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Ultrasound in Emergency Medicine

A PILOT STUDY EXAMINING THE VIABILITY OF A PREHOSPITAL ASSESSMENT WITH ULTRASOUND FOR EMERGENCIES (PAUSE) PROTOCOL

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☐ Abstract—Background: Prehospital ultrasound has been shown to aid in the diagnosis of multiple conditions that do not generally change prehospital management. On the other hand, the diagnoses of cardiac tamponade, tension pneumothorax, or cardiac standstill may directly impact patient resuscitation in the field. Study Objective: To determine if prehospital care providers can learn to acquire and recognize ultrasound images for several life-threatening conditions using the Prehospital Assessment with UltraSound for Emergencies (PAUSE) protocol. Methods: This is a prospective, educational intervention pilot study at an urban fire department with integrated emergency medical services (EMS). We enrolled 20 emergency medical technicians – paramedic with no prior ultrasonography training. Subjects underwent a 2-h training session on basic ultrasonography of the lungs and heart to evaluate for pneumothorax, pericardial effusion, and cardiac activity. Subjects were tested on image interpretation as well as image acquisition skills. Two bedside ultrasound-trained emergency physicians scored images for adequacy. Image interpretation testing was performed using pre-obtained ultrasound clips containing normal and abnormal images. Results: All subjects appropriately identified the pleural line, and 19 of 20 paramedics achieved a Cardiac Ultrasound Structural Assessment Scale score of ≥4. For the image interpretation phase, the mean PAUSE protocol video test score was 9.1 out of a possible 10 (95% confidence interval 8.6–9.6). Conclusion: Paramedics were able to perform the PAUSE protocol and recognize the presence of pneumothorax, pericardial effusion, and cardiac standstill. The PAUSE protocol may potentially be useful in rapidly detecting specific life-threatening pathology in the prehospital environment, and warrants further study in existing EMS systems. © 2013 Published by Elsevier Inc.

☐ Keywords—EMS; ultrasonography; pneumothorax; cardiac tamponade; cardiac arrest

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INTRODUCTION

Over the past two decades, bedside ultrasound use has continued to expand to a variety of applications to help answer focused clinical questions, such as whether a trauma patient has cardiac tamponade, or whether a patient with shortness of breath has a pneumothorax. Bedside ultrasound is an ideal device for the prehospital setting because it can be rapidly applied, is increasingly portable, and can provide improved diagnostic accuracy over physical examination.

In the critically ill or seriously injured patient, an accurate physical examination is vital to the care of the patient. However, it is generally recognized that the physical examination is fairly insensitive when compared

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to advanced imaging modalities. Similarly, the use of auscultation to detect a pneumothorax/hemothorax in a penetrating chest trauma patient is only 58% sensitive (1). In contrast, the use of ultrasound in the hands of emergency physicians has been shown to be very sensitive in the detection of pericardial effusions and pneumothoraces, with reported sensitivities as high as 99% (2–4).

The Focused Assessment with Sonography for Trauma (FAST) has been shown to be an effective tool to rapidly identify hemoperitoneum in the Emergency Department (ED). Although it has also been studied in the prehospital setting, the early detection of intra-abdominal free fluid before hospital arrival may not immediately change the management of the patient (5,6). On the other hand, the diagnosis of cardiac tamponade or tension pneumothorax may guide urgent actions during resuscitation in both medical and trauma emergency medical services (EMS) patients, or at least direct proper destination decisions by EMS providers (7–9). Prehospital ultrasound has already been shown to aid in diagnosis and triage of fractures, abdominal pain, or potential hemoperitoneum in remote prehospital settings, all of which can affect critical decisions regarding transport and immediate care (10,11). Additionally, in the case of cardiac arrest, by confirming cardiac standstill with ultrasound, this may allow providers to more assuredly cease futile advanced cardiac life support (ACLS) efforts and redirect resources and personnel to other patients (12).

We created the Prehospital Assessment with Ultra-Sound for Emergencies (PAUSE) protocol to serve as a tool for the paramedic to rapidly and accurately identify life-threatening conditions that would require immediate interventions, as well as to guide continued resuscitative efforts in a cardiac arrest situation. When designing the PAUSE protocol, we chose to include an assessment for pericardial effusion, pneumothorax, and the presence/absence of cardiac activity, because these pathologies can be difficult to accurately assess with physical examination alone and because they are readily detectable by bedside ultrasonography. The goal of this study is to determine if prehospital care providers can learn to acquire and recognize ultrasound images for several emergent life-threatening conditions, including pneumothorax, pericardial effusion, and cardiac standstill, using the novel PAUSE protocol after a brief training session.

