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REVIEW ARTICLE

Use of ultrasound by emergency medical services: a review

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Abstract Prehospital ultrasound has been deployed in certain areas of the USA and Europe. Physicians, emergency medical technicians, and flight nurses have utilized a variety of medical and trauma ultrasound assessments to impact patient care in the field. The goal of this review is to summarize the literature on emergency medical services (EMS) use of ultrasound to more clearly define the potential utility of this technology for prehospital providers.

Keywords Emergency medical services · Ultrasound · Disaster

Background

Although diagnostic medical ultrasound had become widely used since the early 1980s, machine cost and bulk limited its use to inhospital settings for decades [1]. By the mid-1990s several manufacturers offered portable ultrasound machines, often weighing less than 6 pounds. Modern portable ultrasound machines are lightweight (most are the size and shape of a laptop computer), provide high image quality, and are built to withstand abusive environmental conditions. The performance of portable units has been investigated in many applications, including the focused assessment with sonography in trauma (FAST) [2–4], echocardiography [5, 6], and aorta evaluations [7] among others.

Increased portability and ease of use of modern ultrasound machines initially led to non-radiologists adopting the technology in a host of environments, including obstetrics, surgery, emergency medicine, and others. Recently there has been increased use of these devices outside of the hospital as well. Physicians, military medics, and emergency medical services (EMS) personnel have used portable ultrasound machines in the field to diagnose conditions such as pleural, peritoneal, and pericardial effusion and deep venous thrombosis [8–10].

The feasibility of ultrasound deployment, and evaluation of the potential for avionic equipment interference, was examined in 2000 [11]. Physicians, flight nurses, and sonographers performed FAST examinations in a helicopter, and there was no interference with avionic equipment by the ultrasound machine. The durability of portable ultrasound machines has been subjectively described (though not specifically tested) by several authors. In a study of ultrasound use during helicopter transport, no mechanical problems were encountered during a 1-year study period with 100 patients assessed [9]. However, other authors noted bright sunlight and battery failure limited the utility of ultrasound during flight [12]. When used in a field hospital in Iraq, a portable ultrasound device was used in conditions of limited space, high ambient temperature and light, and often under battery power [13]. Other authors in a similar military environment found portable ultrasound to have "great utility in the field or during patient transport" [14].

The views expressed in this paper are those of the author(s) and not those of the editors, editorial board or publisher.

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Prehospital ultrasound experience

Ultrasound use in the field has been described in Germany, France, Italy, the USA as well as in other countries [15]. In the USA, it is common for non-physician EMS crews to focus on rapid transport of patients to emergency departments. In other areas, providers spend more time on scene evaluating and managing patients, and physicians are often part of the field team. Thus, the indications for and utility of point-of-care ultrasound may differ based on the practice environment of a particular clinician.

In Germany, the use of ultrasound in the field has focused on the FAST exam and cardiac sonography for non-traumatic patients. The German Air Rescue Organization (*Deutsche Rettungsflugwacht*) as well as several ground-based ambulance services (in Darmstadt and Frankfurt/Main) have incorporated ultrasound into their field management algorithms since 2002–2003. Emergency physicians and paramedics comprise the crews in these centers [15].

French prehospital clinicians have adopted ultrasound in certain areas as well, including SAMU (*Service d'Aide Médicale d'Urgence*) 93. French intensivists first reported the feasibility of deploying a portable ultrasound unit on a helicopter for field examinations in 1998 [16]. Studies have described field use of the FAST exam as well as evaluation for pericardial effusion, deep vein thrombus, and aortic aneurysm in this region [8].

The Italian EMS system began incorporating ultrasound into prehospital care in 2005 [15]. It is being investigated as an adjunct to triage and patient assessment as well as field management of illness. Helicopter and ground units in Milan are equipped with portable ultrasound devices, and three major clinical indications are being evaluated: cardiac arrest, torso trauma, and acute dyspnea. Prehospital ultrasound is employed in this setting to differentiate reversible causes of pulseless electrical activity (PEA), assess for pericardial, intraperitoneal, and pleural fluid in trauma, and to differentiate between pulmonary edema and emphysema.

