person lectures, was held in six of the studies. Whereas in the other three, education was given bedside (Dalen et al., 2015; Graven et al., 2015; Ünlüer et al., 2014). The last mode, hands-on training, was carried out in all of the included studies. Analysis of the second delivery mode identified three modules: (1) basics of ultrasound: use of handheld ultrasound (including probe positioning and techniques, views and storage of images), knowledge of use and benefits of using POCUS by nurses, (2) focused anatomy, physiology and pathological findings: inferior vena cava, pleural cavities (A- and B-lines) and cardiac views, and (3) handouts given to participants containing pictures and videos of pathological findings. The last mode focused on image acquisition and interpretation of the different pathologies in all of the studies. In 6 (67%) of the studies, participants practiced ultrasound on patients. One study included hands-on training on not only patients, but also on phantoms and healthy subjects (J. Donovan et al., 2022).

The *duration* of the in-person and online lectures, as well as hands-on training periods, was variable. The duration range of the in-person lectures was 90 minutes to 4 hours. In addition, Guy et al. (2019) developed an obligatory online pre-reading module, which had to be completed before the hands-on training, where the mean reading duration was 13 hours (median 8 – 18). Regarding hands-on training, the duration varied from 2 hours to a 2-day course. Dalen et al. (2015) and Graven et al. (2015) held a 1 – 3 months bedside training period where nurses performed POCUS examinations supervised by cardiologists. Some studies documented the number of scans performed by the participants during the training period, range from 15 to 62 scans (Dalen et al., 2015; Graven et al., 2015; Ünlüer et al., 2014), whereas in Sørensen et al. (2022), nurses had a 6-week non structured pilot period, after training and prior to the study, in which nurses had the opportunity to practice.

Feedback provided during education and training programmes was classified in two ways: formal and informal feedback. Formal feedback included an evaluation test of the participant's knowledge and informal feedback regards expert evaluation of the video clips. Only two of the studies performed an evaluation after education and training in POCUS. While Schoeneck et al. (2021) ran a pre-test and post-test survey, Guy et al. (2019) combined a written examination with both multiple-choice and written questions. Guy et al. (2019) also had a hands-on examination where participants were required to obtain adequate views and evaluated the time of completion of adequate scans. Regarding feedback, in all the included studies real-time feedback was provided by the instructors during the hands-on training. In addition, Gustafsson et al. (2015) provided retrospective feedback to the ultrasound video clips recorded by the nurses.

The instructors were cardiologists in three (33%) of the studies, and physicians with expertise or sonographers in five (56%) studies. Only Sørensen et al. (2022) included both cardiologists and nurses with POCUS experience as instructors.

Table 6. Data-chart for education and training programmes.

Study (year)	**Study participants**	**Delivery modes**	**Duration**	**Pre-test** **Post-test**
Ünlüer, EE (2014) Turkey	2 ENs*	*Online theoretical* training (video) *Hands-on*: 60 patients	3 hours	Not documented / Not applicable
Gustafsson, M (2015) Sweden	4 Nurses	3 hour-*theoretical training*, supplied with hand-outs. *Hands-on*: 1 hour of US* examinations on patients without supervision. Retrospective feedback checked by expert.	4 hours	Not documented / Not applicable

Dalen, H (2015) Norway	2 SN*	1-month *practical training period.* *Hands-on*: Each nurse performed 15 - 20 examinations on patients.	1 month	Not documented / Not applicable
Graven, T (2015) Norway	2 SN*	*Hands-on*: The nurses performed 62 and 58 supervised focused US* examinations. All education was given bedside.	3 months	Not documented / Not applicable
Guy A, (2019) Canada	17 CCP*	*Online pre-reading module*. A 2-day course including a 4 hours didactic session, hands-on training and examination components. *Hands-on*: Bedside teaching by experts on healthy adult models. Real-time feedback from instructors.	2-day course	**Written examination score**: 30 multiple-choice and written questions. Score: 75,5% CPPs scoring >70%: 76% **Hands-on training**: All views were adequately obtained by all paramedics.
Schoeneck, JH (2021) USA	22 PMs*	90-minute *didactic training session,* *Hands-on*: 2-3 hours supervised hands-on session where the paramedics were expected to identify positive or negative findings in at least 6 patients.	4,5 hours	**Pre and post-test.** Identical nine-question multiple-choice pre-and post-test during the didactic session. Pre-test score 76,9%, Post-test score 95,8%
Pietersen, PI (2021) Denmark	100 EMTs* or PMs*	4-hour theoretical lecture including hands-on training. *Hands-on*: Performed US examinations on other participants and one US examinations while being observed by the instructor.	4 hours	Not documented / not applicable
Sørensen, ML (2022) Norway	8 ICN*	4-hour *didactic session*. *Hands-on*: 2 hour supervised practical session. A 6-*week non-structured* pilot *period* took place prior to the study, in which the nurses had the opportunity to practice.	6 hours	Not documented / Not applicable

Donovan, JK (2022) Australia	44 PMs*	A 30-minute *online introduction* training package. *Hands-on*: 4,5-hour session primarily focusing on practical training on phantoms, each other and patients. Participants were observed while performing US* examinations.	4,5 hours	Not documented / Not applicable
EN: Emergency nurses, SN: Specialized nurses, CCP: Critical care paramedics, EMT: Emergency medical technician , PM: Paramedic , ICN: Intensive care nurses; US: Ultrasound				

4.3.2. Qualified and skilled performance of point-of-care ultrasound

The theme, qualified and skilled performance of point-of-care ultrasound contained the validity and reliability of the ICU nurses / non-physicians' performance and interpretation of POCUS (heart, lung and vena cava inferior) with HUD. In total, eight of the nine articles included information on this. Guy et al. (2019) was not included in this thematic analysis because they only discussed POCUS education and training programme content. Details regarding study results are provided in Table 7, Table 8, Table 9 and Table 10.

The total sample size of participants in the eight studies were 184. Of these, 18 of them were nurses and specialised nurses and 166 were paramedics. Total number of scans performed was 899. However, these numbers did not include the scans performed in the studies to Gustafsson et al. (2015), Dalen et al. (2015) and (Graven et al., 2015) since they did not report the number of scans.

Three subthemes were derived from thematic analysis: (1) correct image acquisition and quality, (2) reliability and validity of adequate POCUS interpretation, and (3) challenges related to performing POCUS.

(1) Correct image acquisition and quality.

Three studies reported image quality score (J. Donovan et al., 2022; Graven et al., 2015; Pietersen et al., 2021). Graven et al. (2015) reported image quality by using a binary scale (poor = 1 to good = 3). Their mean quality score was 1.9 ± 0.7, whereas Pietersen et al. (2021) and J. Donovan et al. (2022) applied a Likert scale scoring system that rated: 1) correct depth and gain, 2) two ribs and pleural line present, 3) transducer kept still during the scan, 4) abdominal organs present in lateral zones (landmarks), 5) correct probe and if there was good overview in the picture. Their mean image quality score was 3.32 ± 0.85 for Pietersen et al. (2021) and 2.68 ± 1.13 for J. Donovan et al. (2022).

