Selected Topics: Aeromedical Emergencies

PROSPECTIVE EVALUATION OF PREHOSPITAL TRAUMA ULTRASOUND DURING AEROMEDICAL TRANSPORT

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Abstract—Background: Ultrasound is widely considered the initial diagnostic imaging modality for trauma. Preliminary studies have explored the use of trauma ultrasound in the prehospital setting, but the accuracy and potential utility is not well understood. Objective: We sought to determine the accuracy of trauma ultrasound performed by helicopter emergency medical service (HEMS) providers. Methods: Trauma ultrasound was performed in flight on adult patients during a 7-month period. Accuracy of the abdominal, cardiac, and lung components was determined by comparison to the presence of injury, primarily determined by computed tomography, and to required interventions. Results: HEMS providers performed ultrasound on 293 patients during a 7-month period, completing 211 full extended Focused Assessment with Sonography for Trauma (EFAST) studies. HEMS providers interpreted 11% of studies as indeterminant. Sensitivity and specificity for hemoperitoneum was 46% (95% confidence interval [CI] 27.1%–94.1%) and 94.1% (95% CI 89.2%–97%), and for laparotomy 64.7% (95% CI 38.6%–84.7%) and 94% (95% CI 89.2%–96.8%), respectively. Sensitivity and specificity for pneumothorax were 18.7% (95% CI 8.9%–33.9%) and 99.5% (95% CI 98.2%–99.9%), and for thoracostomy were 50% (95% CI 22.3%–58.7%) and 99.8% (98.6%–100%), respectively. The positive likelihood ratio for laparotomy was 10.7 (95% CI 5.5–21) and for thoracostomy 235 (95% CI 31–1758), and the negative likelihood ratios were 0.4 (95% CI 0.2–0.7) and 0.5 (95% CI 0.3–0.8), respectively. Of 240 cardiac studies, there was one false-positive and three false-negative interpretations (none requiring intervention). Conclusions: HEMS providers performed EFAST with moderate accuracy. Specificity was high and positive interpretations raised the probability of injury requiring intervention. Negative interpretations were predictive, but sensitivity was not sufficient for ruling out injury.

Keywords—trauma ultrasound; FAST; EFAST; prehospital; aeromedical

INTRODUCTION

For more than 3 decades, physicians and surgeons have successfully utilized ultrasound for the injured patient (1). The Focused Assessment with Sonography for Trauma (FAST) is a goal-directed sonographic assessment of the intraperitoneal and pericardial spaces for blood, and the extended version (EFAST) also includes an evaluation of the pleural spaces (2). FAST decreases time to operative care and reduces exposure to the ionizing radiation of computed tomography (CT) (3–5).
Lung ultrasound has been shown to be more accurate than chest radiography for the diagnosis of pneumothorax (2).

The improved portability of ultrasound has expanded its use beyond the traditional hospital setting. Handheld ultrasound has been introduced into prehospital settings around the world (6–9). Potential advantages to EFAST in the prehospital setting include improved triage of patients, guidance of prehospital management, and expediting time to definitive care (9). Ultrasound may allow helicopter emergency medical services (HEMS) crews to discern the etiology of undifferentiated hypotension in the trauma patient (i.e., intraperitoneal hemorrhage, tension pneumothorax, hemopericardium). Ultrasound has been used in a decision tool to initiate blood product transfusion in the field (10). Pneumothorax is frequently misdiagnosed by clinical examination, resulting in a rate of unnecessary needle decompression as high as 26% (11). Prehospital providers may be able to use ultrasound to more accurately diagnose life-threatening conditions and to more appropriately manage them.

Several European studies report success with prehospital ultrasound protocols, however, prehospital providers in Europe differ from their American counterparts in that most are physicians, often with advanced ultrasound training (12). In the United States, a small number of studies describe the use of FAST in ground ambulances and, to an even lesser extent, during aeromedical transport (13–17). These helicopter studies were conducted a decade ago and evaluated small samples of in-flight FAST with varying success (14–18).

We evaluated a large-scale HEMS trauma sonography program. The goal was to assess prehospital provider accuracy in performing the abdominal, cardiac, and lung components of EFAST.

**METHODS**

**Study Design**

This was a prospective observational study of the accuracy of EFAST performed by HEMS flight nurses and paramedics. HEMS providers performed in-flight EFAST on a sample of trauma patients if time allowed after patient stabilization. This study was approved by the Committee for the Protection of Human Subjects and the Institutional Review Board (HSC-MS-08-0085). Informed consent was obtained from the HEMS providers participating in the study. Patient data were used via waiver of consent. SonoSite, Inc. (Bothell, WA) provided funding and the ultrasound machines used for this study.