MATERIALS AND METHODS

Study Design

This prospective, educational intervention study was approved by the study institution's Institutional Review Board.

Population and Setting

Subjects were professional firefighter paramedics with the City of Orange Fire Department who voluntarily agreed to participate in this study.

Experimental Protocol

Participants received study information sheets, and verbal informed consent was obtained. To simulate a reasonable amount of time for ultrasound instruction within a paramedic training curriculum, we limited our didactic time to a single 2-h session per group. A 2-h session was selected to simulate a realistic teaching module length that paramedics routinely go through already. We trained paramedics in groups of four to six at a time to ensure a satisfactory student-teacher ratio of 1:3 or better. Paramedics received a 1-h lecture on the basics of ultrasonography, the PAUSE protocol (Figure 1), image acquisition, and basic image interpretation for the heart and lungs. After the lecture, we instructed paramedics in a 1-h hands-on session. An Emergency Physician trained in bedside ultrasonography demonstrated the following views on a human model: a thoracic view of the pleural interface of the lung, a subxiphoid cardiac view (Figure 2), and a parasternal long cardiac view. Paramedics then took turns practicing the views individually and in series. A SonoSite (Bothell, WA) NanoMaxx with L25n 13-6-MHz linear and P21n 5-1-MHz phased-array transducers was used. Instruction focused on image acquisition and identifying satisfactory views. There was no formal instruction on probe orientation, identifying cardiac structures, Doppler functionality, or image quality adjustments, as these specifics were deemed unnecessary to obtain and interpret ultrasound images for the purposes of identifying the presence or absence of cardiac activity and large pericardial effusions. Paramedics performed the hands-on session until they were satisfied they could acquire adequate views. Models used in the examination were female. No participants were compensated in any way.

Key Outcome Measures

Once the hands-on training was complete, we immediately gave each paramedic two tasks to assess the efficacy of the educational intervention. The first task was a test on image recognition. This examination was a series of 10 questions viewed on a laptop computer. Each question consisted of a video clip presenting two views of the lungs, one of the right hemithorax and a second of the left hemithorax, and either a subxiphoid or a parasternal long-axis view of the heart. We asked each paramedic to identify if each series of three clips showed an abnormality and, if so, to name the abnormality. The test

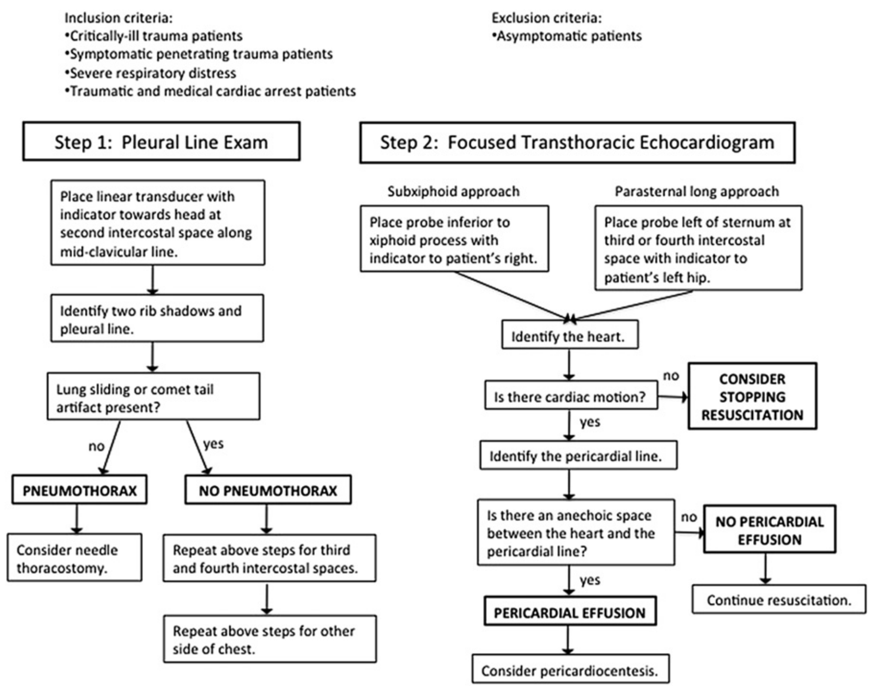

Figure 1. Flow chart demonstrating application of the PAUSE protocol in evaluation of the critically ill patient.