Four of the studies (50%) did not report image quality, but they did not report discarding video clips due to being uninterpretable (Dalen et al., 2015; Gustafsson et al., 2015; Sørensen et al., 2022; Ünlüer et al., 2014), whilst Schoeneck et al. (2021) reported 63% (n=117) of scans as adequate for interpretation.

Five of the included studies describe the duration of POCUS examination. Ünlüer et al. (2014) reports that when only assessing B-lines the examination took less than 2 minutes, whilst assessing B-lines, pleural effusion and vena cava inferior the examination lasted for 23 minutes (Dalen et al., 2015). Duration of POCUS examination was not reported in three (37,5%) of the studies (J. Donovan et al., 2022; Pietersen et al., 2021; Schoeneck et al., 2021).

(2) Reliability and validity of adequate POCUS interpretation.

The results of this subtheme are divided into four sections for a better comprehension: (1) B-lines detection, (2) vena cava inferior assessment, (3) pleural or pericardial effusion detection, and (4) education and training programmes related to the nurses' / non-physicians' measurements.

The sensitivity and overall agreement of B-lines detection (pulmonary oedema / interstitial syndrome) are presented in Table 7. In three of the studies, sensitivity ranged from 79% to 100% and specificity 72,9% to 100% (Gustafsson et al., 2015; Schoeneck et al., 2021; Ünlüer et al., 2014). Overall agreement, specific positive agreement (SPA) and specific negative agreement (SNA) of B-line detection were calculated in two of the studies (J. Donovan et al., 2022; Pietersen et al., 2021). Among all the studies, Cohen's kappa (k) results for B-lines detection ranged from 0,26 to 1, which indicates fair to almost perfect agreement with expert or discharge diagnosis (Landis & Koch, 1977).

Table 7. Results of B-lines detection.

Study (year)	**Sensitivity and Specificity**	**Cohen's kappa values**	**Level of agreement**
Ünlüer, EE (2014)	*EN1 sensitivity* 95,35% (95% CI; 84,2 - 99,4) *EN1 specificity* 95,74% (95% CI: 85,5 - 99,5) *EN2 sensitivity* 100% (95% CI; 91,8 - 100,0) *EN2 specificity* 100% (95% CI; 92,5 - 100,0)	EN1 *k*=0.917 EN2 *k*=1	Almost perfect agreement between EN and discharge diagnosis.
Gustafsson, M (2015)	*Sensitivity* 79% (95% CI 59 - 91) *Specificity* 91% (95% CI 81 - 96)	*k*= 0,705	Substantial agreement between total number of B-lines found as by the nurses and by the cardiologist.
Schoeneck, JH (2021)	*Sensitivity* of 80.0% (95% CI, 51,4 - 94,7%) *Specificity* of 72,9% (95% CI, 57,3 - 83,3).	*k*=0,60	Moderate agreement for detection of any B-lines found by paramedics compared with expert sonologist interpretations of archived images.
Pietersen, PI (2021)	OA: 89,9%; SPA 30,5%; SNA 94,6%	*k*=0.26	Fair agreement for B-lines between paramedics and expert sonologist interpretations of archived images.
Donovan, JK (2022)	OA: 91%, SPA: 66%, SNA: 94%	*k*=0,57	Moderate agreement for B-lines detection as found by paramedics compared with expert interpretations of archived images.
EN1: Emergency nurse 1, EN2: Emergency nurse 2, OA: Overall agreement, SPA: Specific positive agreement, SNA: specific negative agreement.			

The sensitivity and overall agreement of the vena cava inferior assessment are presented in Table 8. In two of the studies, the sensitivity of the nurses' vena cava diameter assessment ranged from 65% to 72% and specificity ranged from 51% to 95% (Dalen et al., 2015; Gustafsson et al., 2015). Sørensen et al. (2022) calculated inter-rater agreement using Gwet's agreement coefficient (AC_2) indicating moderate agreement for IVC respiration variation and substantial agreement for IVC diameter when comparing nurses performing POCUS versus a complete standard echocardiography. Gustafsson et al. (2015) presented Cohen's kappa result of 0,39 which indicated fair agreement for the nurses performing POCUS compared with cardiologist reviewing the video clips. In Dalen et al. (2015) correlations of all the measurements of end-expiratory and end-inspiratory IVC were very high, comparing specialized nurses POCUS interpretation to cardiologists' reference echocardiography.

Table 8. Results of inferior vena cava assessment

Study (year)	**Sensitivity and Specificity**	**Correlation and agreement measures**	**Level of agreement**
Gustafsson, M (2014)	*Sensitivity* 64% (95% CI 42 - 81) *Specificity* 51% (95% CI 34 - 69)	*k*= 0,393	Fair agreement between nurses and the experts' measures.
Dalen, H (2015)	IVC*>21mm and C index*<35% (n=62): *Sensitivity* 72%, *Specificity* 98%, IVC*<17mm and C index*>50% (n=62): *Sensitivity* 64%, *Specificity* 95%,	End-expiratory dimension IVC r=0,89 (95% CI 0,81 - 0,95) p<0,001 End-inspiratory dimension IVC r=0,79 (95% CI 0,57 - 0,93) p<0,001	Correlation with the reference echocardiography was very high.
Sørensen, M (2022)	Not registered	IVC respiration variation: (AC_2 0,60; 95% CI: 0,38 - 0,82). IVC diameter: (AC_2 0,70; 95% CI: 0,50 - 0,90).	Moderate agreement for the IVC respiration variation. Substantial agreement for IVC diameter
IVC: Inferior vena cava; C index; Collapsibility index.			

The results for pleural and pericardial effusion detection are presented in Table 9. In three of the studies, sensitivity of detecting pleural effusion ranged from 88% to 98% and specificity 70% to 100% (Dalen et al., 2015; Graven et al., 2015; Gustafsson et al., 2015). In Graven et al. (2015), the accuracy of the nurse's pleural effusion assessment was compared to chest X-ray, which showed low sensitivity (40%) compared to nurses' performing POCUS (98%). While in Gustafsson et al. (2015) nurses' performed POCUS and video clips of pleural effusion assessment were scrutinized by an expert cardiologist and in Dalen et al. (2015) study, nurses' accuracy was compared to a standard echocardiography performed by cardiologist.

Another study calculated the Gwet's agreement (AC_2) (Sørensen et al., 2022). The results of this study showed that ICU nurses performed POCUS with substantial agreement for right-sided pleural effusion and almost perfect agreement for left sided pleural effusion compared with the physicians' conventional ultrasound examination (Sørensen et al., 2022).

Three of the studies presented Cohen's kappa (*k*) results that ranged from 0,25 to 0,66 (J. Donovan et al., 2022; Gustafsson et al., 2015; Pietersen et al., 2021), which indicates fair to substantial agreement for nurses' or paramedics POCUS interpretations compared with the expert cardiologist in Gustafsson et al. (2015) and (J. Donovan et al., 2022)

Pericardial effusion was only evaluated in two of the studies (Graven et al., 2015; Sørensen et al., 2022). The sensitivity and specificity to detect at least moderate PE by POCUS performed by the nurses was 91% and 56%, and the correlations of the quantification of PE performed by the nurses was high compared to reference echocardiography performed by experienced cardiologists in (Graven et al., 2015).

