

Prehospital Ultrasound in Trauma: A Review of Current and Potential Future Clinical Applications

Tharwat El Zahran, Mazen J. El Sayed¹

Department of Emergency Medicine, Emory University School of Medicine, Atlanta, Georgia, USA, ¹Department of Emergency Medicine, American University of Beirut Medical Center, Beirut, Lebanon

Abstract

Ultrasound (US) is an essential tool for evaluating trauma patients in the hospital setting. Many previous in-hospital studies have been extrapolated to out of hospital setting to improve diagnostic accuracy in prehospital and austere environments. This review article presents the role of prehospital US in blunt and penetrating trauma management with emphasis on its current clinical applications, challenges, and future implications of such use.

Keywords: Clinical, emergency medical services, prehospital, trauma, ultrasonography

INTRODUCTION

Acute trauma is the primary cause of mortality, and morbidity in the United States with cost of care reaching up to 27 billion dollars per year. Increased time from injury to definitive care by a trauma team at the hospital is directly associated with the need for more complex care and therefore higher costs.^[1-3]

Prehospital trauma management consists of rapid transport to an appropriate facility within the “Golden hour” that has been found to be the most important predictor of mortality in acute trauma.^[4] Evidence is conflicting regarding prehospital advanced life support interventions such as advanced airway management for trauma patients in the field.^[5] Other interventions such as early tourniquet or hemostatic agents application are promising in terms of reducing morbidity and mortality of trauma patients.^[6]

Injury prevention is also important to reduce trauma-related deaths.^[4] Studies estimate that 39%–47% of prehospital fatalities are potentially preventable through standardized training of emergency and prehospital providers in trauma management.^[7,8]

Ultrasonography is routinely used in the emergency department (ED), particularly for trauma patients. This tool improves clinical decision-making by emergency physicians at the bedside. Ultrasound (US) allows for faster and more accurate diagnosis of life-threatening injuries such as tension

pneumothorax or occult hemorrhage. The 2008 American College of Emergency Physicians US Guidelines represents a very comprehensive resource document on emergency US.^[9] Because of technological advances that transformed US into a portable handheld (HH) user-friendly devices, increasing US applications in trauma management in out of hospital settings (prehospital, austere environments, and space stations) are reported in the literature.

In this review article, we examine the role of prehospital US in trauma management and present the evidence behind its current applications in both penetrating and blunt trauma. We also discuss the challenges of this imaging modality in different out of hospital settings and future implications of this technology in trauma.

METHODS

This is a review article that summarizes the available evidence concerning prehospital US use in trauma. The following

Address for correspondence: Dr. Mazen J. El Sayed, Department of Emergency Medicine, American University of Beirut Medical Center, PO Box 11-0236, Riad El Solh 1107 2020, Beirut, Lebanon.
E-mail: melsayed@aub.edu.lb

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search strategy was used: The National Library of Medicine's MEDLINE database (PubMed) was systematically searched for articles from 1990 to 2017 using the following keywords and strategy: (1) ([Prehospital or Emergency Medical Services] and trauma) and US (3528 articles); (2) 1 and focused abdominal sonography for trauma (FAST); (3) 1 and thoracic; (4) 1 and austere environment or remote; (5) 1 and patient triage; (6) 1 and fractures; (7) 1 and procedures; (8) 1 and training and prehospital providers; (9) 1 and telemedicine; and (10) 1 and future applications. Every search triggered further review of additional articles. Abstracts of articles were reviewed and selected for inclusion if they discussed prehospital US use for a trauma-related cause. An independent hand search of the bibliography of studies was also conducted to identify relevant articles that were not identified on the initial automated search. No limits on types of articles were set. Articles were excluded if found to be irrelevant to the scope of this review such as those where US was performed in the ED and not in the prehospital setting or those where US was performed in the prehospital setting but for a medical nontrauma cause. Case reports or small studies for the same US applications were excluded to abide by the reference and word limit for a review article.

