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Prehospital point-of-care ultrasound: A transformative technology

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Abstract

Point-of-care ultrasound at the bedside has evolved into an essential component of emergency patient care. Current evidence supports its use across a wide spectrum of medical and traumatic diseases in a variety of settings. The prehospital use of ultrasound has evolved from a niche technology to impending widespread adoption across emergency medical services systems internationally. Recent technological advances and a growing evidence base support this trend. However, concerns regarding feasibility, education, and quality assurance must be addressed proactively. This topical review describes the history of prehospital ultrasound, initial training needs, ongoing skill maintenance, quality assurance and improvement requirements, available devices, and indications for prehospital ultrasound.

Keywords

Critical care, emergency medicine, point-of-care ultrasound, emergency medical services, prehospital medicine

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Introduction

Clinician-performed ultrasound at the bedside of a patient has become increasingly common over the past two decades.[1,2] As the evidence base has grown supporting its use across a wide spectrum of medical and traumatic disease patterns in a variety of settings, novel applications and rapid assessment protocols have emerged.[3,4] Improvements in mortality, diagnostic accuracy, patient care metrics, and patient satisfaction have all been associated with bedside ultrasound use.[5–8] Interest in ultrasound outside of traditional practice settings such as hospitals or physician offices has also increased. Prehospital medicine in many ways is often considered an austere environment, as patients are frequently critically ill and require immediate care based on limited history and very limited advanced diagnostic tools.[9] Therefore, the use of ultrasound in prehospital emergency care to improve diagnostic accuracy and facilitate rapid treatment decisions has attracted significant interest in recent years.[10]

Methods

For this topical review, the team of authors included a critical care paramedic with training in point-of-care ultrasound (POCUS), an emergency medical technician-basic with formal training in literature analysis and a prehospital physician medical director with training and certification in emergency medicine, critical care medicine, emergency medical services (EMS), and clinical ultrasonography. We first conducted two sessions akin to focus group meetings to define the scope of prehospital ultrasound, during which we agreed on the following five aspects of prehospital ultrasound: technology, clinician training, prehospital operations, patient needs and outcomes, and medical oversight. We then conducted an extensive search in the PubMed database combining the search terms "ultrasound", "prehospital" and "emergency medical services". We selected relevant manuscripts via group consensus based on the five pre-established categories. In addition, we reviewed related articles and their list of references from the authors' personal literature libraries.

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Review

History of ultrasound

The first clinical ultrasound imaging machines were developed in the 1950s. It would take another 20 years for these machines to be refined enough for widespread clinical use.[11] By the 1980s, technological improvements led to widespread adoption across hospitals.[12] In the last two decades, ultrasound performed and interpreted by physicians at the bedside has seen widespread adoption, including in the United States.[13] These exams are often performed on critically ill patients in whom diagnostic decisions and the response to therapies provided can be assessed rapidly by ultrasound. This type of ultrasound is referred to as POCUS.[14]

Initial routine use of portable ultrasound devices in the prehospital setting dates back to the late 2000s, mostly in European physician-based EMS systems.[15] Since then, a new generation of portable ultrasound devices have emerged that are small and lightweight enough to qualify as "handheld" devices which can be easily used in the prehospital emergency care field.[16] As these ultrasound devices have also become more affordable, adoption in the prehospital setting has further increased.

Although there is much potential for PHUS performed by EMS personnel, to date, there are no universally acknowledged guidelines for prehospital ultrasound (PHUS) use, indications, educational and credentialing requirements, and quality assurance.