Table 9. Results of pleural effusion and pericardial effusion detection

Study (year)	**Sensitivity and Specificity**	**Correlation and agreement measures**	**Level of agreement**
Gustafsson, M (2015)	*Sensitivity* 88% (95% CI 50 - 99) *Specificity* 93% (95% CI 85 - 97)	*k*= 0,66	Moderate agreement between nurses detecting PLE and expert cardiologist.
Dalen, H (2015)	*Sensitivity* 93% *Specificity* 100%	PLE both cavities r=0.96, (95% CI 0.93 – 0.98, p<0.001)	Good agreement with high end-ultrasound examinations performed by cardiologists.
Graven, T (2015)	**Pleural effusion** (nurses): *Sensitivity* 98%,	PLE was high r=0,81 (95% CI 0,73 - 0,89; p<0,001).	High correlation of the quantification of PE and

	Specificity 70%, **Pericardial effusion** *Sensitivity* 91%, *Specificity* 56%,	PE was high r = 0,76 (95% CI 0,46 - 0,89; p<0,001)	PLE performed by the nurses and reference echocardiography.
Pietersen, P (2021)	**Pleural effusion**: OA 96,3%, SPA 70,6%, SNA 98,0%	*k*=0,69	Substantial agreement between the EMS and the reviewer.
Sørensen, M (2022)	Not registered	Right-sided pleural effusion (AC_2 0,70; 95% CI: 0,52 - 0,88). Left-sided pleural effusion (AC_2 0,85; 95% CI: 0,75 - 0,95). Pericardial effusion (AC_2 0,95; 95% CI: 0,90 - 1,01)	Substantial agreement for right-sided pleural effusion Almost perfect agreement for left-sided pleural effusion Almost perfect agreement for pericardial effusion
Donovan, JK (2022)	**Pleural effusion** OA: 56%	*k*=0,25	Fair agreement for pleural effusion between paramedics and reviewer.
OA: Overall agreement, SPA: Specific positive agreement, SNA: specific negative agreement.			

Table 10 presents an overview of the education and training programmes carried out in the studies is presented together with the correlation and agreement measures of the nurses' and non-physician's measurements.

In five of the studies, the duration of the education and training programmes combining theory and hands-on ranged from 2,5 hours to 6 hours (J. Donovan et al., 2022; Gustafsson et al., 2015; Schoeneck et al., 2021; Sørensen et al., 2022; Ünlüer et al., 2014). The lectures covered basic principles of HUDs, recognition of B-lines, IVC diameter assessment, PE and PLE, transducer positioning and landmark identification.

In these studies, Cohen's kappa for B-lines recognition indicated moderate to almost perfect agreement (*k*= 0,57 to *k*=1) with the expert after completing the education and training programme (J. Donovan et al., 2022; Gustafsson et al., 2015; Schoeneck et al., 2021; Ünlüer et al., 2014). The education programme in Pietersen et al. (2021) was similar in duration and content, however, Cohen's kappa results showed fair agreement (*k*=0,26) when assessing B-lines.

In two studies, the IVC assessment after their education and training programmes indicated sensitivity and specificity of 64%-72% and 51%-98%, respectively (Dalen et al., 2015; Gustafsson et al., 2015). Gustafsson et al. (2015) and Sørensen et al. (2022) dedicated one and two hours of the lectures, respectively, to recognition and interpretation of CTA, PE and IVC, as well as transducer positioning and handling techniques. Cohen's kappa results in Gustafsson et al. (2015) showed fair agreement (k=0,393) compared with cardiologist, whereas Sørensen et al. (2022) Gwet's AC_2 showed moderate agreement for IVC respiration variation and substantial agreement for the IVC diameter. Results in Dalen et al. (2015) indicated high correlation of all the measurements of IVC collapsibility with $r \geq 0.79$. In this study, nurses had performed over 200 focused ultrasound examinations prior to the study and their training programme consisted of 15-20 examinations of pleural cavities supervised by cardiologists.

On the one hand, agreement measures for PE ranged from substantial agreement (k=0,66) to almost perfect agreement (AC_2=0,95) in Gustafsson et al. (2015) and Sørensen et al. (2022) after a 4 to 6-hour lecture combining theory and hands-on. On the other hand, correlation of the quantification of PE performed by nurses was high with $r \geq 0.76$ ($p<0.001$) after a 3-month bedside hands-on training where each nurse, without prior experience with POCUS, performed 60 supervised focused ultrasounds (Graven et al., 2015).

Concerning agreement measures for PLE detection, after a 4 to 6-hours combined theoretical and hands-on programme Cohen's kappa results indicated substantial agreement between the EMTs pleural effusion assessment and the expert reviewer that scrutinized the video clips in (Pietersen et al., 2021), and Gwet's AC_2 in Sørensen et al. (2022) showed substantial to almost perfect agreement for right-sided and left-sided PLE assessment (AC2=0,70 and AC2=0,85). Participants in J. Donovan et al. (2022) completed a 30-minute online introduction, one hour dedicated to general knobology and scanning technique, and 75 minutes dedicated to normal and pathological lung scan identification with focus on pneumothorax, interstitial syndrome, pleural effusion, and pneumonia. Their results indicated fair agreement (k=0.25) of paramedics' PLE detection compared to expert reviewer opinion.

Two of the studies carried out a bedside hands-on training programme supervised by cardiologists (Dalen et al., 2015; Graven et al., 2015). Both studies reported high correlation values of nurses' quantification of PLE compared to reference echocardiography (r=0.81 (p<0.001) and r=0.96 (p<0.001), respectively).

Table 10. Overview of the education and training programmes compared to correlation and agreement measures of the nurses' and non-physicians performing pocus.

Study (year)	**Study participants**	**Examination area**	**Characteristics of the programme**	**Correlation and agreement measures**	**Level of agreement**
Ünlüer, EE (2014) Turkey	2 ENs*	B-lines	Online theoretical training (video) Hands-on: 60 patients	EN1 k=0.917 EN2 k=1	Almost perfect agreement between EN and discharge diagnosis.
Gustafsson, M (2015) Sweden	4 Nurses	B-lines, PE and IVC	Theoretical training: 3 hours Hands-on: 1 hour	B-lines k= 0,705	Substantial correlation between total number of B-lines found as by the nurses and by the cardiologist.
				IVC k= 0,393	Fair agreement between nurses and the experts' measures.
				PE k=0,66	Substantial correlation between nurses detecting PE and expert.
Dalen, H (2015) Norway	2 Specialized nurses	IVC and PE	Training period: 1 month Number of scans performed: 15 - 20	End-expiratory dimension IVC r=0,89 (95% CI 0,81 – 0,95 p<0,001) End-inspiratory dimension IVC r=0,79 (95% CI 0,57 – 0,93) p<0,001 PE r=0.96 (95% CI 0,93 – 0,98) p<0,001	High correlation for IVC diameter with reference echocardiogram. Good agreement for PE detection compared with high end-ultrasound examinations performed by cardiologist.
Graven, T (2015) Norway	2 Specialized nurses	PLE PE	Bedside education with hands-on training. Number of scans performed: 58 - 62	PE r = 0,76 (95% CI 0,46 - 0,89; p<0,001) PLE r=0,81 (95% CI 0,73 - 0,89; p<0,001).	High correlation of the quantification of PE and PLE performed by the nurses and reference echocardiography.
Schoeneck, JH (2021) USA	22 PM*	B-lines	90-minute didactic training session, Hands-on: 2-3 hours	k=0,60	Moderate agreement for detection of any B-lines found by paramedics compared with expert sonologist interpretations of archived images.