**Setting**

HEMS is a hospital-based, accredited, critical care, air medical transport service, operating within a 150-mile radius of a large urban medical center. At the time of the study, the service included 4 helicopters (EC145, American Eurocopter, Grand Prairie, TX), 17 flight nurses, 16 paramedics, and 13 pilots. Typical flights consisted of a flight nurse, paramedic, and pilot. The emergency department (ED) is an urban academic Level I trauma center with an annual patient census of nearly 70,000 and > 6000 trauma admissions.

**Selection of Participants**

Participation in the study for HEMS providers was voluntary. HEMS providers were trained to perform EFAST during a 2-month period. The training curriculum has been described in a previous study; it included a 1-day didactic and hands-on course, six weekly internet-based training modules, proctored scanning sessions in the ED, pocket flashcards, a review session, pre- and post-testing, and remedial training for those that need it (18). Three weeks before the start of the study, the helicopters were equipped with the ultrasound machines and providers performed several practice scans. Portable ultrasound machines with phased-array cardiac probes were used for all helicopter imaging (M-Turbo and P-21x transducer; SonoSite).

**Protocol**

Study protocol instructed HEMS providers to perform EFAST on adult trauma patients (18 years or older) transferred directly from scene if time allowed after standard stabilization. In this observational study, HEMS providers were instructed not to alter management based on ultrasound findings. Timing the ultrasound after stabilization was to preclude management alterations, as most of our prehospital interventions (such as needle thoracotomy, intubation, and blood transfusion) are only performed on unstable patients.

HEMS providers performed EFAST using the following views: hepatorenal, splenorenal, suprapubic, cardiac (subcostal or parasternal long-axis), right lung, and left lung. All views were standard and in accordance with imaging described by the American College of Emergency Physicians and American Institute of Ultrasound in Medicine (19). Abdominal and cardiac examinations were performed to evaluate for intraperitoneal and pericardial fluid, respectively. Lung ultrasound was performed to evaluate for lung slide to exclude or diagnose pneumothorax. Abdominal views were saved as still images, and cardiac and lung views as 4-s video clips.

HEMS providers documented interpretations before patient delivery to the ED and were blinded to ED diagnostics and management. Receiving teams were blinded to HEMS EFAST, unless providers felt it essential to
share critical information. CT imaging was performed at the discretion of the emergency physician and trauma surgery service, but trauma patients requiring helicopter transport frequently received chest radiography and pan-CT (head, cervical spine, chest, abdomen, and pelvis).

**Measurements**

The aim of this study was to evaluate the accuracy of HEMS providers in performing in-flight EFAST. HEMS EFAST interpretations were compared to the presence of injury and required interventions. Presence of injury was defined as hemoperitoneum, pericardial fluid, and pneumothorax for respective components. Required intervention for the abdominal component was defined as laparotomy, laparoscopy, or interventional procedure, for the cardiac component it was needle or operative pericardial fluid drainage, and for the lung component it was thoracostomy or thoracotomy.

HEMS providers interpreted each view as positive, negative, or indeterminate. For components with multiple views, a final positive interpretation required a single positive view, a negative interpretation required all views to be negative, and an indeterminate interpretation was not positive with at least one indeterminate view. Only positive and negative interpretations were used to calculate test characteristics.

Chart abstractors proceeded in a stepwise fashion through a predetermined order of modalities to determine the presence of injury. For the abdominal component, the order of modalities was CT, operative findings, and clinical evaluation during hospital stay; for the cardiac component, the order was CT, formal echocardiography, operative findings, and clinical evaluation during hospital stay; and for the lung component, the order was CT, operative/procedural findings, chest radiography, and clinical evaluation during hospital stay. Essentially, presence of injury was determined by imaging, primarily CT, or for patients without imaging by operative or clinical evaluation. Final attending radiologist reads were used for imaging reports.

**Data Analysis**

Patient demographics were quantified with mean and standard deviations provided when applicable. Sensitivity, specificity, positive predictive value (PPV), negative predictive value, and positive and negative likelihood ratios were calculated by standard formula. The 95% confidence interval (CI) is reported for each performance metric. Data analysis was performed using STATA 11.0 statistical software (College Station, TX).