subjects had not seen these video clips beforehand. Clips used during the lecture depicted the same pathology as those used in testing, but were not identical clips. Abnormal ultrasounds included clips of pneumothoraces, pericardial effusions, and cardiac standstill. Clips of pneumothoraces showed one intercostal view of a lung, which had pleural sliding either present or absent. Clips of pericardial effusions showed fluid pockets ranging from 1–3 cm in thickness. For clips of cardiac standstill, approximately half were taken during chest compressions, versus no ACLS in progress. The second task was to acquire an adequate view of both the left and right pleural interfaces and one view of the heart without assistance. We permitted the paramedics to use either the parasternal long-axis or subxiphoid cardiac views. Paramedics held the probe in position and signaled when a satisfactory view was acquired. Ultrasound video was captured using a direct feed to a video camera.

We graded the written tests using a key made by the instructor. A question was correct if a paramedic identified all three clips correctly. Two attending Emergency Physicians, trained in bedside ultrasonography, reviewed the image acquisition clips independently. One reviewer had completed an additional 1-year fellowship in Emergency Ultrasound, and the other reviewer was a current fellow in Emergency Ultrasound. Lung views were scored as satisfactory or unsatisfactory based on the ability to clearly visualize the pleural line. Cardiac views were scored according to a six-point scale, the Cardiac Ultrasound Structural Assessment Scale (CUSAS), developed by Backlund et al. (Table 1) (13). If there was disagreement between the two reviewers, the clips were replayed and a consensus score was agreed upon. A CUSAS score of 3 requires partial ventricular visualization, and this was used as the threshold for an adequate cardiac view, as previously published by Backlund et al. CUSAS scores, lung view grades, and test scores were entered into an electronic database (Excel, Microsoft Corporation, Redmond, WA).

Analytical Methods and Sample Size Determination

We calculated the sample size a priori. Assuming that the mean correct would be 90% with a standard error of 20%, a sample size of 19 allowed 90% power to conclude, with alpha = 0.05, that the mean percentage correct would be > 75% among a larger population. For logistical purposes, we recruited a larger-than-necessary sample size of 20 paramedics. We calculated the mean percentage correct for the image recognition examination, with 95% confidence intervals. We performed a Spearman's test to see if image acquisition and image recognition scores were related. The distribution of lung and cardiac image acquisition scores was also calculated.

RESULTS

We enrolled 20 male paramedics with no prior experience in ultrasound. Overall, they scored an average of 9.1 correct answers out of a possible 10 on the image recognition

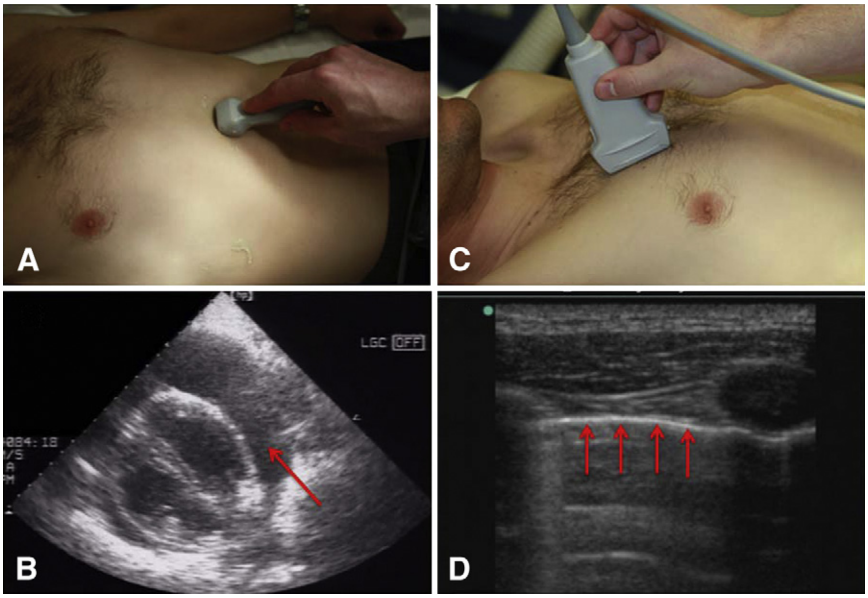

Figure 2. (A) Positioning of phased-array ultrasound probe for subxiphoid imaging of the heart. (B) Subxiphoid view of a heart with a large pericardial effusion indicated by red arrow. (C) Positioning of linear ultrasound probe for evaluation of pleural line. (D) Image of thoracic cavity with hyperechoic pleural line indicated by red arrows.

test (95% confidence interval 8.6–9.6). The lowest image recognition test score was a 6 out of 10 by one participant, whereas half of the paramedics attained the maximum of 10 (Figure 3). Of note, there was one particular question requiring the paramedics to identify cardiac standstill that was answered incorrectly by six paramedics (Table 2).

