Teaching Point-of-Care Ultrasound in Medicine: a scoping review

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Abstract

Point-of-care ultrasound (POCUS) is an important tool for diagnosis and management across medical specialties. This scoping review consolidates POCUS education literature, examining how curricula are developed, implemented, and assessed. We identify literature gaps, explore directions for further research, and provide recommendations for curriculum development, implementation, and improvement.

Methods

We conducted a scoping review per the framework outlined by Arksey & O'Malley. A systematic search of the MEDLINE, EMBASE, Cochrane, ERIC, Web of Science, and Scopus databases was conducted to identify published, English language literature, on POCUS education in undergraduate or graduate medical training.

Results

Of 6,164 articles identified, 421 were analyzed in depth. Curricular content included diverse diagnostic and therapeutic applications, varying significantly by specialty. Teaching modalities included in-person didactics (74%), human models (58%), simulation (33%), and web-based didactics (18%). Several studies showed better outcomes for structured vs. apprenticeship curricula, hands-on teaching vs. didactic lectures, and human models vs. simulators. Web-based didactics were as effective as in-person didactics and conveyed benefits in reusability, cost, and instructor time. Dedicated electives and boot-camps were identified as effective. Few curricula assessed knowledge retention (5%), clinical decision making (3%), learner behavior (12%), or patient outcomes (6%).

Conclusion

Scholarly POCUS education literature is expanding. Curricular content varies and should be tailored to specialty needs. Structured curricula utilizing hands-on learning, electives, and boot-camps can enhance educational outcomes. Higher-level outcomes such as knowledge retention,

clinical decision making, learner behavior, and patient outcomes, are lacking and should be a focus of further research

Resume

L'échographie au point de service (POCUS) est un outil important pour le diagnostic et la gestion dans toutes les spécialités médicales. Cette étude de portée consolide la littérature éducative POCUS, en examinant comment les programmes d'enseignement sont élaborés, mis en œuvre et évalués. Nous identifions les lacunes de la littérature, explorons les directions à prendre pour des recherches plus approfondies et fournissons des recommandations pour le développement, la mise en œuvre et l'amélioration des programmes d'enseignement.

Méthodes

Nous avons procédé à un examen de portée conformément au cadre défini par Arksey & O'Malley. Une recherche systématique dans les bases de données MEDLINE, EMBASE, Cochrane, ERIC, Web of Science et Scopus a été effectuée afin d'identifier les publications en langue anglaise sur l'enseignement POCUS dans le cadre de la formation médicale de premier ou de deuxième cycle.

Résultats

Sur les 6 164 articles identifiés, 421 ont fait l'objet d'une analyse approfondie. Le contenu des programmes d'études comprenait diverses applications diagnostiques et thérapeutiques, variant considérablement selon les spécialités. Les modalités d'enseignement comprenaient la didactique en personne (74 %), les modèles humains (58 %), la simulation (33 %) et la didactique basée sur le web (18 %). Plusieurs études ont montré de meilleurs résultats pour les programmes structurés par rapport aux programmes d'apprentissage, l'enseignement pratique par rapport aux cours magistraux didactiques, et les modèles humains par rapport aux simulateurs. La didactique basée sur le web était aussi efficace que la didactique en personne et présentait des avantages en termes de réutilisation, de coût et de temps de l'instructeur. Les cours optionnels et les camps d'entraînement ont été jugés efficaces. Peu de programmes ont évalué la rétention des connaissances (5 %), la prise de décision clinique (3 %), le comportement des apprenants (12 %) ou les résultats pour les patients (6 %).

Conclusion

La littérature éducative POCUS est en pleine expansion. Le contenu des programmes d'études varie et doit être adapté aux besoins spécifiques. Des programmes structurés utilisant un apprentissage pratique, des cours optionnels et des camps d'entraînement peuvent améliorer les résultats scolaires. Des résultats de plus haut niveau, tels que la rétention des connaissances, la prise de décision clinique, le comportement de l'apprenant et les résultats pour le patient, font défaut et devraient faire l'objet de recherches plus approfondies.

Point-of-care ultrasound (POCUS) has become a valuable clinical tool for the delivery of patient care across medical specialties. It is inexpensive, non-invasive, portable, and studies support its ability to improve patient care by providing timely and accurate diagnoses,^{1,2} guiding clinical management,³⁻¹¹ and increasing success rates of bedside procedures.¹²⁻¹⁷

Ultrasonography was first proposed as a clinical tool in the late 1950s.¹⁸ Over the subsequent decades, technological advances made ultrasound more portable and affordable, paving

the way for its use at the bedside. Initial viability studies in trauma literature of the 1980s-1990s¹⁹⁻²¹ demonstrated POCUS' clinical benefits and led to its expansion across medicine. While POCUS has become increasingly validated and widespread in clinical use, numerous studies detail that clinical training in POCUS is often lacking or highly variable.²²⁻²⁸ Additionally, our understanding of what constitutes educational best practice in POCUS is incomplete.

