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Original Research

A Blended Prehospital Ultrasound Curriculum for Critical Care Paramedics

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A B S T R A C T

Objective: Point-of-care ultrasound is a nascent and growing area of prehospital care. Most previously described ultrasound curricula for paramedics examine a single type of ultrasound scan. Here, we describe the implementation and evaluation of a prehospital ultrasound curriculum using a blended model of traditional didactics and hands-on experience with online prereading.
Methods: We recruited a prospective convenience sample of critical care paramedics without prior ultrasound experience to take part in a 2-day ultrasound course. All participants completed prereading modules built from online resources followed by a didactic review of the material and hands-on practice. Ultrasound examinations included extended focused abdominal sonography in trauma, cardiac ultrasound, thoracic ultrasound, and vascular ultrasound. A written examination evaluated ultrasound theory and image interpretation, and a practical examination evaluated image acquisition.
Results: Seventeen critical care paramedics completed the course with a mean grade on the written examination of 76%, with 76% of paramedics achieving the predetermined passing mark of 70% or greater. All paramedics passed the practical examination.
Conclusion: The implementation of a prehospital critical care ultrasound program is feasible in our provincial emergency medical services system. Further assessment is necessary to determine future knowledge and skill retention as well as clinical application and utility in real-world settings.

Point-of-care ultrasound (POCUS) has become a standard tool for safe and effective bedside diagnosis and treatment of critically ill patients (Figure 1).[1] Numerous applications have been described for POCUS, with reproducible improvement in morbidity and mortality when used for specific applications.[1] Typically, POCUS has been used for emergency department and intensive care unit applications by physicians; however, there are ever-expanding roles for POCUS outside of these settings and by paramedical staff.[2] Prehospital assessment traditionally relies heavily on the physical examination, which is inherently unreliable, particularly in special circumstances common to the prehospital critical care environment, such as during air medical transport. With the advent of portable and pocket-sized ultrasound machines, this imaging modality has potential benefit for the prehospital management of patients.

POCUS use in the prehospital environment has been growing over the past decade, although widespread use has not yet been adopted nor shown to be beneficial for patients.[2-4] In 2014, approximately 4% of North American emergency medical systems (EMS) agencies used POCUS in a prehospital setting, and use has likely increased since.[5] Most of those prehospital POCUS programs used flight physicians, although several programs have described successful implementation of POCUS programs for critical care paramedics.[2,6,7] A systematic review by McCallum et al[6] in 2015 and a more recent review by Meadley et al[7] in 2017 found these programs have varying curricula

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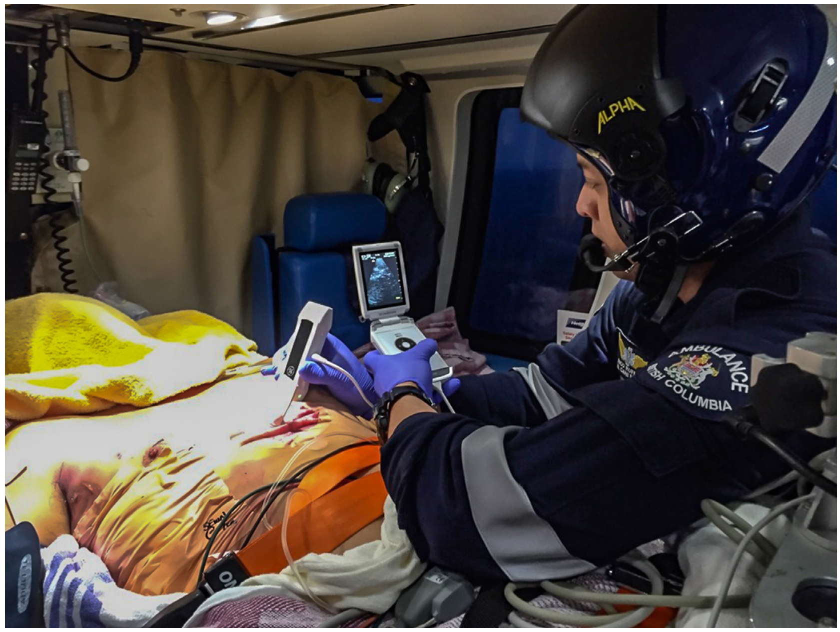

Figure 1. British Columbia Ambulance Service Critical Care Paramedic Using Ultrasound.

for focused assessment with sonography for trauma (FAST), pleural ultrasound, and cardiac ultrasound, with significant variation in the duration and type of education delivered.[8] Almost all of these programs focused on 1 specific aspect of POCUS (eg, FAST), and none implemented a comprehensive prehospital POCUS program.