On image acquisition testing, 100% of the images were deemed satisfactory for evaluation of a pneumothorax. However, with image acquisition of the heart, there was a larger variability. The lowest CUSAS score given was a 3 to one paramedic, whereas all the other scores were ≥ 4 (Figure 4). Only 11 of the 20 paramedics (55%) were able to obtain cardiac views sufficient for a maximum CUSAS score of 6. Four paramedics were given CUSAS scores of 5, and another four were given CUSAS scores of 4. Views of the lung were acquired in < 5 s. Views of the heart were acquired in < 10 s for 16 paramedics. One paramedic took approximately 90 s, and the other three ranged between 10 and 25 seconds. The times to obtain clips were tracked using the timer on the video equipment.

The performance on image recognition did not correlate with performance during image acquisition. Using Spearman's rank correlation, we found no association between the image acquisition and image recognition score. The value of ρ was 0.19, with a *p*-value of 0.42.

DISCUSSION

There is a growing body of literature evaluating the use of bedside ultrasound in the prehospital setting. Previous studies have suggested that paramedics could be taught to perform FAST scans (5). However, the immediate usefulness of a prehospital FAST scan to the prehospital

Table 1. Cardiac Ultrasound Structural Assessment Scale (CUSAS) Grading Scale for Echocardiography

Score	Description
1	No myocardium visualized
2	Myocardium visualized
3	Partial ventricle visualized
4	Multiple partial chambers visualized (including at least one ventricle)
5	Full ventricle visualized
6	Multiple full chambers visualized (including at least one ventricle)

From (13): Backlund B, Bonnett C, Faragher J, Haukoos J, Kendall J. Pilot study to determine the feasibility of training Army National Guard medics to perform focused cardiac ultrasonography. Prehosp Emerg Care 2010;14:118–23.

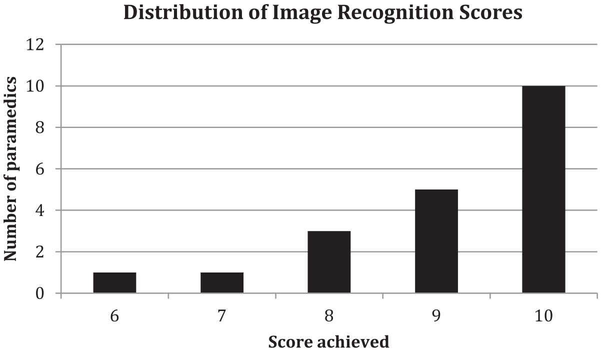

Figure 3. Distribution of image recognition scores.

Table 2. Frequency of Correct and Incorrect Responses by Question Number on Image Recognition Test

Question #	Answer	Correct	Incorrect
1	L PTX	19	1
2	Standstill	20	0
3	Normal	17	3
4	PCE	19	1
5	L PTX	19	1
6	PCE	19	1
7	Normal	17	3
8	R PTX	20	0
9	Standstill	14	6
10	R PTX	18	2

PTX = pneumothorax; Standstill = cardiac standstill; PCE = pericardial effusion.

provider is limited, given that many etiologies of a positive FAST scan, particularly those causing free intra-abdominal fluid, are not readily managed in the prehospital setting. We developed the PAUSE protocol to specifically evaluate for conditions that would require immediate life-saving interventions in the prehospital environment. After a brief training session on the PAUSE protocol, our paramedics obtained adequate images that could be used in evaluation of pneumothoraces, pericardial effusion, and cardiac standstill, and correctly evaluate ultrasound video of those conditions. Our intention is that the PAUSE protocol would be used as an adjunct available to the paramedic in the field when the physical examination is inconclusive, or for confirmation of their clinical assessment, in patients with treatable life-threatening conditions.