In the USA, the focus on rapid transport and limiting on-scene time may have contributed to slower adoption of prehospital ultrasound into clinical algorithms [15]. Ultrasound use has been described in several helicopter EMS programs in the USA (in Portland, Ohio, and Minnesota). There is less experience in the routine use of ultrasound on ground ambulances; the first group to use the technology was in Odessa, TX.

EMS training in ultrasound

Several types of practitioners (physicians, emergency medical technicians, and flight crews) have used portable ultrasound in a variety of practice environments including air and ground deployment. In the USA, flight crews consisting of flight nurses, paramedics [9, 12], and physicians [17] have been trained in the use of ultrasound. Training time in these studies varied from 3 h up to 7 h, and some clinicians received additional scanning time supervised in the emergency department. In one French study, emergency physicians staffing the ground EMS system were trained through 8 h of didactics in trauma ultrasound and 25 initial FAST ultrasound scans [18]. Surgeons, internists, and anesthetists in German air rescue centers and ground ambulance teams have been studied as well. In this study, physicians who were not already familiar with trauma ultrasound received 1 day of didactic and hands-on training in the FAST exam prior to field use of the technology [10]. A study of portable ultrasound aboard a Norwegian Air Rescue helicopter utilized a physician with 100 h of training in the modality [19].

An ongoing multicenter study in the USA examined an ultrasound training curriculum for non-physician EMS providers. In this study, 93 advanced life support (ALS) providers completed a standardized 6-h curriculum on the FAST exam and evaluation of the abdominal aorta. Didactic lectures, hands-on scanning experience, and observed structured clinical encounter (OSCE) scenarios were used. Comparing pre-course and post-course written test scores, providers significantly improved their image recognition skills after the curriculum. In addition, 100% of the 34 paramedics who completed an OSCE 3 months after the initial training passed the ultrasound scanning practicum [20].

To date, no study has compared variations in the amount of training per provider with the quality of examinations they are capable of performing. The combined experience in prehospital ultrasound thus far comprises both physician and EMS providers with varied experience in ultrasound use at baseline. Based on current literature, it is difficult to draw conclusions regarding the optimal training criteria for prehospital providers, especially among those not already familiar with the technology.

Indications

FAST exam

The FAST exam has been well described in the literature of emergency medicine [21, 22], demonstrating that hemoperitoneum and hemopericardium can be accurately diagnosed by non-radiologists. When the FAST exam is employed early in the patient's evaluation, it has been shown to decrease time to needed operation, decrease treatment costs, and decrease hospital admission lengths [23]. A study of combat deaths in 210 US Marines found that early diagnostic ultrasound was one factor which could decrease overall traumatic mortality [24]. Preliminary studies in helicopter transport have examined the feasibility of FAST exams performed by EMS and physician personnel while moving at high speeds in confined quarters. A prospective study of 71 patients transported by helicopter found a complete set of adequate images could not be obtained in 48% of cases by EMS providers, mainly due to time constraints [12]. Flight surgeons performing a FAST exam on a helicopter found a sensitivity of 81.3% and specificity of 100% for free fluid [25]. Another prospective study of 100 patients transported via helicopter by EMS demonstrated adequate image capture of the right upper quadrant view in 90% of cases, with a sensitivity of 60% and specificity of 93% for that single view [9]. Cardiac exams were adequate in 94% of cases, and the exam was 100% sensitive and specific for pericardial fluid. There was only one positive cardiac study in this series, however. When performed by an experienced physician (with 100 h of ultrasound training and over 400 prior exams) in another study, ultrasound completed while in flight was 90% sensitive and 96% specific for detecting hemoperitoneum, pneumothorax, and pericardial fluid in 38 patients [19].