Pietersen, PI (2021) Denmark	100 EMTs* or PMs*	B-lines PLE	4-hour theoretical lecture including hands-on training.	B-lines k=0.26	Fair agreement for A-lines and B-lines between paramedics and expert sonologist interpretations of archived images.
				PLE k=0,69	Substantial agreement between the EMS and the reviewer.
Sørensen, ML (2022) Norway	8 ICN*	IVC, PE, PLE	4-hour didactic session. Hands-on: 2 hour supervised practical session. A 6-week nonstructured pilot period to practice	IVC respiration variation: (AC_2 0,60; 95% CI: 0,38 - 0,82). IVC diameter: (AC_2 0,70; 95% CI: 0,50 - 0,90).	Moderate agreement for the IVC respiration variation and Substantial agreement for IVC diameter
				Right-sided pleural effusion (AC_2 0,70; 95% CI: 0,52 - 0,88). Left-sided pleural effusion (AC_2 0,85; 95% CI: 0,75 - 0,95). Pericardial effusion (AC_2 0,95; 95% CI: 0,90 - 1,01)	Substantial agreement for right-sided pleural effusion Almost perfect agreement for left-sided pleural effusion Almost perfect agreement for pericardial effusion
Donovan, JK (2022) Australia	44 PM*	B-lines PLE	30-minute online introduction training package. Hands-on: 4,5 hour	B-lines k=0,57	Moderate agreement in B-lines detection as found by paramedics compared with expert interpretations of archived images.
				PLE k=0,25	Fair agreement between paramedics and reviewer.
EN: Emergency nurses, SN: Specialized nurses, CCP: Critical care paramedics, EMT: Emergency medical technician , PM: Paramedic , ICN: Intensive care nurses; US: Ultrasound					

(3) Challenges related to performing POCUS.

Some of the studies report difficulties in image acquisition concerning landmark identification in the video clips as well as probe positioning. Gustafsson et al. (2015) describe challenges of accurately assessing and mistaking the abdominal aorta for the IVC. Pietersen et al. (2021) found two significant errors present in 77 (13%)

examinations. First, video clips from the lateral zones were scanned too caudally using no identifiable lung tissue. Second, video clips from the lateral zones did not contain an abdominal organ and could not be used to rule out PLE (n=49 examinations, 7%). Gustafsson et al. (2015) reported difficulties in finding the right probe position, which resulted in uninterpretable recordings.

Schoeneck et al. (2021), (Pietersen et al., 2021) and J. Donovan et al. (2022) reported low quality video clips, categorized as "normal, but low quality images" or "inadequate for interpretation".

The last challenge identified was the lack of gold standards. On one hand, there are no standardized certification or training programmes used in the studies, and only two studies performed a pre-test and post-test to evaluate participants' progress (Guy et al., 2019; Schoeneck et al., 2021). On the other hand, most of the studies compared nurses' or paramedics' POCUS examinations with expert evaluation of the archived video clips (J. Donovan et al., 2022; Gustafsson et al., 2015; Pietersen et al., 2021; Schoeneck et al., 2021), whereas in other studies a complete standard echocardiography was performed by an expert cardiologist or medical resident (Dalen et al., 2015; Graven et al., 2015; Sørensen et al., 2022). Graven et al. (2015) utilizes both standard echocardiography and Chest X-ray as gold standards. Two of the studies compare nurses' POCUS examinations with discharge diagnosis (Gustafsson et al., 2015; Ünlüer et al., 2014).

5. Discussion

In this restricted review, we have summarized information from 9 studies about the content and delivery mode of the education and training programmes designed to educate ICU nurses / non-physicians to perform and interpret point-of-care ultrasound, and the possibility of ICU nurses accurately performing and interpreting POCUS cardiac and lung images. To summarize the results, our restricted review shows that the amount of training and education provided before data collection varied among the studies, both in content and duration of the education. However, the common denominator among the majority of the studies was short training duration (2 to 4 hours) and the combination of both theoretical and hands-on training. In addition, our results suggest that ICU nurses / non-physicians can adequately acquire and interpret POCUS cardiac, lung and inferior vena cava images with a handheld ultrasound in a reliable and valid way.

5.1. Structure of the education and training programmes

The structure of the education and training programmes consisted mostly of 1,5 to 4 hour of theoretical instruction, combined with practical training which varied from one-hour hands-on training to a pre-established number of scans or training period. Three delivery modes were identified in this review and they are in line with the statements from the European Association of Cardiovascular Imaging (EACVI). Competence in imaging acquisition and interpretation can be achieved by fulfilling certain requirements for training and competence, such as 1) combining an introductory online programme covering basic principles of cardiac ultrasound, 2) image interpretation and relevant and familiar cardiology topics, 3) instructional lectures and practical training with HUD, and 4) more specific and personalized education and training in HUD (Cardim et al., 2018). In addition, the EACVI recommends to complement the basic HUD training with additional specific education and training in HUD such as FoCUS or echocardiography (Cardim et al., 2018). This is supported by Press et al. (2013) who states that having a training programme that incorporates multiple educational modalities offers the best opportunity for novices to successfully learn ultrasound.

Most of the studies in this review covered one area (lung ultrasound) or combined different areas (i.e. pleural effusion and/or pericardial effusion and vena cava inferior assessment) on POCUS examination in the same lecture (Dalen et al., 2015; Graven et al., 2015; Gustafsson et al., 2015; Sørensen et al., 2022). Whereas Guy et al. (2019) included pleural sliding, A- and B-line detection, FAST examination, presence of cardiac activity, pericardial effusion detection, ejection fraction estimation, IVC size and respiratory variability assessment and correct identification of vascular anatomy in their 8-hour in person course (2-day course) and online pre-reading module. This is in accordance to another study performed by Andersen et al. (2014). In this study, 5th year medical students were specifically instructed to assess for reduced left ventricular function, PE, PLE, lung comets, IVC diameter and variation, hydronephrosis, bladder distention, gallstones, signs of cholecystitis, diameter of abdominal aorta and abdominal free-fluid.

Currently there are no clear guidelines of the delivery mode of the POCUS education and training programme. However, the Australasian College for Emergency Medicine (2021) guidelines recommend a minimum time of two hours for practical ultrasound sessions for each focused assessment. On the other side, EACVI states that a predefined number of hours in training is impractical and that the education of new users in POCUS should be individualized (Cardim et al., 2018).