Our data suggest that after a 2-h training session, paramedics did relatively well at identifying pathology on prerecorded ultrasound images, with an image recognition test score of 91%. One test question demonstrating cardiac standstill had a large number of incorrectly identified diagnoses. Six out of 20 paramedics answered incorrectly; three said the images were all normal and three identified the images as showing a pericardial effusion/tamponade. On review of the image, we believe that the reason for the misdiagnoses was secondary to inexperience of the paramedics in recognizing that the perceived cardiac movements were in fact a result of the ultrasound probe being moved across the patient's chest.

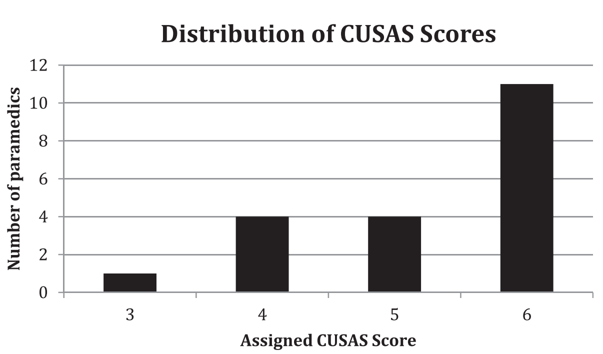

Figure 4. Distribution of Cardiac Ultrasound Structural Assessment Scale (CUSAS) scores achieved by paramedics during image acquisition testing.

Recent studies on the role of focused cardiac ultrasonography in cardiac arrest patients have demonstrated that a lack of cardiac activity on presentation is a predictor of mortality (12,14). If paramedics had the capability to identify patients without cardiac activity in the field, this could enable them to cease futile resuscitation efforts as part of a standard termination of resuscitation protocol, or provide additional objective data when in consultation with medical control, which could conserve resources that are currently being wasted on such cases while protecting EMS providers and the public from unnecessary emergency transports.

Backlund et al. designed the CUSAS scoring system previously in a study looking at whether military medics could be trained to do focused cardiac ultrasonography (13). For the purposes of determining cardiac standstill, being able to visualize any myocardium (CUSAS score 3) should be adequate, in which case there was a 100% success rate in our study. The same standard might not be equally applicable in cardiac imaging for pericardial effusion, as enough of the heart as well as part of the pericardium would need to be visualized to assess for presence of effusion. Although we would speculate that a significant pericardial effusion causing tamponade would likely be seen with CUSAS scores ≥ 4, as these images offer at least a partial view of the pericardium. In this study, 95% of the participants (19/20) were able to quickly acquire images that would likely be useful in assessing for both cardiac activity and a pericardial effusion.

Thoracic ultrasound for pneumothorax has readily made its way into ED trauma protocols as the extended FAST, but has not yet been widely accepted in the prehospital environment. In the noisy setting of the back of an ambulance or a helicopter, listening for breath sounds with a stethoscope in a patient with respiratory distress is often difficult and sometimes impossible. The sensitivity of auscultation of breath sounds in the diagnosis of a pneumothorax is poor, with one study citing a 58% sensitivity by surgeons evaluating trauma patients during the primary survey (15). Currently, the prehospital detection of pneumothoraces is limited to auscultation of breath sounds and other physical examination findings, such as paradoxical chest rise and fall. Recent studies suggest that thoracic sonography is highly sensitive in the detection of pneumothoraces (sensitivity 98.1%, specificity 99.2%), and we feel that this modality of diagnosing pneumothoraces would be better than what is currently in place in the prehospital setting (2,3). When used in the appropriate clinical scenario (i.e., a trauma patient in respiratory distress), prehospital evaluation for pneumothorax with ultrasonography could help improve the accuracy of prehospital-diagnosed pneumothoraces and the confidence of the paramedic in the diagnosis of a pneumothorax requiring needle thoracostomy.

As with any physical finding, diagnostic test, or radiologic study, the information provided should always be used in context with the clinical scenario and the patient's evolving medical condition. If the feasibility of the PAUSE protocol is further delineated in future studies, it may prove to be an invaluable tool in enhancing the medical care provided in the prehospital environment through the improved accuracy of diagnosing several immediately life-threatening conditions.

Limitations

Although paramedics might be able to recognize pathology on high-quality images acquired by an experienced ultrasonographer, this may not translate to the same paramedics being able to recognize the same pathology on their own images. If the PAUSE protocol were to be implemented in a prehospital setting, paramedics would need to have more hands-on experience to gain proficiency in their sonographic technique. This is especially true for cardiac sonography, as this is where our study subjects made most of their errors. This study does not address the long-term retention of the PAUSE protocol, and similar to any other skill in medicine, would presumably require regular refresher hands-on training to maintain competency in this skill.