One French study of portable ultrasound deployment via helicopter investigated the feasibility of ultrasound exam performance. Although a portable machine was transported and stored in the helicopter cab, the scans were performed on patients on the ground (at a desert rally). Here, an experienced physician screened 15 patients for hemothorax, pneumothorax, hemopericardium, hemoperitoneum, and flattened inferior vena cava. Of the 75 possible views, 68 were adequate for diagnosis (90.6%). It was possible to assess for pleural and peritoneal fluid in 100% of cases. Each patient was scanned in less than 3 min.

Portable ultrasound feasibility has also been examined by the Royal Adelaide Hospital Medflight helicopter unit in Australia [26]. In this study, three retrieval physicians performed a FAST exam on 38 patients; in 36 a complete series was performed. In two, a cardiac view was not obtained. All images were acquired during flight in the aircraft cabin. Of 150 total images obtained, 143 were determined to be adequate by blinded physician review. Technical difficulties noted by authors included learning to scan with either hand (based on which side of the cabin the patient was loaded), communicating with the pilot to avoid problems with unanticipated turbulence, and limited space available around obese patients.

Physicians deployed on ground transport have used sonography to improve the accuracy of their physical exam, altering trauma management at the scene in one third of cases [10]. In this study, 202 patients were assessed in the field, and the average FAST exam was completed in less than 3 min. The prehospital FAST exam was found to be 93% sensitive and 99% specific compared with diagnoses made in the destination emergency department. Physicians scanning 302 patients in the field found their diagnostic accuracy improved in 67% of cases overall and in 90% of cases where there was initial diagnostic uncertainty [8].

Cardiac evaluation and resuscitation

Several studies have examined the utility of ultrasound use in assessing circulation. Recently, an algorithm for the incorporation of bedside ultrasound into standard advanced cardiac life support (ACLS) algorithms has been described [27]. This model has been incorporated into the prehospital cardiac evaluations by EMS providers in Germany and Italy [15]. In a study of non-physician aeromedical crews performing cardiac ultrasound for cardiac activity and pericardial effusion, adequate exams were obtained in 86 of 91 cases (94.5%) [9]. Although the sensitivity and specificity were both 100%, this study was limited in that only one patient had an exam positive for effusion and no cases of cardiac standstill were recorded. The absence of cardiac activity on bedside echocardiography has been associated with a 100% mortality rate [28, 29], irrespective of the cardiac rhythm as visualized on the monitor. A recent case report described the use of prehospital ultrasound to diagnose pericardial tamponade in a penetrating trauma victim [30]. Ultrasound in this case demonstrated the need for pericardiocentesis; spontaneous circulation returned while en route to the hospital. A thoracotomy was performed soon after hospital arrival and the patient survived. Thus, portable ultrasound may yield additional objective data helpful in determining prognosis and guiding allocation of scarce resources.

Medical illness

Although traumatic injury remains the most commonly studied indication for EMS ultrasound, several studies have examined the role of ultrasound in non-traumatic illness as well. A French study examined the impact of ultrasound on clinical accuracy in the field when performed by physician providers [8]: 302 scans were performed on 169 patients in this study, including assessments for pleural, pericardial, and peritoneal fluid, deep vein thrombus, and “other” indications. Physicians rated confidence in their clinical assessment on a visual analog scale before and after using ultrasound on a given patient. The final diagnosis (established by confirmatory studies upon hospital evaluation) was compared to the clinical and ultrasound scores to determine whether ultrasound improved or hindered diagnostic assessment in each case. Ultrasound evaluation in the field was found to improve diagnostic accuracy in 67% of cases, decreased diagnostic accuracy in 8% cases, and had no impact in 25% of cases.