BODY OF MANUSCRIPT

Clinical applications of prehospital ultrasound in trauma Focused abdominal sonography for trauma

FAST has been incorporated in the primary survey assessment of trauma patients to screen for occult hemorrhage. Early detection of hemopericardium or hemoperitoneum using FAST allows for expedited definitive treatment in addition to improved patient outcomes after blunt and penetrating trauma.^[10] Several studies examined the feasibility and practicality of FAST in the prehospital setting.

Prehospital FAST (PFAST) resulted in improvement in diagnostic accuracy, in streamlining patient care, and in changing disposition to an appropriate treatment center.^[11] A prospective multicenter study by Walcher *et al.* assessed patients with blunt abdominal trauma and compared the accuracy of a physical examination performed at the scene with PFAST to ED examinations (ultrasonography or computed tomography [CT]). PFAST examinations were performed on 202 patients by either a physician or a paramedic, with a mean investigation time of 2.4 (0.8) minutes, sensitivity of 93%, specificity of 99%, and accuracy of 99%. With the help of PFAST, prehospital therapy and management were altered in 30% of the patients, as well as hospital disposition was changed in 22% of cases. Based on these findings, the authors concluded that PFAST is a reliable and useful tool for surgical triage at the trauma scene.^[12]

Another study assessed the adequacy of FAST images obtained during air transport of patients by retrieval physicians.^[13] In this FAST *en route* study, 38 patients were included with 36 having a complete FAST examination in as little, as 2–3 min during short transports (8 min) in a rotatory wing aircraft.

A blinded physician with dual emergency medicine and US qualification reviewed the images and deemed 95.3% of the images to be adequate.^[13] In this study, FAST was possible during transport and did not affect transport times. Similar findings were reported by other air rescue services.^[14,15]

PFAST is, however, only feasible with a portable HH US device. A study by Kirkpatrick *et al.* compared FAST performed using 2.4 kg HH US device with formal FAST, CT, serial examinations and operative findings in 313 blunt trauma victim resuscitations in two trauma centers.^[16] Handheld FAST (HH FAST) performance was comparable to formal FAST in detecting free fluid (sensitivity 77%, specificity 99%, and negative predictive value [NPV] 94%), intrabdominal injuries (sensitivity 64%, specificity 99%, and NPV 89%), and injuries requiring therapeutic interventions. Based on those findings, authors concluded that HFAST detects intraperitoneal fluid accurately but should be complemented with a selective CT rather than a repeat US.^[16]

Prehospital thoracic ultrasound

Prehospital US in patients with a blunt or penetrating thoracic trauma can be applied to identify serious thoracic injuries early. In the ED, Plummer *et al.* showed that the introduction of US in the evaluation of patients with penetrating cardiac injuries resulted in shorter time to diagnosis or to disposition to surgical interventions, as well as, improved survival rates and neurologic outcomes in patients who underwent echocardiography compared to those who did not.^[17] Similar benefits may result from the use of US in the prehospital scene or during transport.^[18,19] Several case reports describe improved patient outcomes when prehospital thoracic US was used in trauma patients.^[18,20-24] Byhahn *et al.* showed that focused echocardiographic evaluation during resuscitation (FEER), can evaluate cardiac function in the prehospital setting, in a time-sensitive manner with 93% sensitivity, and 99% specificity for cardiac tamponade.^[20] Prehospital pericardiocentesis by physicians after US diagnosis of cardiac tamponade resulted in survival of a pregnant stabbing victim.^[21] Similarly, prehospital US performed by paramedics detected pericardial effusion in a stabbing victim and resulted in improved triage, as well as faster patient transport to the closest level 1 trauma center.^[23]

Prehospital detection of a pneumothorax before it develops into a clinically detectable tension pneumothorax is also possible using US through evaluation of Lung Sliding Sign (Pleural sliding concomitant with insufflations or respirations). US had a higher sensitivity in diagnosing a pneumothorax than clinical examination and chest radiography (CXR) in a study of 204 trauma patients who underwent extended FAST (EFAST) in addition to CXR and CT scan.^[25] Similar findings were reported by another study examining the detection of occult pneumothoraces in undifferentiated Intensive Care Unit patients.^[26] US is not only useful in detecting pneumothoraces but also in preventing harm from unnecessary needle decompression in patients with clinical suspicion for a traumatic pneumothorax.^[22] Detection of pneumothorax in flight presents

an opportunity for decreasing mortality rates. A 15-month prospective study assessed the use of prehospital US by flight crews in detecting pneumothorax and misplaced endotracheal tubes (ETTs). The diagnostic accuracy was 91% for US performed by the aeromedical crew compared to 98% for US performed by surgeons. Persistent pneumothorax on repeat US after needle decompression prompted the aeromedical crew to readjust the needle until air return was noted.^[27]