POCUS is often taught through apprenticeship models whereby learners undergo “on-the-job” training in clinical settings by more experienced practitioners. This creates a dependency on educators’ abilities to convey skills and knowledge, identify weaknesses, and assess competency, making this model highly variable. Furthermore, little data is showing its efficacy. Recent literature has shown the benefits of structured teaching curricula over apprenticeship models in POCUS education.^{29–31}

Educational bodies^{32–35} have established recommendations for content knowledge and competency in POCUS, but do not provide direction regarding other key aspects of POCUS education, such as optimal teaching modalities, and methods of learner assessment and training evaluation. The International Federation of Emergency Physicians (IFEM)³⁶ provides some recommendations on curriculum delivery and learner assessment, but these are minimal compared to their guidelines on content.

There is a robust body of primary literature on POCUS education, but it is diverse in scope and methodology. Various reviews have attempted to summarize this literature. Scoping reviews by Birrane et al.³⁷ and Tarique et al.³⁸ focus on undergraduate medical education literature and identify themes in curricular content and learner assessment. A scoping review by Meadley et al.³⁹ focuses on POCUS education in paramedics to examine curricular structure. Our scoping review asks: what content is being taught in POCUS education curricula and how does this differ between specialties; what training methods are effective; how are learners evaluated; and what are the gaps in the POCUS education literature. Our review differs from those above in that we assess POCUS education literature in both undergraduate and graduate medical education. Additionally, our review takes a more specific look at the exact content that is being taught across specialties. Finally, we look specifically at and summarize comparative studies to better understand the relative merits of various teaching modalities. We excluded studies that solely focused on central line insertion, as this topic has been studied extensively and summarized in other reviews.^{40–42} This was done to ensure the number of included studies was kept at a manageable number and allowed us to focus more closely on other aspects of POCUS education. The goals of our study are threefold: (1) contribute to the understanding of current practices in POCUS curriculum development, implementation, and assessment, (2) provide specific recommendations to educators to aid in the design of POCUS curricula, and (3) discover gaps in the POCUS education literature and explore directions for further research.

Methods

Our decision to utilize a scoping review methodology was made after a first look at the literature revealed a study base that was too heterogeneous in methodology, study population, and objective

to be adequately captured by a systematic review. We decided that a scoping review would better allow us to capture and understand the full depth and breadth of the primary POCUS education literature. We used the scoping review framework outlined in 2005 by Arksey & O’Malley⁴³ and expanded on by Levac et al.⁴⁴ Our strategy is summarized as (a) identifying the research question (described above); (b) identifying relevant studies; (c) study selection; (d) charting the data; (e) collating, summarizing, and reporting the results. This scoping review methodology was chosen to systematically capture the full depth and breadth of the existing literature.

Identifying Relevant Studies

A comprehensive search strategy was developed by a medical librarian (AOC) to identify published, English language literature on ultrasound education for medical trainees. The initial search strategy was developed for Ovid MEDLINE by using a combination of database-specific subject headings and text words; this was then customized for each subsequent database search.

Searches were conducted between March 9 and 15, 2017 in the following databases: Ovid MEDLINE, Ovid MEDLINE Epub Ahead of Print and In-Process and Other Non-Indexed Citations, Ovid EMBASE, Cochrane Database of Systematic Reviews (Ovid), Cochrane Central Register of Controlled Clinical Trials (Ovid), ERIC (EBSCOHost), Web of Science Core Collection, and Scopus. No date limits were applied. See [Appendix I](#) for the full search strategy.

After the initial database search, duplicates were removed, and an initial title and abstract review were performed (AM), whereby exclusion criteria were used to eliminate irrelevant articles. Then, a full article review to assess the viability of the remaining studies was independently performed (AM, WW), and disagreements were resolved by consensus.

Inclusion and Exclusion Criteria Research Methodology

We included primary research (RCTs, cohort studies, and cross-sectional studies). We excluded review articles, surveys, case reports, textbook chapters, conference proceedings, research in progress, letters to the editor, comments, and unpublished literature.

We did not assess for study quality as our goal was to capture the full breadth of existing POCUS education literature. Additionally, current practice in scoping reviews is to not assess for study quality.^{43,44}

Point-of-Care Systems

Studies investigating the use of POCUS were included. We defined POCUS as a “portable ultrasound intended for use at

the patients' bedside for immediate diagnostic or therapeutic purposes." This definition includes "handheld" and "pocket-sized" ultrasound. We excluded non-POCUS systems, such as trans-rectal ultrasound, trans-esophageal echocardiogram, formal transthoracic echocardiogram, radiology department ultrasonography, endoscopic ultrasound, and endo-bronchial ultrasound.

Educational Intervention

Studies that investigated an educational intervention or training curricula were included. We excluded studies in which there was no defined educational intervention, or where the educational intervention was disconnected to the study in question.

Study Population

We included studies that involved undergraduate medical learners, residents, or fellows. Articles that focused solely on allied health professions or practicing clinicians were excluded. Studies that involved combined training of medical students, residents, fellows, and allied health care or clinicians were included.

Central Line Insertion Studies

We excluded studies that had a sole focus on central venous access procedures. This topic has been studied and summarized extensively in prior literature.^{40–42} We felt that the inclusion of these studies was unnecessary and could potentially dilute the value of the other studies. Additionally, the inclusion of these studies would substantially increase the number of studies in this review to an unmanageable degree. However, we decided to include studies that involved central venous access education as part of a broader POCUS curriculum, to ensure we did not unjustly eliminate valuable studies on POCUS curricula.