Traditional teaching methods for POCUS involve didactic sessions followed by a practical or experiential phase with continuing feedback.[9] More recently, programs have been using customized online modules to provide an ongoing reference and source of continuing education even after didactic sessions are complete.[10] The advent of free open-access medical education (FOAMed) offers an even more attractive option for learners because content is free and updated in real time as new or updated material becomes available.[11]

In this study, we designed a comprehensive prehospital POCUS curriculum and delivered it to our critical care paramedics (CCPs) in 1 provincial EMS system. Paramedics had no prior ultrasound experience before the educational program. We designed our curriculum using FOAMed resources such that the curriculum would be readily usable by other EMS agencies, if desired. We hypothesized that previously untrained CCPs could accurately perform POCUS assessing cardiac, thoracic, abdominal, and vascular scans after a series of dedicated Web-based, didactic, and hands-on learning sessions. We examined their ultrasound knowledge and image interpretation, as well as assessed image acquisition in a formalized fashion. Here, we describe our curriculum and present the results of our evaluation so that other EMS systems may consider adopting this evolving technology into their critical care programs.

Methods

Study Design

This was a prospective observational cohort study to evaluate the feasibility and effectiveness of a comprehensive prehospital critical care ultrasound training program for CCPs. Institutional research ethics board approval was waived. All participants were aware of the study and consented to participation. Funding for this study was provided internally by British Columbia Emergency Health Services and the British Columbia Ambulance Service, and this research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Study Population and Setting

The British Columbia Ambulance Service is the largest single EMS agency in North America and the only EMS service provider for the province of British Columbia, Canada. The critical care transport program services approximately 4.5 million people over an area of 945,000 km^2. The service delivers approximately 8,000 critical care air transports annually using a combination of fixed wing and rotary wing aircraft. Critical care transports are staffed by paired critical care paramedics, and physicians are not used for transport. Teams respond for interfacility transport as well as scene response calls. CCPs are highly trained, with generally a minimum of 5 years of advanced/critical care paramedicine education and 5 years of practical experience. CCPs have completed primary care paramedic (8 months) as well as advanced care paramedic (2 years) and significant additional practical work experience before being accepted into the training program. CCP training includes 2.5 years of combined didactic and practical training in a broad range of critical care practice. CCP scope of practice is broad and encompasses nearly all critical care therapies and medications at the direction of physician EMS transport advisors. Subjects in this study were CCPs who voluntarily agreed to participate (Table 1).

Study Protocol

Subjects were recruited as a convenience sample from current CCPs at 2 British Columbia Ambulance Service stations for

Table 1
Demographics of Critical Care Paramedics

Characteristics	CCPs (n=17)
Age, years (median, IQR)	46.5 (40-54)
Sex, male, %	100
Previous ultrasound experience, n (%)	1 (6)
Previous experience with ultrasound, avg hours	0.18
Completed prereading, %	100
Time spent prereading, hours (median, IQR)	13 (8-18)

CCPs = critical care paramedics; IQR = interquartile range.

Table 2
Content of 2-Day Prehospital Ultrasound Training Program for Critical Care Paramedics

Topic	Time Allotted
Introduction to Equipment	15 minutes
Physics and Knobology Theory	30 minutes
Thoracic Ultrasound Theory and Applications	45 minutes
Abdominal Ultrasound Theory and Applications	45 minutes
Thoracic/Abdominal Practice	1h 45m
Hemodynamic Ultrasound Theory and Applications	60 minutes
Hemodynamic Ultrasound Practice	2 hours
Vascular Ultrasound Theory and Applications	30 minutes
Vascular Ultrasound Practice	60 minutes
General Review of Theory and Applications	30 minutes
General Practice All Scans	3 hours
Written Examination	60 minutes
Practical Examination of Image Acquisition	2 hours (15 minutes per participant)
Debriefing and Feedback	30 minutes
Total Time	15 hours 30 minutes

participation in online prereading module and a 2-day in-person course. FOAMed lessons were distributed describing introductory ultrasound physics; knobology; image acquisition; and image interpretation of cardiac, lung, abdominal, and vascular windows (Appendix 1). These modules were chosen by the instructing faculty based on the objectives of the program, quality of educational content, level of complexity, clarity, and duration. No specific objective criteria were used for selection but rather vetted by 2 experienced ultrasound practitioners (critical care and emergency physicians). The completion of each module was required before hands-on ultrasound instruction.