Performing thoracic US in the prehospital setting on scene or during transport (ground and air) was shown to be feasible in multiple studies. Garrett *et al.* showed that echocardiograms transmitted from a moving ambulance were similar to echocardiograms performed in-hospital, particularly for ruling out pericardial effusion and assessing left ventricular function and size.^[28] Similarly, Roline *et al.* showed that bedside thoracic US image acquisitions as well as lung sliding sign interpretation are feasible in a helicopter setting, with limited training.^[29] Lyon *et al.* also showed that prehospital critical care providers can acquire the necessary skills for detecting the lung sliding sign, after a brief tutorial using cadaveric models.^[30]

Applications in remote settings and mass casualties

US use in the prehospital setting is not limited to regular ground and air EMS services. Settings such as high altitude, military combats, refugee camps, disaster relief, and the International Space Station are some of the environments where US has been used. FAST has been shown to be feasible in harsh environments in which the effects of gravity are drastically reduced.^[31] Nonphysician astronauts were able to get adequate normal FAST images within 5.5 min while on the International Space Station.^[31] Similarly, sonographers were able to detect peritoneal fluid in porcine model at 0 g and 1.8 g environments without much variation in accuracy at decreased or increased gravity.^[32] In addition to that, using US in microgravity enabled the diagnosis of mild-to-severe pneumothorax and hemothorax.^[33]

Mass casualty incidents are another setting where prehospital trauma US is being used. EMS providers often face challenges when triaging mass casualty victims.^[34] Several studies have evaluated US deployment during multicasualty incidents and operational military deployment (Haiti earthquake, Armenia earthquake, Turkey earthquake, Guatemala mass-casualty mudslides, and wars in Iraq and Afghanistan, and Second Lebanon War).^[35-41] Despite the feasibility of prehospital US in mass casualty incidents, clear evidence of the benefit of incorporating US use in triage protocol is still lacking.^[42] US benefit during single and mass casualty events is not limited to trauma. Two cases diagnosed acute abdominal aortic aneurysm (AAA) in prehospital setting, one of them performed by critical care retrieval team in the field, and the other was diagnosed at 20,000 feet in a king airplane.^[43,44]

US is also helpful in austere environments with limited resources. In one study, direct voice communication and transmission of real-time video US images were feasible between the field caregiver in the Dominican Republic and the expert physician at Hackensack University. This

was feasible with the help of different secure cellular and satellite networks from an austere environment.^[45] Portable ultrasonography utility has extended to diagnosing fractures in austere combat environments. A prospective study showed that the use of portable US by certified emergency physicians on patients presenting with acute closed fractures assisted in field triage: cases where a fracture or cortical irregularity was detected on US were triaged to an appropriate facility with radiographic capabilities. This helped in reducing unnecessary further evaluations and wise resource utilization.^[46] US is also benefit in high-altitude conditions. US was used successfully at an alpine ski resort to exclude the presence of a traumatic pneumothorax in an injured snowboarder who presented with dyspnea and hemoptysis.^[47] Portable US devices were also used on Mount Everest, where physicians at the University of Ottawa in Canada and Henry Ford hospital (USA)-assisted paramedics and civilians in US image interpretation.^[48] FAST is also crucial during wartime for triaging injured soldiers and guiding laparotomy: reported sensitivity, specificity, positive predictive values (PPV), and NPV in this setting were 55.6%, 97.8%, 86.5%, and 89.5%, respectively, when using therapeutic laparotomy as a goal.^[49] Multiple studies have reported the accuracy of FAST ranging from 85% to 98% in blunt torso trauma patients.^[50] During the Lushan earthquake (Richter 7.0), 11,826 people were injured and a “modified, streamlined FAST scan methodology” was used successfully for prehospital triage of blunt torso trauma patients.^[50]