Charting the Data

Prior to the study analysis, we devised categories under which study data could be tabulated. These categories were: study date, journal of publication, study design, type of learner, curricular content, teaching modality, instructor type, learner assessments, and training evaluation. Data about these categories were extracted from the selected articles.

Decisions related to which aspects of POCUS education to explore in further detail were borne out of patterns that emerged during a review of the literature, and topics that the authors found interesting. Given the scoping review methodology we used, and heterogeneity of the studies included, we did not assess study quality, nor did we perform statistical analysis on any of the studies. Instead, we performed a narrative summary of the studies to help map the landscape of the existing literature base,

form preliminary conclusions on the data found within, and explore directions for further research.

Results

Search Results

The screening and review process is outlined in Figure 1 using a PRISMA diagram framework.⁴⁵ The initial search identified 12,647 articles. After duplicates were removed, 6164 abstracts were screened. On the initial screen of abstracts, 4,954 articles were excluded. The remaining 1,210 studies underwent full review by two independent investigators (AM, WW). The kappa statistic for agreement between evaluators was 0.663, indicating good consensus. Disagreements were resolved through discussion, and 421 studies were included for analysis.

The papers explored in further detail are cited in the body of this paper. A listing of all studies included in the review is shown in [Appendix 2](#).

Study Demographics

Types of Studies

There were 269 prospective cohort studies (63.9%), 89 randomized controlled trials (21.1%), 51 cross-sectional studies (12.1%), and 12 retrospective studies (2.9%).

Journals

The included studies were published in 166 individual journals (Table 1).

Date of Publication

Dates of study publication revealed major increases in publications from 1991 to 2017 (Figure 2).

Specialty

Studies were categorized by the specialty of the trainees involved. Studies involving internal medicine and subspecialty trainees (nephrology, rheumatology, and cardiology) trainees were grouped under "internal medicine." Studies involving surgical trainees (all specialties) were grouped under "surgery." Specialties with few publications, including radiology, pediatrics, physical medicine and rehabilitation (PM&R), and family medicine, were grouped into "other."

We plotted the relative frequency of publications by trainee specialty over time (see Figure 2). The earliest learners of POCUS were surgical trainees in the early 1990s. Over the next decade, the literature on emergency medicine trainees was the most published. In recent years, the share of publications in internal medicine, anesthesiology, undergraduate medical education (UME), and obstetrics and gynecology (OBGYN) has increased, while the share in emergency medicine has

Figure 1. There were 12,467 records were identified from databases MEDLINE, MEDLINE epub & in-process, EMBASE, Central, ERIC, Web of Science, and Scopus. There were 6843 duplicates, and 6164 titles were screened. We excluded 4954 records based on title review. We assessed 1210 articles in-depth, of which 421 were included in the final analysis.

declined. Currently, the largest share of POCUS education literature is in UME.

Curricular Content

Determining relevant content is essential in developing effective curricula. We analyzed the content of the 421 included studies. Content included ultrasound ‘fundamentals’ (226 studies, 54%), cardiac (188, 45%), abdominal (141, 33%), pelvic (122, 29%), vascular (111, 26%), procedural (104, 25%), pulmonary (80, 19%), MSK (62, 15%), genitourinary (62, 15%), head and neck

(39, 9%), and ocular (17, 4%) ultrasound. A detailed breakdown of specific content and the variation between specialties is shown in [Appendix 3](#) and [Appendix 4](#).

Anatomy/Physiology Learning

Fourteen studies employed POCUS to teach anatomy or physiology.^{46–59} Nine studies revealed improved anatomy and physiology knowledge after POCUS teaching.^{46,50–53,55–58} Four studies only looked at subjective measures such as learner satisfaction and confidence.^{47–49,54} Five studies employed control

Table 1. Journals in which the 421 analyzed studies were published.

Journal	# of citations
Journal of Ultrasound in Medicine	31
Journal of Emergency Medicine	18
Critical Ultrasound Journal	15
Academic Emergency Medicine	13
Academic Radiology	10
Journal of the American Society of Echocardiography	10
The Western Journal of Emergency Medicine	10
Medical Education	9
Regional Anesthesia & Pain Medicine	9
Journal of Surgical Education	9
Journal of Trauma-Injury Infection & Critical Care	8
American Journal of Emergency Medicine	7
Anatomical Sciences Education	7
BMC Medical Education	7
Ultrasound in Obstetrics & Gynecology	6
Annals of Emergency Medicine	6
Echocardiography	6
Anaesthesia	6
Simulation in Healthcare: The Journal of The Society for Medical Simulation	5
Teaching & Learning in Medicine	5
Journal of Clinical Anesthesia	5
Journal of General Internal Medicine	4
Canadian Journal of Anaesthesia	4
Anesthesiology	4
Critical Care Medicine	4
Advances in Physiology Education	4
Journal of Graduate Medical Education	4
Internal & Emergency Medicine	4
Other	191

groups,^{51–53,56,59} comparing ultrasound to cadavers,^{52,53,56} and traditional anatomy teaching programs.^{51,59} These studies did not find a significant improvement in anatomy and physiology knowledge with ultrasound training compared to controls.