The studies included in our review, which were based on a short time didactic and hands-on training demonstrated that both nurses and paramedics were able to accurately acquire and interpret POCUS with fair to almost perfect agreement, regarding B-lines, PE, PLE and VCI. Additionally, the three studies that were based on a number of scans showed that nurses were able to perform focused ultrasound with HUD and reliable detect and quantify PE and PLE (Graven et al., 2015); perform lung ultrasound (LUS) in the emergency department with high degree of accuracy to dyspnoeic patients (Ünlüer et al., 2014); and specialized nurses reliably assessed volume status on HF patients after 15 to 20 POCUS examinations under the training period (Dalen et al., 2015). This is in line with two other studies (Andersen et al., 2014; Steinwandel et al., 2018). However, in these two studies the training programmes are based on a theoretical lecture, hands-on training and, also include a pre-set number of scans to improve the techniques and reinforce practice (Andersen et al., 2014; Steinwandel et al., 2018). This combination is also found in one of the included studies in this review, where paramedics after completing a 90-minute didactic training session and 2-3 hour of supervised hands-on training, they had to perform at least 6 examinations each (Schoeneck et al., 2021). This study results showed sensitivity of 80% and specificity of 72% for the presence of bilateral B-lines for diagnosis of congestive heart failure, as well as, good agreement for detection of any B-lines (k=0.60) compared to expert sonographer interpretation of images.

Regarding lung ultrasound, the CCCS recommends 20 lung and pleural ultrasound to ensure a minimum level of competency and experience. Whereas the recommendations from the Thoracic Society of Australia and New Zealand (TSANZ) is to complete 40 scans to accurately and safely use a HUD (Williamson TSANZ, 2017). In one of the studies included in this review, the nurses performed over 40 ultrasound examinations of pleural and pericardial cavities and reliably detected PE, PLE (Graven et al., 2015), whereas in another study the nurses only performed 15 to 20 POCUS examinations due to prior experience with over 200 focus examinations performed in the last three years. These findings are in accordance with another study, where participants acquired a satisfactory technique and image interpretation was concordant with the expert in all cases by performing 20 lung ultrasound examinations in the education programme, in addition to simulator practice, online learning and mentored wards (Tivendale et al., 2021).

According to the results of this review and the literature, nurses and paramedics are able to accurately perform and interpret cardiac and lung POCUS, despite a short training programme duration. This is contrary to the results in one observational study that did not support the ability of paramedics to adequately acquire lung ultrasound images after two hours of training (Becker et al., 2018). However, according to the CCCS recommendations a minimum of 10 hours of general training (combined hands-on and didactic) and at least 10 additional hours of basic critical care echocardiography training should be carried out during the theoretical education and training programmes (Arntfield et al., 2014).

Our results suggest that a focused module on each examination area could improve POCUS performance. For example, regarding lung ultrasound, the Australasian College for Emergency Medicine (2021) guidelines recommend an anatomy approach based on the zones 1 to 4 (international consensus) and Lichtenstein's zones (Lichtenstein, 2015). Four of the studies included in our review utilized the BLUE-protocol or an adaption in the training programme (J. Donovan et al., 2022; Guy et al., 2019; Pietersen et al., 2021; Ünlüer et al., 2014).

Most of the studies included in the review held hands-on training sessions with patients that presented pathology or in settings that would resemble clinical practice (Dalen et al., 2015; J. Donovan et al., 2022; Graven et al., 2015; Gustafsson et al., 2015; Schoeneck et al., 2021; Sørensen et al., 2022; Ünlüer et al., 2014). Only a few studies held hands-on training with healthy volunteers in this review (Guy et al., 2019; Pietersen et al., 2021).This is in line with other studies in the literature which have also combined simulated patients (with pathology) and real patients (Press et al., 2013). In Quick et al. (2016) non-physicians aeromedical providers performed POCUS on healthy models and animal models in the hands-on sessions. In addition, in Brooke et al. (2012) POCUS was not performed by the paramedics, but they evaluated pre-recorded video clips under the lectures. Training with phantoms and healthy volunteers seems to be necessary to acquire a good technique to perform POCUS (ie., probe positioning, familiarizing with the view and ultrasound settings, such as depth or gain). However, performing POCUS in patients with the pathologies that are being learned is also necessary to acquire enough competence to correctly interpret POCUS.

Teacher ratio in the education programmes is also discussed in the ACEM guidelines, where they recommend a maximum student: instructor ratio of 5:1 (Australasian College for Emergency Medicine, 2021). Most of the included studies were pilot studies with a small participant sample, so student: instructor ratio was in line with recommendations (Australasian College for Emergency Medicine, 2021). However, Schoeneck et al. (2021) performed a study including 63 paramedics and Pietersen et al. (2021) included 100 paramedics, but none of them specified the student: instructor ratio. This appears to be an important issue to take into account when the education and training programmes are held for a larger number of participants in terms of feasibility, applicability, cost-effectivity and quality.

Feedback given in the education and training programmes

The feedback provided in the included studies was mainly informal feedback by experts giving real-time assessments to participants performing the ultrasound examinations or giving retroactive evaluation of the stored video clips. This is in line with the CCCS recommendations, competency assessment and feedback should be provided to learners throughout their training and until robust and valid assessment tools are developed, competency is best assessed by a local expert (Arntfield et al., 2014). However, few studies perform a pre-test and post-test evaluation of the participant's knowledge and improvement after the education and training programme. Regarding the studies included in the review, the pre- and post-test performed by Schoeneck et al. (2021) consisted of an identical nine-question multiple-choice completed during the didactic session, whereas in Guy et al. (2019) study, participants performed a 30 multiple-choice and written examination covering the four domains of the curriculum: thoracic, abdominal, hemodynamic and vascular. In addition, a hands-on examination was held where paramedics were required to obtain adequate views in all components of the practical examination. In two of the included studies, paramedics were expected to correctly identify positive or negative findings. In the study by Pietersen et al. (2021) emergency medical technicians and paramedics were expected to perform one POCUS ultrasound while being supervised, whilst in the study by Schoeneck et al. (2021) paramedics were expected to perform POCUS examination on six patients presenting with undifferentiated pathology. In a recent study, assessment and knowledge evaluation consisted of with multiple-choice tests performed after online learning, observed ultrasound image acquisition, a case interpretation test compared to an expert, and a teaching preference survey (Tivendale et al., 2021).

On the one side, the ACEM guidelines recommend a pre- and post-test to demonstrate acquisition of ultrasound proficiency and interpretation, however they do not specify the content or if the test should include hands-on examination (Australasian College for Emergency Medicine, 2021). On the other side, the EACVI in their online programme of basic training and certification for HUD, perform a self-assessment test and participants have to submit a proof of hands-on practical training to obtain the basic certification (Cardim et al., 2018). Further research and standardized evaluation tools development is needed to evaluate the quality and effectivity of the education and training programmes.

None of the studies included in this review evaluated competence maintenance over time after the education and training programmes, neither the need for *brush-up* sessions. Previous investigations have demonstrated an inherent learning curve associated with diagnostic ultrasonography that improves over time with exposure and repetition (Ma et al., 2008). This requires a commitment from the novice non-physician to continuing education as well as use HUDs and POCUS examinations in daily practice. In addition, the workplace must guarantee that sufficient training is given (Helsedirektoratet, 2018). The CCCS suggest image review sessions, attendance at courses or lectures, or provision of education and quality assurance locally to maintain competence (Arntfield et al., 2014).