We recognize that although study participants might be able to identify a pericardial effusion, this does not mean they would also recognize cardiac tamponade on ultrasound. The physiology of cardiac tamponade differs from a chronic or physiologic pericardial effusion in that during tamponade, the heart's ability to fill one or more chambers in diastole is impaired (16). This issue should be minimized by the application of the PAUSE protocol only for patients meeting the defined selection criteria (Figure 1). Regardless, further training would be needed to ensure that paramedics understand the distinction between a hemodynamically significant pericardial effusion requiring immediate pericardiocentesis versus one that is stable for transport to a hospital.

Similarly, not all pneumothoraces require immediate needle thoracostomy. The inclusion criteria for initiating the PAUSE protocol should help minimize unnecessary needle thoracostomies. In addition, the PAUSE protocol could be used to confirm or refute the need for a needle thoracostomy for patients already presenting with physical findings suggestive of a pneumothorax. In such a scenario, an unnecessary procedure could be avoided through the improved accuracy of ultrasonography over that of the physical examination. Further training would still be required to ensure that prehospital care providers understand which pneumothoraces need immediate intervention.

The independence ($p = 0.42$) of image acquisition and image recognition scores implies that skill with the ultrasound probe and understanding of the image are not related. It is therefore important to keep in mind that although paramedics may be able to acquire images, interpreting them is a different skill that should not be ignored and requires independent testing and likely additional training.

In this study, we used two different probes for thoracic evaluation and cardiac imaging. Realistically, in a prehospital setting, this protocol should be performed with a single probe for efficiency. Prehospital care providers are trained to minimize on-scene times and to have to switch probes in the middle of the PAUSE protocol would be an additional consideration in the management of an unstable patient. Future studies will need to take this into account.

Another limitation of this study is that it was conducted with paramedics performing ultrasounds in a classroom setting as opposed to their typical prehospital environment, such as in the back of a moving ambulance or on scene at an incident. It is unclear how image acquisition and interpretation would be affected in such an environment; however, similar concerns can be made in regards to advanced airway management skills and for cardiac monitoring and electrocardiogram acquisition and interpretation. Further studies will need to look at whether a paramedic's ability to obtain and interpret images is affected in more austere conditions.

Our study tested whether specific ultrasound skills could be taught, but did not look at long-term retention. Paramedics are required to obtain continuing education to maintain their skills and certification, and ultrasound image acquisition and image recognition training would also be subject to the same requirements.

CONCLUSION

Using a brief lecture and hands-on experience, paramedics seem to be capable of acquiring and interpreting ultrasound images for several immediately life-threatening conditions. Whether the PAUSE protocol can be successfully initiated in the field still needs to be determined. Prehospital providers would need further education on procedures and more training on recognizing conditions addressed in the protocol that require immediate intervention, versus those that are stable. In the future, ultrasonography for very specific purposes as outlined in our protocol may prove to enhance prehospital care providers' ability to diagnose critical conditions and intervene in a timely fashion to enhance patient survival.

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ARTICLE SUMMARY

1. Why is this topic important?

Although not yet used routinely in the prehospital care setting in the civilian world, there are already instances when ultrasound is used in combat settings to make decisions affecting patient care. Currently, there are no protocols for ultrasound use targeted directly at the prehospital care setting.

2. What does this study attempt to show?

This study attempts to establish a protocol for ultrasound use in the prehospital setting that could have implications for critical actions that could affect patient morbidity and mortality before hospital arrival. In addition, this study attempts to establish that paramedics can quickly learn to obtain the ultrasound images required by the protocol, and can learn to recognize pathology versus normal anatomy.

3. What are the key findings?

The study shows that in a brief classroom session, paramedics can learn to obtain images of the heart and lungs on a healthy model that would be used for assessing the presence of cardiac standstill, pericardial tamponade, and pneumothorax. In addition, the study shows that paramedics can quickly learn to recognize normal versus abnormal images of the same organ systems in prerecorded ultrasound videos.

4. How is patient care impacted?

In the future, implementation of this new ultrasound protocol in the prehospital setting can help paramedics make medical decisions concerning critical actions required in the setting of pericardial tamponade, tension pneumothorax, and cardiac standstill.