Teaching Modalities

Teaching modalities are how content is delivered. We were interested in which modalities were being used to teach POCUS and their comparative efficacy. Fifteen teaching modalities were identified (Figure 3). Commonly employed modalities were in-person didactics (313 studies, 74%), human models (244, 58%), simulators (140, 33%), web-based didactics (76, 18%), live demonstrations (76, 18%), and clinical exposures (72, 17%). Many studies analyzed the comparative effectiveness of various teaching modalities. We took a narrative approach to discussing these comparisons.

Structured Training versus Apprenticeship Model of Learning

Structured training and apprenticeship training were compared in 12 studies.^{29–31,60–68} Outcomes included knowledge,^{29–31,60,61,63,65–68} image acquisition,^{29–31,61,63,65–68} image interpretation,^{29–31,65–67} procedural skills,^{62,63,65} and confidence.^{29–31,61,66,68} Ten studies showed significantly better outcomes with structured training curricula than apprenticeship models,^{29–31,60–64,67,68} while one study showed a trend towards improved outcomes,⁶⁶ and one study did not find any difference.⁶⁵

Web-Based Didactic versus In-Person Didactic Training

Web-based and in-person didactic training was compared in 9 studies.^{69–77} Outcomes included knowledge,^{69,70,72–75,77} image acquisition,^{72,74,77} image interpretation,^{69,70,73–75,77} procedural skills,⁷¹ clinical decision making,⁷² and confidence.^{75,77} Eight studies found no difference in outcomes between web-based and in-person didactics.^{69–71,73–77} The remaining study found no difference with novices, but inferior outcomes for web-based training with more experienced learners.⁷²

Didactic Training versus Hands-On Training

Hands-on training included training with human models, simulators, clinical training, or cadavers, and was included in 96% of studies. Hands-on training was compared to didactic training in 8 studies.^{31,77–83} Measured outcomes included knowledge,^{31,77–80,82,83} image acquisition,^{31,77–80,82} image interpretation,^{31,77,78,82,83} confidence,^{31,77,78,80} and procedural skills.⁸¹ Four studies found that hands-on training alone, or hands-on training combined with didactic training had better outcomes than didactic training alone.^{78,79,81,82} One study found that hands-on training alone was equivalent to didactic training plus hands-on training.⁷⁷ One study found that didactic plus

Figure 2. Total number of publications in POCUS education (vertical bars) and the share of publications by specialty (lines) from 1991 to 2017. The number of publications in POCUS education has increased exponentially from 1991–2017. Over that time, the share of POCUS education literature has shifted from surgery and emergency medicine to undergraduate medical education (UME), internal medicine, and anesthesiology.

Figure 3. Teaching modalities identified in the 421 analyzed studies. In-person didactics, human models, and simulators are the most commonly used teaching modalities.

hands-on training was superior to hands-on training alone,⁸³ and two studies did not find any difference in outcomes.^{31,80} No studies found that didactic training alone was superior to hands-on training alone.

Simulation Training versus Human Model Training

Simulators and human models were compared in 11 studies.^{69,84–93} Outcome measures included knowledge (all studies), image acquisition,^{69,84–86,88–93} image interpretation,^{69,84,85,87–89,92,93} and confidence.^{69,84,85,88} Overall, one study showed superior outcomes with simulation,⁹¹ six showed no difference in outcomes,^{84,85,87,90,92,93} and four showed superior outcomes with human models.^{69,86,88,89} Several studies found that human models conveyed superior outcomes in image acquisition,^{69,86,88,89} even when there was no improvement in image interpretation or knowledge.^{69,88} Chung et al.⁸⁹ found that learners trained on human models had superior outcomes in image acquisition and interpretation than their simulation-taught counterparts when tested on a human model, while the opposite was true when tested on a simulator. Training with human models and simulators together versus one modality alone was assessed in three studies,^{92,94,95} and no differences were found in image interpretation,^{92,95} time to completion,⁹⁴ or biometric measurements.⁹⁴

Simulator Fidelity

High-fidelity and low-fidelity simulators were compared in three studies.^{96–98} In one study, the high-fidelity simulator was associated with better learner feedback.⁹⁶ In the other two studies, there was no difference in learner feedback,⁹⁷ knowledge,⁹⁷ or procedural skills.⁹⁸

Instructors

Ultrasound instructors included attending physicians (348 studies, 83%), residents or fellows (28, 7%), medical students (17, 4%), and allied-health staff (4, 1%). Fifty-six studies (13%) did not specify the type of instructor.

Self-Directed versus Instructor-Led Training

Self-directed training was compared to instructor-led training in four studies.^{69,99–101} One study demonstrated significantly improved outcomes with self-directed learning but did not have a comparison group.¹⁰¹ The remaining three studies employed comparison groups. Of these, two found worse outcomes with self-direct learning,^{69,99} and one found no difference.¹⁰⁰

Peer-Led versus Expert-Led Training

Peer-led training was evaluated in 18 studies.^{51,55,56,58,77,102–114} Fifteen studies used medical students as teachers,^{51,56,58,77,102–109,111–113} two studies used residents,^{55,110} and one study used a fellow.¹¹⁴

Twelve studies did not use comparison groups, of which eleven found positive outcomes.^{58,77,106–114}