The instructors participating in the education programmes, included in this review and in the literature, were predominantly expert cardiologists or expert sonographers. Only in one of the included studies in this review, experienced nurses in HUDs and POCUS held and supervised the practical session (Sørensen et al., 2022). This session also covered knowledge of the fields of use and the benefits of using a HUD by an intensive care nurse. In our opinion, regarding the low implementation rates of POCUS performed by non-physicians (such as nurses and paramedics) despite the potentially positive outcomes, including patient care and follow-up and patient safety could be related to non-physicians not understanding the benefits of performing POCUS, the lack of protocols and routines in the units, the lack of time to train novice non-physicians, the existing hierarchies and restrictions on what health care workers can do as well as law regulation regarding documentation. Probably, being taught by a collegue that have performed POCUS and have routinized protocols in their unit could be an inspiration to nurses and paramedics for learning POCUS examination and taking this into daily clinical practice. Nurses teaching other nurses in the use of HUDs while performing POCUS is a reality at Levanger Hospital, where five nurses taught a total of 28 novice nurses in POCUS in the use of HUD (Helse Nord-Trøndelag, 2018). Further research is needed to recognize the barriers for non-physicians to take part in education and training programmes on POCUS as well as implementing this to their daily clinical practice.

5.2. Qualified and skilled performance of point-of-care ultrasound

Correct image acquisition and quality

In this review, an overall acceptable image quality was outlined, however, in several studies images were reported to be of low quality or inadequate for interpretation (J. Donovan et al., 2022; Pietersen et al., 2021; Schoeneck et al., 2021). Some of the included studies, reported image quality as a scale rather than rating images as adequate or inadequate for interpretation (J. Donovan et al., 2022; Graven et al., 2015; Schoeneck et al., 2021). Whilst Guy et al. (2019) was the only study using a 6-point scale, called CUSAS, for cardiac image acquisition evaluation; median 5 (IQR 4-6). Schoeneck et al. (2021) reported 37% of scans as uninterpretable and Pietersen et al. (2021) reported 12,5% of the examinations as low-quality images. These results are in accordance to other studies in the literature that have reported similar numbers of uninterpretable scans. Becker et al. (2018) reported 41,2%, Roline et al. (2013) reported 46%, Ronaldson et al. (2020) reported 13,6%, and Brunhoeber et al. (2018) reported 14% of scans as not accurately acquired. Based on these studies, it appears that there are consistent issues with accurately acquisition of POCUS images, as well as tools to objective evaluate image quality. A POCUS Image Quality (POCUS IQ) scale was developed by POCUS-trained physicians to assess sonographers' image acquisition skills in lung ultrasound by evaluating image quality (Dessie et al., 2022). This scale evaluated three elements: 1) technical (including probe choice, depth and gain/pre-sets), 2) scanning skills (regarding probe control and anatomy/landmarks) and 3) interpretability (including location/orientation and completeness (appropriate views and measurements)). In two of the included studies in this review, these elements were evaluated and rated from 1 to 5, reporting a poor image quality (J. Donovan et al., 2022; Pietersen et al., 2021).

A section in some of the education and training programmes in this review included transducer positioning to obtain the correct projections, handling techniques to obtain views adequately and settings such as change of depth, cardiac or abdominal mode (J. Donovan et al., 2022; Gustafsson et al., 2015; Schoeneck et al., 2021; Sørensen et al., 2022). The results from this review indicate that including a specific module on accurately image acquisition based on landmarks and probe positioning in the education and training programme might enhance the programmes in order to improve image acquisition, as well as including an assessment with solid validity evidence, such as CUSAS or POCUS IQ (Backlund et al., 2010; J. Donovan et al., 2022; Guy et al., 2019; Pietersen et al., 2021) (Dessie et al., 2022).

The results from this review suggest that the source of low image quality could be multifactorial; it might be related to education programmes that miss focused training, participants' experience or the context (pre-hospital and in-hospital settings). The studies included in this review that reported low image quality or uninterpretable images were performed by paramedics in pre-hospital settings which suggests that obtaining adequate images in the prehospital setting may be difficult for POCUS-naïve non-physician sonographers (J. Donovan et al., 2022; Pietersen et al., 2021; Schoeneck et al., 2021). This is in accordance to the study performed by Becker et al. (2018) where paramedics were not able to acquire adequate lung ultrasound scans. However, the study performed by Bhat et al. (2015) indicated that emergency medical technicians and students could identify images of pericardial effusion, pneumothorax and cardiac standstill. Further research is needed to identify the amount of training needed on each examination area for paramedics to accurately perform and interpret POCUS examinations.

Challenges regarding vena cava inferior assessment

Findings from this study suggest that there are some challenges and common errors that participants encountered while performing POCUS. These errors include finding the proper probe positioning, scanning too caudally, video clips not containing any identifiable abdominal landmarks and mistaking the abdominal aorta for the IVC (J. Donovan et al., 2022; Gustafsson et al., 2015; Pietersen et al., 2021). These errors are also described in other studies along with difficulties with optimal visualization of the tubular IVC in the longitudinal plane and determining the correct level of the IVC scans when in the transvers plane (De Lorenzo & Holbrook-Emmons, 2014; Steinwandel et al., 2018).

The duration of training required for an ultrasound examination may vary depending on the specific areas that need to be assessed. After completing this review, the results suggest that some POCUS examinations are more challenging and need further training to develop skills, such as accurately assessing IVC diameter (Gustafsson et al., 2015). This is in accordance to the literature (Brunhoeber et al., 2018; De Lorenzo & Holbrook-Emmons, 2014). The participants in Sørensen et al. (2022) received four hours didactics and two hours hands-on training focused on PE and PLE detection and IVC assessment, whilst participants in (Gustafsson et al., 2015) underwent a total of four hours education, where one hour focused on recognition and interpretation of comet-tail artifacts, PE and IVC. The education programmes from this review are comparable to the education programme in another study, including medical students, a nine-hours course combining theoretical and hands-on training, in which more than 5 examination areas where taught during the education programme. The medical students in this study obtained acceptable IVC presentation in 87% and correct diagnosis in 71% of the cases (Andersen et al., 2014). Further, in Steinwandel et al. (2018) a novice renal nurse showed good to substantial agreement with expert, when assessing volume status, after receiving a 4 hours of didactic training and 4 hours of practical training under supervision focusing on relevant anatomy and physiology, the clinical relationship between central venous pressure and IVC diameter, as well as effects of variation in intrathoracic pressure throughout the respiratory cycle. Nonetheless, Corl et al. (2020) performed a prospective observational study of spontaneously breathing ICU patients and compared novice physician sonographers' measuring IVC collapsibility with POCUS to expert physician sonographer who independently reviewed the POCUS images. Only one physician had received ultrasound training, the others had no prior formalized training (n=5). Each underwent a 3-hour mandatory training session to reliably measure IVC collapsibility on 10 participants before the study. Results showed that expert physician sonographer performed better than novices at measuring IVC collapsibility (Corl et al., 2020).

On the one side, results from this review suggest that a 4-hour combination of didactics and hands-on training is not sufficient to adequately obtain and interpret POCUS images of IVC and volume status assessment. This is in line with (Andersen et al., 2014; Corl et al., 2020; De Lorenzo & Holbrook-Emmons, 2014; Steinwandel et al., 2018). The optimal components and length of that training are not known, but should be the subject of future research.