Training requirements

Prehospital physicians are more likely to have had formal ultrasound training during their medical education, while nursing and paramedic schools traditionally have not provided ultrasound training.[17] Nonetheless, nurses and paramedics can learn POCUS and perform select exams competently with relatively short training periods.[18–21] Prehospital POCUS programs vary widely, with training ranging from minutes to several days. In general, training programs included didactic and practical training, with some successfully implementing blended online and in-person curricula.[22] There is a paucity of literature regarding the education practicing prehospital clinicians have obtained outside of feasibility studies or pre-implementation surveys. However, in two studies, paramedics with advanced training or significant experience demonstrated higher degrees of accuracy in lung ultrasound.[19,23] Beyond formal training, additional ultrasound education is likely being obtained from unit-level in-services, courses, and conferences, as well as free open-access medical education, especially in the non-physician clinician base where formal ultrasound education may be harder to obtain because of availability and/or cost. Guy et al. describe a comprehensive prehospital POCUS curriculum for Canadian critical care paramedics spanning cardiac, thoracic, abdominal, and vascular scans. This curriculum utilized web-based, didactic, and hands-on learning sessions. Online pre-reading was followed by a 2-day in-person course. Free open-access medical education was utilized to allow for easy flow of information to potential future adopting departments. Scans performed included the extended Focused Assessment with Sonography for Trauma (eFAST), cardiac views (parasternal long axis and subxiphoid), pleural assessment, inferior vena cava (IVC) measurement, and vascular structure identification. All students passed the practical examination, and >75% of the students passed a post-course written examination.[21]

In most studies of prehospital ultrasound programs, assessment involves pre- and post-implementation knowledge checks followed by either simulation or volunteer practice and finally proctoring or expert review of exams in the clinical setting. Sensitivity, specificity, and succesful image acquisition were commonly used primary study outcome measures. EMS clinicians generally perform favorably and significantly improve on post-implementation knowledge assessment. A 2015 systematic review of paramedic ultrasound curricula found that most studies centered on paramedic-performed Focused Assessment with Sonography for Trauma (FAST) exams.[24]

While academic knowledge assists in the application and understanding of ultrasound, competency is a key factor in successful clinical application. Competency may be measured by a standardized minimum competency level, and the number of scans performed to achieve this minimum level is a frequently-used educational matric.[24] There is no current evidence for a minimum number of scans to be considered competent in paramedic-performed prehospital ultrasound. The American College of Emergency Physicians (ACEP) recommends 25 to 50 scans per assessment type as indicative of competency for emergency physicians.[25] Logically, these suggestions may seem generally extrapolatable to paramedical clinicians; however, over the international spectrum, paramedical clinicians vary widely in knowledge and skill sets.[26]

Recent work has begun to lay the framework for both initial training guidelines and minimum competency levels for prehospital ultrasound. The Air Medical Physician Association recommends the following minimum competency outcomes for initial training: (1) Identify the function of basic controls of the ultrasound machine, (2) discuss the basic physics principles of ultrasound, (3) demonstrate how to optimize ultrasound images, (4) describe normal ultrasound anatomy, (5) describe common pathological ultrasound anatomy, (6) discuss basic ultrasound artifacts and their use, and (7) describe expectations of ultrasound imaging during patient care encounter. In addition, they also include recommendations for simulation-based procedural skills prior to live human attempts and image acquisition on live humans where both normal and abnormal anatomy can be found.[17] Micheller et al. developed a theory-driven prehospital POCUS curriculum outlining basic critical competencies for prehospital services to utilize to suit their needs. A total of five modalities (cardiac, thoracic, FAST, aorta, and procedural) were defined, with 32 measured competencies and 72 subcompetencies. This consensus was developed by a multi-institutional expert panel utilizing the Delphi technique to develop and refine the competency list.[27] It is important to note that this curriculum is yet to be validated in actual prehospital clinical practice.

Workforce

Prehospital personnel combinations vary significantly, both internationally and between ground and air transport systems. Teams may be made up of different levels of emergency medical technicians, nurses, respiratory therapists, physicians, or any combination thereof. The educational background of each individual clinician may range from no experience to significant POCUS exposure, in addition to general physics knowledge relevant to ultrasound theory. Clinician comfort and perceptions on topics such as scene time, effect on medical decision making, and clinical outcomes may also be important areas to focus on in initial education. Identification of the most prominent barriers and negative clinician perceptions to address in initial training may help to recruit a larger clinician base. There is minimal literature regarding clinician perceptions and barriers on general prehospital ultrasound use. In feasibility studies where feedback is elicited, there is a positive trend toward ease of use, interest in field application, and clinical utility.[28,29] A survey of Scottish paramedics and consultant physicians' perspectives on remotely supported prehospital ultrasound found that paramedics were enthusiastic and saw ultrasound as a logical, helpful progression in the care they provide. Physician perspectives were generally more reserved with concerns for limited clinical utility, inadequate training, misinterpretation, and deskilling. Both parties recognized the need for good interprofessional communication and potential transmission difficulties. Finally, both parties questioned the likelihood of measurable clinical benefit.[30] These studies are usually small, specific to the local system studied, and designed for feasibility, reducing their generalizability.