A 2-day course was designed that included didactic, hands-on, and examination components (Table 2). The didactic sessions (totaling 4 hours) focused on a pragmatic review of the topics covered in the online FOAMed modules (Table 3). After these lectures, the CCPs took part in hands-on bedside teaching with ultrasound-trained emergency medicine and critical care physicians on healthy adult models. The paramedics were split into groups for a student to teacher ratio of 4:1. The physicians demonstrated the following views: right upper quadrant; left upper quadrant; pelvic; subcostal/subxiphoid; thoracic lung; subcostal inferior vena cava and cardiac; cardiac parasternal long axis; and vascular views of the inguinal crease, neck, and wrist. The CCPs practiced each view sequentially after each lecture, with real-time feedback from the instructors. Paramedics rotated through the adult models acquiring all views. Bedside assessment focused on image acquisition with the identification of anatomy and expected locations of pathology with simulated examples. Pathologic images and videos were also emphasized in the Web-based and didactic curricula. The ultrasound machines used were the GE (Buckinghamshire, UK) VScan with 1.7 to 3.8 MHz phased array and 3.4- to 8.0-MHz linear array Dualprobe and Sonosite (Bothell, WA) NanoMaxx 5- to 8-MHz curved array and 5- to 10-MHz linear array probes. Ultrasound machines were used on loan from GE and Sonosite.

Table 3
Topics and Pathologies Covered by Prehospital Ultrasound Program

Topic (View[s])	Pathology
eFAST (right upper quadrant, left upper quadrant, suprapubic, subxiphoid/subcostal, anteromedial chest, anterolateral chest)	Intra-abdominal free fluid Intrathoracic free fluid Pericardial effusion Cardiac standstill Pneumothorax
Cardiac (parasternal long axis, subxiphoid)	Pericardial effusion Cardiac standstill
Pleural assessment (linear and phased array probes)	Pneumothorax Alveolar interstitial syndrome (B-lines)
Inferior vena cava	Plethoric collapsed
Vascular identification (radial artery, internal jugular vein, femoral vein)	NA

eFAST = extended focused abdominal sonography in trauma; NA = not applicable.

Outcome Measures

Demographic data were collected from all participants before the course. After the full hands-on component of the course, paramedics completed a written examination and subsequently a hands-on examination. The written and hands-on examinations were based on the 4 main domains of the curriculum: 1) thoracic, 2) abdominal, 3) hemodynamic, and 4) vascular.

The primary outcome for the study was the score on the written examination, which included 30 multiple-choice and written questions covering the previously taught material. The examination used images and video clips with multiple-choice and short answer–type questions for assessment. Examiners predetermined that a score of at least 70% on the examination would be considered a passing grade. Secondary outcomes were derived from the hands-on examination, and paramedics were required to obtain adequate views in all components of the practical examination in order to pass the course (Appendix 2).

The secondary outcomes of time to completion of adequate scans were evaluated by the overseeing physician educator. Thoracic lung views included bilateral 2-point assessment, which is consistent with established protocols.[12] The paramedics were evaluated on their ability to successfully acquire adequate views of 2 rib shadows and their recognition of pleural line sliding. Additionally, they were required to recognize and interpret sonographic images suggesting pulmonary edema (B-lines), as well as identify normal A-lines. The abdominal assessment was consistent with the well-established FAST examination of the right upper quadrant, left upper quadrant, and pelvis.[10] The hemodynamic assessment included the successful identification and time to image acquisition for the presence of cardiac activity (subcostal/subxiphoid). The paramedic would simultaneously assess for clinically significant pericardial effusion with this view. Furthermore, cardiac ultrasonographic assessment was scored with the 6-point validated Cardiac Ultrasound Structural Assessment Scale for image acquisition. Parasternal long-axis views were used to estimate ejection fraction as either normal ($\geq$ 50%) or abnormal (< 50%). Finally, a subcostal inferior vena cava (IVC) view was used to assess IVC size and respiratory variability. Finally, the CCP students were evaluated on correct identification of vascular anatomy, specifically differentiation between arterial and venous systems of the wrist, inguinal crease, and neck.