Six studies compared peer-led training to expert-led training.^{55,56,102–105} Of these, four studies found no difference between peer-led and expert-led education outcomes.^{55,56,103,104} Two studies found worse outcomes with peer instructors compared to expert instructors in learner feedback, time to acquire images, and OSCE scores.^{102,105}

Curriculum Length

Of the 421 studies analyzed, 341 involved curricula of less than one month (81%), and 71 were one month or greater (17%). Nine studies did not specify curriculum length (2%). The average curriculum was 1.94 months. Three studies assessed whether curriculum length impacted learner outcomes,^{5,115,116} and found that longer curricula led to better outcomes in image acquisition,¹¹⁵ image interpretation,^{115,116} and knowledge retention.^{115,116}

Feedback

Three studies compared whether providing feedback during training led to improved outcomes.^{117–119} All three studies demonstrated improved outcomes when learners were provided with feedback. Farjad et al.¹¹⁷ found that addressing errors and providing correctional advice was associated with improved skills compared to simply designating whether a procedure had been performed correctly.

Electives/Boot-Camps

Dedicated electives and boot-camps were employed in 24 out of 421 studies (5.7%).^{51,57,58,65,68,104,116,120–136} All studies reported positive outcomes, including confidence,^{51,68,104,120,122,123,125–127,135} knowledge,^{58,65,68,116,120–127,129,130,132,134–136} image acquisition^{68,120–127,129,130,134,135} and interpretation,^{65,116,120–127,129,130,132,134,136} and number of scans performed.^{120,121,124,128}

Eight studies compared dedicated electives or boot-camps to standard training.^{57,65,68,104,129,130,132} Five of these revealed better outcomes with electives.^{68,104,129,130,132} In two separate studies, Jang et al.^{129,130} found that elective groups performed a threshold number of scans in a significantly shorter time frame, and had equivalent image acquisition and interpretation scores compared to standard training. Maskatia et al.⁶⁸ found that fellows trained in an intensive three-day “boot-camp” had superior image acquisition and interpretation scores than historical cohorts trained over a longer time.

Novel Educational Methods

Two studies introduced novel methods of POCUS education in the form of ultrasound competitions and an educational conference.^{137,138} The educational conference led to improved

scores in knowledge, image acquisition, and image interpretation.¹³⁷ The ultrasound competition compared image acquisition skills in medical students and selected winners for each content group.¹³⁸

Learner Assessments, Outcomes, and Training Evaluation

Outcome evaluation is essential to determine curriculum effectiveness and make improvements. Educators must decide how and what outcomes to measure, and ensure that these outcomes provide insight on the value their curriculum is trying to create.

Learner Assessment Methods

Learner assessments included questionnaires and surveys (179 studies, 43%), non-procedural practical examinations (160, 38%), pre-and-post intervention assessments (134, 32%), comparisons to control (118, 28%), written examinations (110, 26%), procedural skills assessments (62, 15%), comparisons to gold-standard tests (54, 13%), comparisons to experts (49, 12%), OSCEs (33, 8%), and review of archived images (30, 7%).

Learner Outcomes and Training Evaluation

We assessed learner outcomes by using the Kirkpatrick model¹³⁹ of training evaluation (Figure 4). This model assesses measured outcomes to determine the efficacy of a training program, assigning a numerical score as follows:

- Kirkpatrick I: The degree to which participants find the training favorable, engaging and relevant to their jobs
- Kirkpatrick II: The degree to which participants acquire the intended knowledge, skills, attitude, confidence and commitment based on their participation in the training
- Kirkpatrick III: The degree to which participants apply what they learned during training when they are back on the job
- Kirkpatrick IV: The degree to which targeted outcomes occur as a result of the training

Studies that elicited learner enjoyment or satisfaction with the curriculum were designated as fulfilling Kirkpatrick level I. Kirkpatrick II was accorded to studies that assessed confidence, knowledge, image acquisition, image interpretation, knowledge retention, procedural skills, clinical decision making, anatomy knowledge, and physical exam skills. Kirkpatrick III was accorded to studies that assessed learners' use of ultrasound by monitoring the number of scans performed or through self-reports. Kirkpatrick IV was accorded to studies that measured end-outcomes, including changes or improvements in diagnostics, changes in patient management, procedural success rates, and patient satisfaction.

Overall, Kirkpatrick I outcomes were assessed in 141 studies (33%), Kirkpatrick II outcomes in 398 studies (95%), Kirkpatrick III outcomes in 50 studies (12%), and Kirkpatrick IV outcomes in 27 studies (6%). We took particular interest in

Figure 4. Learner and program outcomes assessed in the 421 analyzed studies, divided by Kirkpatrick levels of training evaluation. The majority of studies assess Kirkpatrick levels I-II outcomes. Few studies assess Kirkpatrick III-IV outcomes. Even within Kirkpatrick II, few studies assess knowledge retention and clinical decision making.

outcomes that we believed were of value, but understudied, and from which we could present data-driven conclusions; these are summarized below.