On the other side, a total of four to six hours of education and training was deemed as sufficient in the studies included in this review for nurses and paramedics to correctly identify pleural effusion, pericardial effusion and B-lines (J. Donovan et al., 2022; Gustafsson et al., 2015; Pietersen et al., 2021; Sørensen et al., 2022). The results from this review are comparable to the results of a recent systematic review performed by Swamy et al. (2019) where nurses were able to identify B-lines and pleural effusions with a sensitivity of 79- 98% and specificity of 70-99% after 0 to 12 hours of didactic training and 58 to 62 lung ultrasound examinations. In the same study, medical students with two to nine hours of training were able to acquire adequate images for B-lines and pleural effusion in 50 – 100%. However, in this review one study did not support the ability of paramedics to perform and interpret LUS after 2 hours of training (Swamy et al., 2019).

Challenges related to performing POCUS

There might be several reasons related to challenges when novice non-physicians perform POCUS with HUDs compared to expert cardiologist or sonographers. First, even though HUDs are proved to be reliable they have also some limitations (Cardim et al., 2018), they are smaller and have lower quality display screen compared to a high quality and larger video display screen of echocardiographic machines (Corl et al., 2020). Second, novices might feel pressured to complete their assessments quickly while in the presence of an expert and other study participants. For example, the expert physician sonographer in Corl et al. (2020) completed assessments privately and without a perceived time pressure whilst the novice sonographer did so while being evaluated. In addition, both the expert and novice sonographer in the study by Corl et al. (2020) could scroll back and forth through the video loops to maximize / minimize IVC images, and anecdotally the novices did this less. Third, in some studies performance varies greatly across novice non-physicians, such as in two of the included studies where one of the participants performed most of the POCUS examinations (J. Donovan et al., 2022; Gustafsson et al., 2015), or those where experience with POCUS and HUDs was variable (J. Donovan et al., 2022; Guy et al., 2019; Schoeneck et al., 2021). This might be related to some participants being more motivated or having a better perceived self-confidence while performing POCUS than participants with no experience. Fourth, many of the studies perform the POCUS examinations on stable patients. According to De Lorenzo and Holbrook-Emmons (2014) it is possible that measurements on sicker patients would result in degraded performance and thus worsened image quality.

Education and training programmes related to the nurses' / non-physicians' measurements.

The structure of the education and training programmes was related to the nurses' / non-physicians' measurements in Table 10. We sought to evaluate if the amount of ultrasound education and training correlated with POCUS acquisition and interpretation accuracy. The results from this review suggest that, after a short training period, nurses, specialized nurses and paramedics could acquire and interpret POCUS examinations using HUDs, when assessing PE, PLE, detecting B-lines and IVC collapsibility and volume status in a reliable and valid way. However, further empirical research is needed to evaluate the impact of didactic education compared with the impact of guided, experiential education on POCUS performance, as well as, identify the most efficient, cost-effective and feasible content and delivery modes.

5.3. Limitations

To make our restricted systematic review more feasible, it was held by two reviewers which contributed to discussions from different points of view along the process. In addition, the inclusion of articles, quality appraisal of the included studies with MMAT and the thematic analysis was positively influenced by this, and increases the reliability and validity of this study. The fact that one of the supervisors was expert in the use of HUDs has helped us to a better acknowledge of POCUS examinations. Regarding the study selection, data extraction and analysis, the authors worked independently by using Rayyan programme to sought for a blinded appraisal and selection. Consensus was reached in both the quality assurance of the studies with MMAT and the first part of the data analysis, expert opinion from both supervisors was also taken into account. This also strengthens the study as it added different viewpoints.

This study also had some limitations. First, as with any systematic literature review, the authors cannot rule out that there is relevant research that has not been identified. This is indeed a risk bias in restricted systematic reviews due to their characteristics (Plüddemann et al., 2018). In order to limit the risk of missing findings, hand searches could have been carried out in international journals and this was not done for this study. Second, meta-analysis was not possible due to heterogeneity of the included studies, therefore a qualitative thematic analysis was applied. Such analysis is prone to interpretation bias (Whittemore & Knafl, 2005). Third, the generalizability and external validity of this study is limited due to most of the included studies are pilot studies (44%). Several studies have small sample sizes, low participation rates and the measures are compared to non-standardized methods. Fourth, although the majority of the included studies indicated good methodological quality, it is important to note that certain studies included participants who were not POCUS-naïve and performed a higher number of ultrasounds than others. As such, these inconsistencies may have introduced several biases to the data. In the last place, this study is also the authors' first time performing a restricted review and their experience with this method is therefore limited.

6. Conclusion

Point-of-care ultrasound performed by intensive care nurses, nurses and paramedics aims to assess or identify various conditions related to the heart and lungs, as well as to evaluate volume status. The use of handheld ultrasound devices allows non expert physicians to perform POCUS in different clinical settings, such as pre-hospital, in-hospital and outpatient clinics.

The structure of the education and training programmes should be standardized, and the recommendations from national and international guidelines should be taken into account when creating an education programme. The results of this review suggest that a combination of theoretical didactics (2 to 4 hours), a minimum of 2 hours hands-on training and a pre-set number of scans might be enough to adequately perform and interpret POCUS for novices. However, results indicate that focused training is needed in inferior vena cava examinations to enhance reliability and improve the level of agreement with expert reviewer.

Overall, after a short training period, ICU nurses and non-physicians demonstrated that, when applying handheld ultrasound devices, they could acquire and interpret point-of-care ultrasound focused examinations to assess pleural effusion, pericardial effusion, detecting B-lines and inferior vena cava assessment in a reliable and valid way. Results showed a high sensitivity and specificity compared to expert reviewer, standard echocardiography or discharge diagnosis.

6.1. Clinical implications

The highly technological, continuous and advanced care that critical patients require emphasizes the use of HUD as a powerful tool for ICU nurses who continuously work bedside. This study can be a contribution to the discussion of task shifting and nurses performing a more independent practice and assuming greater responsibility within clinical assessment and patient follow-up. As a result, implementing the use of HUD by ICU nurses might improve patient care and follow-up by using additional monitoring, as well as detecting signs of early deterioration. For example, the adoption of routine focused ultrasound nursing practice to monitor lung condition, pleural or pericardial effusion might reduce the need for ionising radiation. This could increase patient safety and might reduce hospitalization days.

Nevertheless, the implementation and applicability of POCUS examinations routines and protocols requires theoretical education and training programmes that ensure the necessary competence to adequately perform POCUS, competence maintenance overtime, clarifying areas of responsibilities, documentation and safe storage of the video clips and feasibility regarding patient outcomes and changes in clinical decisions.

6.2. Further research recommendations

This systematic literature review only identified nine relevant studies, including nurses, specialized nurses and paramedics. In addition, most of the studies were pilot studies or included a small sample of participants performing POCUS. This suggests that there is a need to conduct studies with larger sample sizes to strengthen statistical power and generalizability of the studies. It is also recommended to carry out studies that aim to investigate both the content and length of training given to nurses who perform focused point-of-care ultrasound using standardized tools to evaluate pre and post-test.

There is also a need to conduct feasibility studies that focus on enhanced training, expert supervision and feedback. In addition, evaluation of how the training programmes and POCUS examinations routines and protocols are implemented as well as how competence is maintained over time in the units is needed. Furthermore, a qualitative study exploring how intensive care nurses perceive the theoretical education and training programmes, the use of HUDs, applicability and implementation in the daily basis routine could help to identify low participant rates and gaps in the programmes and routines to improve the implementation of HUDS in the units.