Results

Our convenience sample of CCPs had 17 volunteers in 2 cohorts each trained over 2 days. The mean age of the CCPs was 47 years, and all were male. Only 1 paramedic had any prior ultrasound exposure, and this did not involve any formal training. We had a requirement of completing the prereading (Web-based FOAMed materials) before didactic teaching, and the entire cohort finished the readings, although with significant variation in the duration of the prereading.

All paramedics completed the course, including the written and practical examinations. The primary outcome of the mean score on the written examination was 75.5%, with 76% of the CCPs passing the predefined benchmark of 70% on the examination (Table 4). The secondary outcomes were the time to completion of the extended focused assessment with sonography for trauma (eFAST) (median = 400 seconds, interquartile range [IQR] = 357-442 seconds), subxiphoid cardiac examination (median = 28 seconds, IQR = 22-41 seconds), IVC assessment (median = 28 seconds, IQR = 18-50 seconds), and pleural line

Table 4
Outcome Measures for a Prehospital Ultrasound Curriculum

Primary Outcome	
Written examination score, average (%)	75.5
CCPs' scoring > 70%, n (%)	13 (76)
Secondary Outcomes	
Time for eFAST (s), median (IQR)	400 (357-442)
Time for cardiac view (s), median (IQR)	28 (22-41)
CUSAS score, median (IQR)	5 (4-6)
Time for IVC view (s), median (IQR)	28 (18-50)
Time for pleural line identification (s), median (IQR)	21 (15-39)
Distinguishing arterial and venous systems, % correct	100

CUSAS = Cardiac Ultrasound Structural Assessment Scale; eFAST = extended focused abdominal sonography in trauma; IQR = interquartile range.

identification (median = 21 seconds, IQR = 15-39 seconds). All views were adequately obtained by all paramedics. Arterial and venous systems of the wrist, neck, and inguinal crease were correctly identified with 100% accuracy.

Discussion

Our study aimed to evaluate the development and implementation of a comprehensive prehospital critical care ultrasound training program. To our knowledge, there are no other similar training programs previously described in the literature, and all other programs evaluate single aspects of POCUS.[10,13-19] Didactic instruction and hands-on scanning were complimented by an online prereading component using FOAMed resources in order to encourage ongoing continuing education among our paramedics as well as to allow the use of this curriculum by other EMS agencies. All participants completed the course practical examination, and the majority of participants passed the written examination.

Prehospital critical care ultrasound has numerous important applications, particularly for large geographically diverse areas with long transport times and informing earlier triage and management decisions. In our province, CCPs are often the most skilled critical care practitioner caring for very ill patients in rural and remote facilities that are often without diagnostic capabilities and whose staff has limited case exposure and infrequently manage critically ill patients. For those patients receiving scene response for trauma-related activations, eFAST allows early notification of the receiving hospital for activation of surgical capabilities and massive transfusion protocols in hemodynamically unstable patients.[20] Also, our CCPs have blood products available in the field and with ultrasound can potentially use the validated ABC score for massive transfusion to assist with the decision to administer prehospital transfusion.[21] Thoracic ultrasound for pneumothorax is a valuable tool in an air medical environment, where typical signs of pneumothorax may be difficult to assess. With long transport times and limited resources between destinations, it is of the utmost importance that pneumothoraces are recognized and definitively managed before transport. Since implementing and validating this curriculum, there have been examples of appropriate chest tube insertion and withholding insertion based on ultrasound data. Arterial vascular access has been shown to have higher success rates when ultrasound is used, especially for practitioners who infrequently perform the skill.[22] Also, central venous access may be a skill our CCPs obtain in the future, and the evidence is clear that cannulation is safer and more efficient when aided by ultrasound.[23] Combined hemodynamic and respiratory assessment of critically ill patients with multifactorial shock and hypoxemic respiratory failure is complex, especially in low resource settings before transport. Although there are certainly limitations to POCUS and incorrect decisions can be made based on inaccurate or incomplete POCUS assessment, we feel that with practice this tool will be invaluable in assisting our practitioners with determining the most appropriate titration of hemodynamic and respiratory therapies.[24] Lastly, the ability of our prehospital critical care providers to perform ultrasound acts as an additional diagnostic arm for our physician transport advisors, providing valuable additional information in complex therapeutic and transport decision making.