Knowledge Retention

Knowledge retention (Kirkpatrick II) was assessed in 22 studies (5%).^{9,31,63,80,83,90,100,106,115,116,140–151} These studies varied in terms of curriculum length, time to follow-up, method of assessment, and rates of retention. Twelve studies found that knowledge was maintained,^{9,31,63,100,106,116,141–146} seven found a decline in knowledge,^{90,115,140,147,148,150,151} and three had mixed results.^{80,83,149}

Of the 12 studies in which learners maintained knowledge, the average time to follow-up was 5.2 months and the average number of teaching modalities used was 2.83. Outcomes included knowledge,^{9,31,63,106,116,141–146} image interpretation,^{9,106,116,141–143,145,146} image acquisition,^{9,31,106,141,144,145} learner confidence,¹⁴¹ psychomotor skills,⁶³ and procedural skills.¹⁰⁰ However, two studies found a trend towards knowledge decay.^{31,144}

Of the seven studies that showed a decline in knowledge retention, the average time to follow-up was 11.75 months, and the average number of teaching modalities used was 3.0. Measured outcomes included knowledge (all studies), image interpretation,^{115,140,147,148,150,151} image acquisition,¹⁵⁰ and learner confidence.¹⁴⁸ Kimura et al.¹⁵⁰ discovered striking reductions in image acquisition, interpretation, and knowledge with an average follow-up time of 2.9 years for practicing physicians who had been trained in a 36-month curriculum, to the point where the average learner would not have passed their final competency test after only one year of non-use. Hempel et al.¹⁵¹ found that medical students retained only 20% of knowledge at two weeks after a didactic presentation. Duloher et al.¹⁴⁸ found that residents had a significant decline in their ability to differentiate fluid from air at 22 months after a one-day ultrasound course.

Three studies had mixed results. One study found that anesthesia residents tested at three weeks follow-up were able to obtain simpler ultrasound views of the spine, but had a significant decline in the ability to identify more difficult views.⁸⁰ Another study found that theoretical knowledge declined at three months, but found no decline in procedural skills.¹⁴⁹ Finally, one study compared pre-intervention knowledge and image interpretation to the same outcomes at six months but did not include an immediate post-intervention test.⁸³

Learners in curricula that were one day or less tended to have more knowledge decay than those in curricula more than one day. Of the former, seven studies revealed a degree of decay in outcomes (58%), while five did not. Of the latter, two studies revealed a degree of decay in outcomes (22%), while seven did not.

Clinical Decision Making

Clinical decision making (Kirkpatrick II) represents the transition from acquiring and interpreting images, to make clinical decisions based on them. Clinical decision making was tested in 12 of 421 studies (3%).^{72,126,152–161} Learners' decision-making skills were assessed through OSCEs,^{126,154,156–158} and written tests.^{72,152,153,155,159,161} Jozwiak et al.¹⁶⁰ asked residents to perform bedside echo on ICU patients and graded their hemodynamic diagnosis and management plan. All studies found improvements in clinical decision making after POCUS curricula.

Changes in Behaviour

Changes in learner behaviour (Kirkpatrick III) was evaluated in 50 studies out of 421 studies (12%).^{3,6,7,9,10,61,67,68,114,121,124,125,128–130,132,141,142,162–193} The majority of these studies measured learner behaviour by determining the amount of POCUS scans performed after the training period had finished (42, 84%),^{3,7,10,67,68,114,121,124,128–130,132,142,162–167,169–186,189–193} or through surveys and questionnaires (8, 6%).^{6,9,61,125,141,168,187,188} Major barriers to continued practice of POCUS included difficulties in obtaining and using equipment⁶, time constraints,^{10,170,179} lack of adequate supervision or continued feedback,^{6,187} and learner motivation and confidence.^{10,172,187} Twelve studies used ongoing formal assessments,^{7,114,121,124,128,162,166,167,169,172,178,184} including web-based upload and review strategies^{114,121} to encourage ongoing POCUS use. Five studies^{61,68,114,129,141} found that formal POCUS training encouraged subsequent use when compared to no training,^{114,141} and apprenticeship models,^{61,68,129} and one study found no difference between formal training and apprenticeship models.⁶⁷ One study found that longer training curricula led to more use than a shorter curricula.¹⁷⁴

Changes in Diagnoses or Patient Management

Changes in diagnoses and patient management (Kirkpatrick IV) were assessed in 11 out of 421 studies (3%).^{3–11,137,138} All studies demonstrated striking improvements in diagnostics and patient management (Table 2). Specifically cited diagnostic improvements included finding new evidence of heart failure,^{3,4,11} cardiomyopathy,³ valvular disease,^{3,4,11} left ventricular hypertrophy,^{3,4} previous MI,³ liver metastases,³ and cholelithiasis;³ diagnosing the etiology of dyspnea^{5,8}; verifying the presence of soft tissue abscesses¹⁹⁴; and finding new diagnoses in ICU⁷ and peri-operative settings.⁹ Cited changes in management included changes in the immediate management of cardiac diagnoses,^{4,11} change in management of dyspneic patients,⁸ change in referral practices,^{6,11,61} ordering of formal studies,^{4,11} changes in perioperative management,⁹ and changes in the management of ICU patients.⁷

Table 2. Eleven studies detailing the changes in clinical outcomes after implementation of POCUS curricula.