Beyond the end-user level, medical director endorsement is the foundation for any prehospital ultrasound program. In 2014, a survey of North American medical directors found the highest barriers to implementation were equipment, training costs, challenges in training, transport time, concerns about delaying time to definitive care, and concerns that ultrasound is beyond the current scope of EMS clinicians. Implementation was also felt to require further research in mortality/morbidity, clinical utility, time management, and indications for use, as well as position statements and practice guidelines from stakeholders.[31]

Prehospital ultrasound technology

While in theory almost any type of ultrasound machine could be mounted into an ambulance, portability, as defined by size and weight, is key to its use from a practical perspective. Current handheld devices that are widely available internationally can be dichotomized into those requiring a separate output device, such as a tablet device or smartphone, and those that have a screen included.[32] While the majority of devices on the market continues to use piezoelectric crystals, a device introduced in the market in 2018 uses capacitive micromachined ultrasound transducer technology, allowing for exams across all frequencies to be performed using a single probe, as opposed to the traditional crystal-based technology requiring multiple probes.[33]

Clinical applications and outcomes

While PHUS encompasses the full bandwidth of applications used in in-hospital settings, certain applications stand out as particularly meaningful. Trauma patients were an early focus of PHUS efforts, especially the FAST exam to evaluate for intraperitoneal free fluid and pericardial effusion, and its extension, the eFAST exam, which adds a lung assessment component to evaluate for pneumothorax.[34–36] Echocardiography is another common application of PHUS, as it allows to assess for cardiac standstill during cardiac arrest resuscitation and can help identify pericardial and myocardial disease, such as tamponade, decreased left ventricular ejection fraction, or right ventricular dysfunction.[37–39] Ultrasound can be utilized for procedural guidance, for example, peripheral or central vascular access or confirmation of endotracheal tube placement.[40] Rapid assessment protocols that combine different ultrasound exams to rapidly rule in or out life-threatening causes of hypotension or respiratory distress, such as the Rapid Ultrasound in SHock (RUSH) and Bilateral Lung Ultrasound in Emergency (BLUE) protocols and their modifications, are of particular interest for prehospital use.[1,3,4] They are especially appealing for use in this environment, as current diagnostic methods are mostly limited to physical exam, pulse oximetry, and electrocardiogram. Therefore, prehospital care often leans toward a one-size-fits-all approach of combining treatments for multiple disease processes at once (e.g. acute exacerbations of congestive heart failure and chronic obstructive pulmonary disease), and these rapid assessment protocols may help tailor treatment toward the most likely disease process. However, a sustained effect on prehospital patient outcomes has not been shown yet. Applications such as fracture diagnosis, joint dislocations, and procedural guidance for joint reductions or ocular ultrasound are of limited practical value in the majority of urban EMS systems or those with short transport times, but they can play an additional role in EMS systems that face long transport times, in remote and austere environments, or where a "treat and release" approach is commonly practiced, for example,

Table 1. Ultrasound applications commonly used in prehospital emergency care.

Exam type	Indications	Examples of clinical use
Extended Focused Assessment with Sonography for Trauma (eFAST)	Multi-system trauma	Evaluation for free intraperitoneal fluid or pneumothorax after blunt trauma with advanced notification of the receiving trauma center
Transthoracic echocardiography	Respiratory distress, chest pain, and cardiac arrest	Termination of resuscitation in a patient with cardiac arrest and no cardiac motion identified after 20 mins of resuscitative efforts
Lung ultrasound / Bilateral Lung Ultrasound in Emergency (BLUE) protocol[4]	Respiratory distress	Differentiation between pulmonary edema, suspected pulmonary infection, or pneumothorax in a patient with undifferentiated shortness of breath and a history of congestive heart failure and chronic obstructive pulmonary disease
Rapid Ultrasound in SHock (RUSH) protocol: evaluation of pericardium, left ventricular function, right ventricular size, inferior vena cava, lung ultrasound, evaluation of pleural and abdominal cavity, abdominal aorta ultrasound, proximal deep veins of the lower extremities[2]	Non-traumatic shock	Ruling in pulmonary embolism in a patient with hypotension who is found to have right ventricular enlargement and a deep venous thrombosis
Airway	Endotracheal intubation	Confirmation of endotracheal tube placement after prehospital rapid sequence intubation
Vascular access	Difficult vascular access with non-emergent need for intravenous fluids	Placement of an ultrasound-guided peripheral intravenous catheter
Musculoskeletal	Suspected fracture or dislocation	Diagnosis of radius fracture in a wilderness medical environment