Air transport of pregnant patients has created challenges in fetal monitoring. The use of Doppler auscultation of fetal heart tones is often impractical in flight due to ambient noise levels. A case series of obstetric patients being transported via helicopter demonstrated the possible utility of bedside ultrasound in the evaluation of obstetric emergencies. In this series, the authors describe cases where breech position, normal full-term gestation, and fetal distress (bradycardic episodes and lack of amniotic fluid) were detected using bedside ultrasound. In each case, the ultrasound altered patient management [31].

Future directions

Mass casualty incidents

Preparation for mass casualty incidents (from natural or other disasters) has become a major focus of training for prehospital providers around the globe in recent years. Triage of casualties to an appropriate level of care or disposition is paramount; EMS providers are often faced with an overwhelming number of injured that must be assessed rapidly. Several studies have examined the role that ultrasound may play in enhancing existing triage systems during multicasualty incidents.

In 1988 an earthquake in Armenia killed over 25,000 people and injured over 150,000 [32]. Within 72 h after the disaster, 750 patients were admitted to the large receiving hospitals in the capital city of Yerevan. Although there was only a single computed tomography (CT) scanner available, many ultrasound machines were utilized to perform trauma evaluations on admitted patients; 530 ultrasound examinations were performed on 400 patients in this study. Of these, 96 patients were found to have a clinically significant pathological condition. There were 16 patients in this study who were taken to the operating room based on ultrasound findings and physical examination. There were only three patients in the study who received a CT scan as part of their evaluation if they were not head injury cases; all others were managed based on physical examination and ultrasound. The authors noted four false-negative ultrasound examinations, including kidney rupture, subcapsular splenic hematoma, retroperitoneal hematoma, and an obese patient with hemothorax.

A Turkish earthquake in 1999 was the setting for another study of ultrasound use as a triage tool. In this natural disaster, 17,000 deaths and over 100,000 injuries were reported [33]. Renal ultrasound was utilized by physicians in this study to evaluate nine patients with crush injury. The resistive index (a measure of renal vasoconstriction) was measured using Doppler ultrasonography. The authors found that the resistive index was increased in patients with acute crush injury and correlated with the need for hemodialysis and the duration of dialysis dependence. Ultrasound impacted care of patients with regards to fluid resuscitation and other management options.

In the aftermath of mudslides which killed over 1,000 people in Guatemala, a hand-carried ultrasound unit was brought on-site by relief workers to evaluate injured patients [34]; 137 ultrasound examinations were performed on 99 patients. A wide range of scans were performed, including pelvic, right upper quadrant, cardiac, thoracic, and soft tissue scans. The authors report that for 12% of patients, ultrasound confirmed the presence of an emergent disorder. In 42% of patients, ultrasound was able to rule out disease. Although this study was set during the relief effort after a natural disaster, many patients were evaluated for illnesses which were not acute; 23% of patients presented with illnesses less than 24 h in duration, and 44% were greater than 14 days in duration. Thus, it may be difficult to generalize all of the data to an acute multi-casualty scenario.

During the Second Lebanon War, casualties received by a level I trauma center were triaged according to the Injury Severity Score (ISS) [35]. A FAST examination was performed in 102 of 281 admissions with suspected abdominal injury. The authors report that five hemodynamically unstable patients were taken for operative intervention based on a positive FAST examination; 28 hemodynamically stable patients were managed solely with ultrasound and did not undergo CT scan (based on the negative ultrasound and low suspicion for injury). The authors report that ultrasound was useful as a screening tool in determining which patients should be dispositioned to laparotomy, CT scan, or clinical observation during multicasualty incidents. However, it should be noted that not every casualty was screened with ultrasound, and the study was retrospective in nature.