No large-scale cost-benefit study has been undertaken, neither clinical decision-making changes after POCUS performance has being researched.

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APPENDIX 1. Literature research documentation

Database/source	**Ovid Embase <1974 to 2022 December 29>** Advanced Search	
Date of search	29/12/2022	
Search history	1 "point of care ultrasound"/	3,225
	2 ((ultraso* or sonograph* or echograph* or echocardiograph* or echo-cardiograph*) and ("point-of-care" or POCUS or POC or handheld or hand-held)).mp	12,188
	3 (focused cardiac ultraso* or POCUS or ((bedside or bed-side) adj3 ultraso*)).mp.	6,450
	4 1 or 2 or 3	15,171
	5 (heart or cardiac or cardiovascular or pericardium or lung* or pulmo* or pleura* or vena cava or cava vein or venae cavae).mp.	5,244,895
	6 exp nurse/	209,123
	7 paramedical personnel/ or nursing staff/	89,230
	8 (nurs* or non-physician* or nonphysician* or paramedic* or para-medic*).mp.	890,042
	9 6 or 7 or 8	891,888
	10 4 and 5 and 9	229
Number of results	229	

Database/source	**British Nursing Index** Advanced Search	
Date of search	17/01/2023	
Search history	(((noft(ultraso*) OR noft(sonograph*) OR noft(echogra*) OR noft(echocardiograph*) OR noft(echo-cardiograph)) AND (noft("point-of-care") OR noft(POCUS) OR noft(POC) OR noft(handheld) AND noft(hand-held))) OR (noft("focused cardiac ultraso*" OR POCUS) OR noft(((bedside OR bed-side) NEAR/2 ultraso*)))) AND ((MAINSUBJECT.EXACT("Nurse practitioners") OR MAINSUBJECT.EXACT("Nursing care") OR MAINSUBJECT.EXACT("Nurse specialists") OR MAINSUBJECT.EXACT("Advanced practice nurses") OR MAINSUBJECT.EXACT("Nursing") OR MAINSUBJECT.EXACT("Nurses") OR MAINSUBJECT.EXACT("Paramedics")) OR (nurs* OR non-physician* OR nonphysician* OR paramedic* OR "para-medic*")) AND (heart or cardiac or cardiovascular or pericardium or lung* or pulmo* or pleura* or "vena cava" or "cava vein" or "venae cavae")	30
Number of results	30	

Database/source	**British Nursing Index** Advanced Search	
Date of search	17/01/2023	
Search history	(((noft(ultraso*) OR noft(sonograph*) OR noft(echogra*) OR noft(echocardiograph*) OR noft(echo-cardiograph)) AND (noft("point-of-care") OR noft(POCUS) OR noft(POC) OR noft(handheld) AND noft(hand-held))) OR (noft("focused cardiac ultraso*" OR POCUS) OR noft(((bedside OR bed-side) NEAR/2 ultraso*)))) AND ((MAINSUBJECT.EXACT("Nurse practitioners") OR MAINSUBJECT.EXACT("Nursing care") OR MAINSUBJECT.EXACT("Nurse specialists") OR MAINSUBJECT.EXACT("Advanced practice nurses") OR MAINSUBJECT.EXACT("Nursing") OR MAINSUBJECT.EXACT("Nurses") OR MAINSUBJECT.EXACT("Paramedics")) OR (nurs* OR non-physician* OR nonphysician* OR paramedic* OR "para-medic*")) AND (competenc* OR educat* OR training OR teach* OR learn* OR simulat* OR certificat* OR "program development" OR "program evaluation")	36
Number of results	36	

Database/source	**CINAHL with Full Text** Interface – EBSCOhost Research Databases Search Screen – Advanced Search
Date of search	17/01/2023

Search history	1 ((ultraso* or sonograph* or echograph* or echocardiograph* or echo-cardiograph*) AND ("point-of care" or POCUS or POC or handheld or "hand-held")) OR ("focused cardiac ultraso*" or POCUS or ((Bedside or bed-side) N2 ultraso*)) 2 heart or cardiac or cardiovascular or pericardium or lung* or pulmo* or pleura* or "vena cava" or "cava vein" or "venae cavae" 3 nurs* or non-physician* or nonphysician* or paramedic* or "para-medic*" 4 S1 AND S2 AND S3	4,473 775,343 981,859 63
Number of results	63	
Database/source	**CINAHL with Full Text** Interface – EBSCOhost Research Databases Search Screen – Advanced Search	
Date of search	24/01/2023	
Search history	1 (MH "Education+") 2 (MH "Program Evaluation+") 3 competenc*OR educat* OR certificat* OR training OR learning OR simulation* OR teach* OR program development OR program evaluation 4 S1 OR S2 OR S3 5 nurs* OR non-physician* OR nonphysician* OR paramedic* OR "para-medic*" 6 ((ultraso* OR sonograph* OR echograph* OR echocardiograph* OR echo-cardiograph*) AND	1,013,491 47,847 659,784 1,324,796 982,425 4,473

	("point-of-care" OR POCUS OR POC OR handheld OR "hand-held")) OR ("focused cardiac ultraso*" OR POCUS OR ((bedside OR bed-side) N2 ultraso*)) 7 S4 AND S5 AND S6	 88
Number of results	88	

Database/source	**MEDLINE** Interface – EBSCOhost Research Databases Search Screen – Advanced Search	
Date of search	24/01/2023	
Search history	1 (ultraso* or sonograph* or echograph* or echocardiograph* or echo-cardiograph*) AND ("point-of care" or POCUS or POC or handheld or "hand-held")	8,757
	2 "focused cardiac ultraso*" or POCUS or ((Bedside or bed-side) N2 ultraso*)	4,083
	3 S1 or S2	10,062
	4 heart or cardiac or cardiovascular or pericardium or lung* or pulmo* or pleura* or "vena cava" or "cava vein" or "venae cavae"	3,843,478
	5 S3 AND S4	4,199
	6 nurs* or non-physician* or nonphysician* or paramedic* or "para-medic*"	1,129,802

	7 S5 AND S6	149
Number of results	149	

Database/source	**MEDLINE** Interface – EBSCOhost Research Databases Search Screen – Advanced Search	
Date of search	24/01/2023	
Search history	1 (MH "Education+")	888,437
	2 (MH "Program Evaluation+")	82,855
	3 competenc*OR educat* OR certificat* OR training OR learn* OR simulat* OR teach* OR "program development" OR "program evaluation"	2,336,826
	4 S1 OR S2 OR S3	2,889,174
	5 nurs* OR non-physician* OR nonphysician* OR paramedic* OR "para-medic*"	1,129,802
	6 ((ultraso* OR sonograph* OR echograph* OR echocardiograph* OR echo-cardiograph*) AND ("point-of-care" OR POCUS OR POC OR handheld OR "hand-held")) OR ("focused cardiac ultraso*" OR POCUS OR ((bedside OR bed-side) N2 ultraso*))	10,062
	7 S4 AND S5 AND S6	152
Number of results	152	