to facilitate triage to a referral hospital or urgency of follow-up.[41–45] Many other applications have been described which can be of use in certain care environments or on a case-by-case basis.[10]

Table 1 provides an overview of common PHUS exam types, indications, and clinical use examples.

Medical oversight and quality assurance

Skill retention is vital for successful application of prehospital ultrasound. Therefore, continuing education and quality assurance/improvement (QA/QI) play a critical role. There is no known literature focusing on skill retention in prehospital ultrasound, and skill retention in general is poorly reported in the literature as an outcome for feasibility. Individual studies show a trend toward adequate skill retention; however, methodology and robustness of data are limited.[22,46–48]

A common theme in prehospital emergency care is difficulty to maintain proficiency with low-volume, high-risk procedures (e.g. endotracheal intubation, cricothyrotomy, and thoracostomy). While the risks of ultrasound are negligible compared to the abovementioned procedures, quality of initial education, frequency of use, continuing education, and a robust QA/QI program are key. The continuum between initial education and QA/QI is most prone to lapses in proficiency, and thus continuing education must be provided as a preventive measure. Universal recommendations regarding continuing education requirements for prehospital ultrasound do not currently exist. ACEP recommends 10 hours of continuing medical education every 2 years for emergency physicians.[25] However, this may not generalizable to the prehospital arena, most notably in the non-physician clinician base, because of differences in initial education, extent of ultrasound knowledge base, and frequency of use. The Air Medical Physician Association's position statement suggests utilizing ACEP's Ultrasound Imaging Criteria Compendium to guide QA/QI program development.[49] Clinicians should be able to obtain and capture images for review with appropriate documentation of relevant findings. Images should be reviewed by appropriately qualified experts, and feedback should be provided in a timely manner. Secure storage of QA/QI proceedings for later review and processes for communication with interested parties when missed or incidental findings are identified should be considered crucial components.[17,50]

Feasibility and implementation concerns

Despite the excitement for and potential of prehospital ultrasound, some concerns exist. These include a lack of standardized educational requirements, the implementation of sustainable quality assurance systems (and the associated cost), and the impact of physician medical oversight.[10]. Several technological issues can limit feasibility and image acquisition, such as glare from the screen when used outside, battery life, or limited one-handed operation.[1,51,52] Finally, no systematic data exist on the impact that potential incorrect ultrasound diagnoses could have on patient outcomes and downstream care. Therefore, it is critically important that administrators, medical directors, and front-line clinicians consider any potential unintended negative effects of PHUS use, such as distracting from the basic steps of resuscitation, other important prehospital interventions, or avoidable prolongations of on-scene times in unstable patients.

Limitations of this review

As prehospital ultrasound is an emerging technology, the recommendations made in this article should be considered preliminary and must be applied within the appropriate local context. It is important to note that this topical review is not a systematic review either. In addition, EMS systems vary across different countries, legislatures, and medical care systems, and what works well for one EMS system and the patients that it serves may not be appropriate for a different EMS system.

Conclusion

PHUS has evolved from a niche technology to impending widespread adoption across EMS systems internationally. Recent technological advances and a growing evidence base support this trend; however, concerns regarding feasibility, education, and quality assurance must be addressed proactively. Additional research is needed examining the impact on patient care of widespread prehospital ultrasound use outside of focused research projects. We recommend that EMS administrators and medical directors evaluate the available evidence within the context of their local EMS infrastructure and capabilities. Adoption of this technology requires a robust assessment of the investments needed in terms of finances, training, and quality assurance, along with consideration of the local patient population, transport times, and the needs of receiving hospitals.

Author contributions

C.B.A. and D.C.R. contributed equally to this manuscript.

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