Title	Authors	Impact
Impact assessment of perioperative point-of-care ultrasound training on anesthesiology residents.	Ramsingh D, Rinehart J, Kain Z, Strom S, Canales C, Alexander B, Capatina A, Ma M, Le KV, Cannesson M.	New pathology identified: 31% of patients Change in management: 71% of patients
Model Point-of-Care Ultrasound Curriculum in an Intensive Care Unit Fellowship Program and Its Impact on Patient Management.	Killu K, Coba V, Mendez M, Reddy S, Adrzejewski T, Huang Y, Ede J, Horst M.	New diagnosis made: 65% of patients Change in management: 37% of patients
Lung ultrasound in internal medicine: training and clinical practice.	Mozzini C, Fratta Pasini AM, Garbin U, Cominacini L.	Change in management: 59% of patients Change in immediate management: 33% of patients
Focused bedside ultrasonography by clinicians: experiences with a basic introductory course.	Hillingso JG, Svendsen LB, Nielsen MB	Clinicians reported changing clinical approach: 47% Clinicians reported changing workup/diagnosis: 44% Clinicians reported changing referral patterns: 23%
Diagnostic influence of routine point-of-care pocket-size ultrasound examinations performed by medical residents.	Andersen GN, Graven T, Skjetne K, Mjåstad OC, Kleinau JO, Olsen Å, Haugen BO, Dalen H.	Change in, verification of, or additional diagnoses made: 41% of patients
A pilot study of the clinical impact of hand-carried cardiac ultrasound in the medical clinic.	Croft LB, Duvall WL, Goldman ME.	Diagnostic improvements made: 14%-39% of patients Management decisions reinforced: 36% of patients Management decisions changed: 40% of patients.
Focused cardiac ultrasound by unselected residents-the challenges.	Ruddox V, Norum IB, Stokke TM, Edvardsen T, Otterstad JE	Diagnoses changed: 30% of patients
ABSCSS: applied bedside sonography for convenient evaluation of superficial soft tissue infections.	Squire BT, Fox JC, Anderson C	Diagnoses changed: 17% of patients (correct in 94% of these cases)
Focused cardiac ultrasound is feasible in the general practice setting and alters diagnosis and management of cardiac disease.	Yates J, Royse CF, Royse C, Royse AG, Canty DJ	Management changed: 15% of patients
Impact of pocket ultrasound use by internal medicine housestaff in the diagnosis of dyspnea.	Filopei J, Siedenbueg H, Rattner P, Fukaya E, Kory P.	Improvement in diagnostic accuracy: 5%
Impact of high-fidelity transvaginal ultrasound simulation for radiology on residents' performance and satisfaction.	Ahmad R, Alhashmi G, Ajlan A, Eldeek B	Reduction in repeat scans needed (8/month to 1/month) Decreased referrals to attending physicians (4/month to 1/month)

Procedural Success Rates

Fifteen studies (4%) measured the success rates of various ultrasound-guided procedures (Kirkpatrick IV) completed by residents after undergoing POCUS education.^{16,62,81,181,195–205} Procedures included ultrasound guided regional anesthesia,^{81,181,195,196,198–200,202,204} paracentesis,¹⁶ vascular access,^{62,201,203,205} and renal biopsy.¹⁹⁷ Eleven studies found improvements in procedural success after an ultrasound curriculum compared to controls,^{16,62,81,195–201,205} two found no difference in outcomes compared to controls,^{202,203} and two found positive outcomes, but did not use controls.^{181,204} Specific improvements in outcomes included rates of successful anesthesia,^{81,181,196,198–200,204} fluid aspiration,¹⁶ vein and artery cannulation,^{62,201,205} tissue retrieval,¹⁹⁷ time to procedure completion,^{16,181,195,196,199–201,204,205} errors or complications,^{16,197,200,204,205} number of insertions or attempts,^{16,195,196,204,205} amount of anesthetic used,²⁰⁰ and patient feedback.^{195,196,199}

Patient Feedback

Patient feedback (Kirkpatrick IV) was elicited in four out of 421 studies (1.0%).^{64,195,196,199} These studies looked at patient satisfaction nerve block procedures,^{195,196,199} and patient comfort with transvaginal ultrasound.⁶⁴ All studies demonstrated improved feedback when ultrasound was used compared with controls.

Discussion

This scoping review assesses the current literature on POCUS education for medical trainees. We describe the specific content taught to learners across medical specialties, the teaching modalities used – with a focus on studies that compare modality efficacy, learner assessment methods, outcomes assessed in training evaluation, and trends in the literature.

POCUS education literature has increased substantially over the past few decades, especially in UME, anesthesiology, and internal medicine. This pattern is reflective of POCUS' increasing use and validation across clinical settings. For example, Lichtenstein's^{206,207} work in the late 1990s to study and validate pulmonary ultrasonography opened up an entire field of diagnostics that is now widely taught in internal medicine and critical care. We believe there is room for continued growth in specialties with relatively little published POCUS education research to date, such as family medicine and PM&R.

In developing POCUS curricula, educators must first identify clinically relevant content specific to the target specialty. Our review summarizes the content being taught across specialty, identifying significant variation. Curriculum designers can use our review as a starting point to identify appropriate content for new curricula or to adjust existing curricula.