Patient triage and management

US, through improved diagnostic accuracy, can lead to change in prehospital management of trauma patients and minimize unnecessary invasive procedures. The use of prehospital US prevented unnecessary institution of an invasive thoracic procedure such as needle decompression or a tube thoracostomy in a dyspneic patient whose symptoms were related to another etiology.^[47] Another study by Blavais M showed that 26% of the patients who received needle thoracostomy in the prehospital setting for a suspected pneumothorax did not have a pneumothorax, and this was confirmed on a chest radiograph and a CT scan.^[51] Prehospital US can also impact the therapeutic plan. In one study, US lead to a change of prehospital treatment in 21% of patients and a change in the definitive care destination in 4% of patients who were treated by a Dutch Helicopter emergency medical service team.^[52] Similarly, the use of prehospital US changed the prehospital therapy in 30% of patients with blunt abdominal trauma and altered the final hospital destination in 22% of patients.^[12] A prospective observational study on 190 trauma patients showed that e-FAST performed by flight crew had a PPV of 100% and NPV of 98.3% for identifying hemothorax, pneumothorax, and free abdominal fluid, which was in concordance to results obtained by the trauma team on the same patients.^[53] Early and accurate prehospital US by trained personnel, allows trauma team at the receiving hospital for a better preparation, early activation of massive transfusion protocols, and early notification of the operating room to avoid delays in the care of the unstable bleeding patient.^[53]

Another prospective observational study by Blaivas assessed the impact of US on physician decision-making in the Amazon jungle. They showed that portable US could dramatically alter disposition and treatment when used in a remote setting. Physicians requesting the US were asked to fill a survey of their initial “differential diagnosis, treatment plan, and disposition” before and after US. Trauma and abdominal US scan results of 25 patients drastically “altered the disposition of 7 patients, including 4 patients who avoided a potentially dangerous 2 day evacuation to a more definitive medical care.” Three patients required rapid referral to the nearest clinic for surgical evaluation.^[54] Portable US can also quickly be used to triage trauma patients in the combat environment and to defer unnecessary invasive procedures or patients’ evacuation.^[55]

Other applications

Confirming endotracheal tube placement

Capnography is usually used to confirm ETT position but is limited in certain cases of low cardiac output, cardiac arrest, acute pulmonary embolism, hypothermia, and airway obstruction.^[56] US can be used successfully to confirm ETT placement in the prehospital setting as well and to rule out selective intubation.^[57]

Confirming gastric tube placement

Gastric tube (GT) placement is sometimes required in the field for gastric decompression after intubation. The reported misplacement rate is between 0.5 and 1.5%.^[58] Confirming GT location is crucial to avoid serious complications such as perforation, misplacement in the tracheobronchial tree, intravascular, or intracranial misplacement. In one study, US was effective and reliable in accurately confirming GT placement with 98.3% sensitivity, 100% specificity, 100% PPV, and 85.7% NPV.^[58]

Diagnosing intracranial bleed

Transcranial US can allow imaging of the brain parenchyma to detect intracranial hematomas in patients with traumatic brain injury. Prehospital transcranial sonography detected a hyperechogenic lesion with midline shift in a patient with suspected subarachnoid hemorrhage, which was then confirmed by CT scan in the hospital.^[59] This can help in faster triage and transport of patients to the appropriate facility with the required services.