During the practical examination, the time to complete each scan was significantly longer than previously described in the literature. For example, our time to completion for an eFAST examination was a median of 400 seconds, whereas previous studies have described between 125 and 240 seconds.[13-15] All previously described studies looking at the duration of the scan were only the FAST scan and did not include the thoracic components of the eFAST examination. Another explanation is that we emphasized to our students that completeness should be paramount, so they may have taken additional time to ensure that the scan was complete at the expense of speed. We also expect that with additional experience and comfort the duration for each scan will decrease. However, overall, 400 seconds for eFAST is a significant amount of time and could have significant clinical implications in real-world use. Especially in the setting of trauma, where eFAST is typically used, we know that prolonged scene times and delayed transport are associated with poorer outcomes, and, thus, if used, the eFAST examination would likely need to be during transport.[25] It remains to be seen if the use of eFAST would improve patient care because the use of ultrasound during transport would also take away from other patient care tasks, which may adversely affect outcomes.[3]

Similarly, in the subxiphoid cardiac examination for cardiac standstill, the median time to completion in our cohort was 28 seconds. This is significantly longer than previously described durations of 5 to 10 seconds.[19,26] We know that for cardiac standstill assessment in cardiac arrest, sonography should not impact the amount of time spent without chest compressions. Studies have shown that using ultrasound can adversely affect patient outcomes because of the increased time without cardiopulmonary resuscitation.[27,28] As such, any real-world application would require a significant improvement in the speed of scanning and a strong emphasis to avoid increased time off the chest.

The use of online resources and FOAMed content is becoming increasingly prevalent in acute care disciplines.[11] It has been readily adopted by the emergency medicine, critical care, and anesthesia communities, among others. Many advanced prehospital providers are very motivated to continue their education through the use of FOAMed, and anecdotally from our experience, the majority of our CCPs use some form of FOAMed for continuing medical education already. The online availability of these materials allows adult learners to pace themselves at a convenient time and location and also to explore other related ultrasound topics of interest. Thus, the blended use of a FOAMed curriculum draws a natural link between traditional didactic methods and the future wave of evolving online learning materials.

Limitations and Future Directions

This study was conducted within a single EMS system; therefore, external validity of our approach would need to be reproduced at other institutions. A larger cohort of CCPs would provide more definitive information on the feasibility of larger-scale implementation. These data represent knowledge and skill acquisition immediately after an ultrasound course, and we acknowledge that skill retention over time is equally important. In addition, we cannot be certain that all the individuals completed all aspects of the online training material, nor can we assess the engagement during this phase of the education. This study only addresses the ability to teach CCPs POCUS theory and image acquisition but does not assess the clinical utility, feasibility, and implications in a real-world setting. Also, ultrasound technique is taught on healthy volunteers, so image acquisition and troubleshooting on real patients who may have variable anatomy or body habitus will likely be more difficult. We describe a proposed curriculum for prehospital ultrasound education but are unable to definitively determine which components are the most useful or which may be unnecessary for effective learning and skill retention.

After completion of this study, we introduced POCUS to clinical practice for our CCPs within British Columbia. We feel that a program that emphasizes ongoing longitudinal POCUS education with ample opportunity for practice with timely feedback is necessary for a sustainable program. Prehospital ultrasound programs require close quality assurance and feedback because intrinsic feedback mechanisms (eg, confirmatory imaging with computed tomographic scans) are not easily available. We are implementing a staged approach to the use of ultrasound in prehospital practice, starting with initial scanning without clinical use (ie, perform the scan but do not use the information for decision-making purposes) in order to allow evaluation of the technical adequacy of field scans by supervising physicians. The second phase is a full implementation of prehospital POCUS allowing for the use of scans to influence clinical decision making under the guidance of transport physicians. In addition, we have added optic nerve sheath diameter ultrasound as an additional skill for the assessment of elevated intracranial pressure. We hope to further evaluate the impact of POCUS on prehospital decision making and ultimately patient outcomes in the future.

The implementation of a comprehensive prehospital ultrasound curriculum for CCPs with no prior ultrasound experience is feasible within our EMS system. 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. We hope that other EMS agencies may be able to adapt this curriculum to suit their needs. Further assessment is necessary to determine knowledge and skill retention, as well as clinical application and utility in real-world settings.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amj.2019.07.013.

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