Educators must decide on the modalities of education delivery. The majority of studies in our review show that structured

curricula perform better than apprenticeship models. Didactic training is the most commonly used modality, but we have found that hands-on training is important for the transfer of physical skills. Web-based didactic learning is non-inferior to in-person didactics in most studies comparing the two, which is appealing given its low cost, reusability, and instructor time savings. Simulators and human models are the most commonly applied hands-on methods; both appear to be equivalent for teaching image interpretation and knowledge. However, human models appear to be superior for teaching image acquisition. This may be because most simulators are built to present images as they appear under ideal conditions. Variations in patient anatomy and physiology alter ultrasound acoustics and confound images. Teaching hands-on skills with human models allow for a more accurate representation of the conditions present in real patients. The disadvantages of human models include increased cost and the absence of clinical pathology. Clinical electives, and using standardized or real patients with known pathologies, are potential solutions.

Curricula in our review ranged from half-day sessions to longitudinal programs of four years. Although longitudinal curricula appear to be associated with better outcomes, they come with increased cost, time commitment, and organizational challenges. Promise has been shown with short-term, intensive programs (i.e., boot-camps) and clinical electives as less resource-intensive alternatives. Attending physicians are the primary instructors in POCUS. Although self-led and peer-led teaching is appealing, we found mixed outcomes. Further research in this area is warranted.

Curriculum designers must evaluate the efficacy of their curricula. POCUS requires users to be able to independently acquire images, correctly interpret those images, and then make the correct management decision or perform a procedure. We believe that a minimum evaluative standard should be to target Kirkpatrick level II outcomes; this ensures that learners gain clinically relevant skills and knowledge. This scoping review shows that a majority of studies assess Kirkpatrick levels I-II outcomes in confidence, image acquisition, interpretation, and knowledge. However, Kirkpatrick II assessments of knowledge retention and clinical decision making are lacking. Ongoing use and practice of skills are essential to maintaining competency and retaining knowledge. Some studies hypothesize that using more teaching modalities leads to better retention, but we did not find this to be true in our review. We have found that longitudinal curricula tend to result in better knowledge retention, and recommend this approach to curriculum designers. Curriculum designers should make knowledge and skill retention a priority, and implement ongoing assessments to ensure that there is adequate retention. Evaluation of clinical decision making as an outcome is also underrepresented in POCUS studies. The

ability to translate knowledge into actionable clinical decisions is essential for patient care, making this outcome one that should be more routinely assessed.

Few studies assess Kirkpatrick level III outcomes (50, 12%), which is an important measure to determine whether learners translate knowledge to clinical use. Further research is needed to determine the best ways to promote ongoing POCUS use. Our study has identified longitudinal programs and ongoing clinical assessments as methods that have been used to promote use, but this comes with increased resource costs. Barriers include time, training expertise and supervision, and equipment constraints. More research is needed to determine how to manage these constraints and how best to promote continued POCUS use.

Studies that assess Kirkpatrick level IV outcomes are likewise underrepresented (27, 6%). These studies are especially important since the intention of POCUS is to be used at the bedside to improve patient care; measuring these outcomes ensures that POCUS education is meeting its intended purpose. We found dramatic effects on clinical outcomes in the few studies that assessed Kirkpatrick IV outcomes. Demonstrating improved patient care as an outcome can help increase institutional buy-in, and obtain more funding and resources. Investigators and educators should make an effort to assess Kirkpatrick III-IV outcomes when designing and evaluating their curricula.

Conclusion

Educators should take into account many factors when designing POCUS curricula, including curricular content, modalities of teaching, learner assessments and training evaluation. Curricular content varies significantly between specialties and must be tailored to fit the needs of its specialty. POCUS should be taught in structured curricula with a combination of didactic and hands-on learning. Web-based didactic methods are cost-friendly and effective. Simulators and human models are both viable methods of hands-on teaching, but human models appear to convey better outcomes in image acquisition. Novel teaching methods such as dedicated electives, intensive “boot-camps,” and competitions are promising methods to deliver POCUS education. There is a pressing need to go beyond satisfaction outcomes in evaluating POCUS learning. Educators should target outcomes in knowledge, image acquisition, and image interpretation. Ideally, outcomes in knowledge retention, clinical decision making, learner behavior, and patient care should be sought to provide high-level evidence of the benefits of POCUS curricula.

Limitations

There are several limitations to our study. We did not include studies that focused solely on central line insertion, as this area has been extensively studied and would greatly add to the studies

analyzed in this review. However, central line insertion and POCUS studies related to them make up a large portion of the POCUS education literature, and by excluding them, we may have missed out on valuable insights provided by these studies.

Another limitation is in the narrative interpretation of study results. As this is a scoping review, we did not formally assess for study quality. Also, we did not conduct any statistical analysis of between-group comparisons. As such, the conclusions reached when comparing different modalities should not be interpreted as definitive conclusions. Our goal was simply to form a narrative understanding of what these studies showed to better understand the literature, formulate preliminary conclusions, and provide a starting point for further research. We believe that more statistically robust systematic reviews would greatly add to the understanding of POCUS education. Further to this, our study is incredibly broad and attempts to address every aspect of POCUS education. While this serves to capture the full breadth of POCUS education literature, a more focused analysis may have provided more robust conclusions.

Finally, the modalities that we decided to compare and discuss in further depth were borne out of our ideas generated during the review of the literature; based on what we thought was interesting, and what the studies in the literature appeared to be focused on, as opposed to a theoretical framework or established precedent. As such, there may be other interesting areas to analyze that we did not touch on.

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