Another retrospective study examined the role of ultrasound as an adjunct to the simple triage and rapid treatment (START) mass casualty triage system [36]. In the START system, patients are triaged to ambulatory (green), delayed (yellow), immediate (red), and expectant (black) based on clinical criteria such as vital signs and the Glasgow Coma Scale. The charts of 570 patients from the trauma registry at a level I trauma center were reviewed, and each patient was assigned a START triage classification of yellow, red, or black. FAST examination results were available for 359 patients; 27 were positive. The authors found 22.2% of positive FAST exams represented false positives, which would have resulted in overtriage of yellow patients to the red category. In addition, 12.9% of the negative studies were false negatives. Reliance on ultrasound alone would have undertriaged this group. Although it is difficult to draw conclusions based on this retrospective study, there did not appear to be a benefit of using the FAST examination as a tool to alter triage disposition.

One important question regarding ultrasound deployment in disaster scenarios is the number of ultrasound units which would be required to truly speed triage decisions [36]. A single ultrasound operator would create a triage bottleneck when many patients were being assessed; thus multiple providers with multiple machines would need to be deployed to effect any time savings from the technology. No prospective, controlled studies of ultrasound use in triage have been described and the results of retrospective reviews have been mixed. While the technology holds promise for improved triage assessment in the field, it is difficult to draw conclusions regarding the utility of the technique given current published data.

Telemedicine

Another emerging area for prehospital care is telemedicine, which allows clinicians from remote sites (such as base medical centers) to review images and diagnostic data from EMS providers on-scene or en route. The concept of image data transmission from ambulances is not new; in 1987, a study demonstrated the feasibility of 12-lead ECG transmission via cellular telephone [37]. In the decades that followed, EMS performance, interpretation, and transmission of ECGs has become commonplace and has been shown to positively impact patient care [38]. In 1996, remote review of inhospital echocardiography studies transmitted to laptop computers via standard telephone lines was described [39]: 187 studies were transmitted and reviewed remotely; 153 were abnormal, 19 were technically limited. The authors reported 99% agreement between telemedicine laptop interpretation and conventional workstation interpretation.

The feasibility of real-time wireless transmission of ultrasound images was examined in 2003 [40]. FAST exam images were obtained on an ambulance and transmitted wirelessly to a line-of-sight antenna, then sent via satellite for review at a remote location. The authors noted antenna (line-of-sight) images were of comparable quality to those viewed on-site. There was a reduction in image quality noted when images transmitted via satellite were reviewed remotely (32% reduction for still and 42% for video clips). In another study, prerecorded cardiac scans were transmitted from an ambulance in the field via 2.5-GHz spread-spectrum radio transmitter [41]. Transmitted images were compared side-by-side (in real time) at the base hospital. Recorded (and not live) images were transmitted to allow for the most direct comparison of image quality. In this series, 32 studies were transmitted while the ambulance was in motion (50–75 mph). Findings of left ventricular function, effusion, and inferior vena cava anatomy had the highest image quality ratings (mean 97–100% equivalent to original videos). In contrast, wall motion assessment (mean 13% equivalent) and valvular anatomy (mean 27–60% equivalent) were not well visualized on transmitted images.

Improved image quality upon transmission was demonstrated in a study from 2004; echocardiograms performed in the field were transmitted via wireless microwave signal to a satellite transmission for off-site review [42]. In this study, 12 transmitted studies were compared to on-site images as well as formal echocardiography performed on standard, non-portable equipment. Blinded cardiologist reviewers graded good agreement in technical quality (83%), left ventricle size (92%), pericardial effusion (100%), and ejection fraction (100%).

Conclusion

As the progression of bedside ultrasound utilization from radiologists to non-radiologists continues, we have seen penetration of ultrasound use by non-physicians as well. As cost, machine size, and ease of use continue to improve, the applications of field ultrasound may continue to increase. Ultrasound may provide additional diagnostic information to guide therapy. The utility of this information will depend on the transport time as well as the training level of the provider in the ambulance or helicopter. There are several studies ongoing at this time to evaluate the utility of prehospital ultrasound; further prospective, outcomes-based studies are needed to determine whether prehospital ultrasound should be deployed more widely.

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