Diagnosing fractures in austere environment

Prehospital US could also be performed in austere environments to diagnose extremity fractures. Brooks *et al.* reported on three cases where long bone extremity fractures were detected by portable US in an operational environment (Operation Telic).^[60] Besides that, portable sonography accurately detected “breaks in the cortical surfaces of the long bones” of injured extremities, in remote locations.^[61-63] This can help in realigning fractures when they are splinted for flight. One study found that portable US assessment of suspected fractures at a military battalion aid station altered the disposition of patients and minimized unnecessary radiation, with 100% sensitivity and 94% specificity for fracture detection. Patients with positive

scans were referred to a facility with radiography service and those with negative scans had splints applied and referred for clinical follow-up.^[46]

Prehospital ultrasound training

Multiple studies have assessed the training requirements for physicians performing focused US.^[64-67] The Northern Emergency Medicine for US Group requires a training curriculum with a 1 day didactic US course, followed by around 50 proctored assessments (covering AAA, FAST, and vascular access).^[68] Training requirements for prehospital providers vary by skill level and are based on the goals of scanning. The reported length of training curriculums for performing prehospital US varies across studies from few hours to several months.^[69-71] Challenges reported in training prehospital providers include skill maintenance, brief exposure, and limited access.^[69]

A training consisting of “at least 8 h of initial tutorial and at least 25 examinations including patients’ follow-up” was found to be the minimum requirement for emergency physicians to perform US in the out of hospital setting as successfully as in hospital emergency physicians.^[70] On the other hand, a study by Krogh *et al.* found a significant improvement in the objective structured assessment of US skills score in prehospital physicians after a 4 h course consisting of e-learning (110 min) and hands-on training with a pre- and post-test.^[72]

Different models of effective US training programs for prehospital providers other than physicians are described in the literature. Press *et al.* showed that “a training program that incorporates multiple educational modalities (didactics, hands-on training, proctored scanning sessions, modules, pocket flashcards, review session, and remedial training)” is feasible and successful when provided to prehospital providers over a 2-month period.^[69] Similarly, Heegaard *et al.* used similar multisession didactic approach and reassessed the skills 12 months after the initial training. He concluded that prehospital US in trauma could be taught to prehospital providers with good retention skills.^[71]

Another prospective observational study found that trained paramedics can perform FAST and abdominal aortic US in prehospital care environment and accurately interpret the images, with a 100% agreement with the physician overreader.^[73] However, shorter training programs were not as successful. In one study, FAST examinations performed by nonphysician EMS flight team after 3 h of training in FAST exam, could not be accomplished in 48% of patients “due to insufficient time, inadequate patient access or combativeness.”^[74]

Telemedicine and image transmission

Telemedicine is another solution that was successfully introduced to prehospital care. It allowed clinicians to remotely interpret images in real-time with EMS providers on the scene or *en route*. In one study, FAST examination images were successfully sent through a line of sight antenna from a remote access, with a comparable quality to those viewed on site. However, the quality of images declined when images

were transmitted through satellite and reviewed remotely.^[75] In another study, 32 cardiac scans were transmitted from a moving ambulance driving at a speed of 50–75 mph, with highest image quality obtained for the left ventricular function, effusion, and inferior cava, unlike wall motion assessment and valvular anatomy.^[28] On the other hand, echocardiograms transmitted with a wireless microwave signal to a satellite had improved image quality for the left ventricular size, pericardial effusion, and ejection fraction.^[76] Tele-guided US can be deployed in remote locations with limited resources to facilitate the connection between the minimally trained paramedics and experienced emergency physicians.^[77]

Future applications of prehospital trauma ultrasound

High-intensity focused US has been successful in providing hemostasis in animal studies through its mechanical and thermal effect. Future studies should examine this method of acoustic hemostasis in trauma patients with active bleeding. This can significantly reduce mortality from hemorrhagic shock in the prehospital setting and improve transportation.^[78]

CONCLUSION

US use continues to expand in the prehospital field and in trauma care. In this review, we described several existing and future potential applications of focused ultrasonography in the prehospital management of trauma victims. Challenges in terms of training requirements and skill maintenance for prehospital providers were also discussed. The benefit of US varies from increased diagnostic accuracy to guiding therapy and decision-making (triage, choice of transport modality, and receiving facility). The evidence for such application consists mainly of case reports and small studies. Most of the studies showed that prehospital US is feasible for early diagnosis and treatment; however, no large study discussed whether mortality and morbidity are altered as well. Further prospective studies are warranted to determine whether prehospital US is essential in trauma care and in decreasing morbidity and mortality.

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