**RESULTS**

Thirty-four HEMS providers volunteered for the study and 33 completed training for participation; 1 provider left for another job during the training period. Thirty-one HEMS providers (93.9%) had no prior ultrasound training and 29 (87.9%) had no prior experience performing ultrasound. Median age for HEMS providers was 35–39 years and median time of EMS experience was 15–19 years. Median number of EFASIs performed by HEMS providers was 11 (interquartile range 5.5–19); the most studies performed by a single provider was 42, and the fewest was 1.

Baseline characteristics of patients that received ultrasound by HEMS providers are described in Table 1. Mortality rate was 4.8%. Morbidity of the group was reflected by a mean Injury Severity Score of 16, a blood product transfusion rate of 14.7%, and an intensive care unit admission rate of 31.5%.

During the 7-month study period, HEMS flew 1963 flights, of which 833 were adult patients with traumatic injuries flown directly from scene (Figure 1). HEMS providers performed and interpreted at least one ultrasound view on 293 patients, completing 211 full EFAST studies. The overall rate of HEMS studies interpreted as “indeterminate” was 11%. The abdominal component had a higher indeterminate rate (31.7%) than cardiac (8%) and lung (3.9%), but required more views.

For the abdominal component, all 293 patients who received HEMS EFAST had at least one abdominal view imaged. Ninety-three interpretations were indeterminate, either because at least one view was missing or interpreted by the provider as indeterminate. The right upper quadrant (RUQ), left upper quadrant (LUQ), and suprapubic views were performed in 291 (99.3%), 282 (96.2%), and 279 (95.2%) patients, respectively. An indeterminate interpretation was more common for the LUQ (16.4%) than the RUQ (9.9%) and suprapubic (10.6%) views ($p = 0.02$).

Test characteristics are described in Table 2. The prevalence of hemoperitoneum and a required operation was 13.2% and 8.5%, respectively. The modality for determining hemoperitoneum was CT in 234 patients (80.1%), operative in 10 (3.4%), and clinical evaluation in 48 (16.4%). HEMS providers were more sensitive for hemoperitoneum requiring operation (64.7%) than for hemoperitoneum alone (46%). Specificity was high for hemoperitoneum and required operation (94.1% and 94%, respectively), but positive interpretations were only correct half of the time (55.4% and 50%, respectively).

Of the 293 patients receiving HEMS ultrasound, 263 (90%) had cardiac imaging. HEMS providers interpreted
23 studies as indeterminate. The parasternal long axis view was performed in 212 patients (80.6%), and the subxiphoid view in 68 (25.8%). The modality for determining pericardial fluid was CT in 206 patients (70.5%), formal echocardiography in 12 (4.1%), operative in 1 (0.3%), and by clinical evaluation in 72 (25%). Three of 240 patients (1.25%) had possible or minimal pericardial effusion identified on CT, but none were addressed clinically. No patient had pericardial fluid that required intervention. There was one false-positive interpretation.

HEMS providers imaged 511 (87.2%) of 586 lungs in the 293 patients receiving ultrasound. The prevalence of pneumothorax and required intervention was 8.4% and 3.7%, respectively. The modality for determining pneumothorax was CT for 422 lungs (72.3%), chest radiography for 152 (26%), and 10 by clinical evaluation (17%). HEMS provider sensitivity was poor, but higher for pneumothorax requiring thoracostomy (50%) than for pneumothorax alone (18.7%). Specificity was nearly perfect for pneumothorax and for required thoracostomy, and the rates of accurate positive interpretations were 80% and 90%, respectively. Right lung ultrasound was more sensitive than left for both pneumothorax (18.7% vs. 8.7%) and required intervention (66.6% vs. 33.3%). Chest radiography was similarly poorly sensitive, positive in only 10 of 43 patients (23.3%) with pneumothorax. In the 35 patients with a negative HEMS interpretation but pneumothorax on CT, chest radiography was negative in 31 (88.6%). In the 18 patients who received thoracostomy, chest radiography was positive in 12 (66.7%).

**DISCUSSION**

We demonstrated HEMS providers could perform EFAST with moderate accuracy in the largest trial to date in the United States of in-flight trauma sonography. We found varying test characteristics for different components of EFAST. In general, sensitivity was low and specificity was high. Sensitivity improved when evaluating operative outcomes (required interventions) rather than diagnostic ones (presence of injury). The negligible
number of positive cardiac outcomes limited our ability to draw conclusions regarding this component.

We felt it was critical to evaluate test characteristics with regard to the presence of injury and required interventions. The value of prehospital EFAST depends on expectations of the receiving team and consequent actions, and cannot be appreciated by an isolated test characteristic. We believe that prehospital screening ultrasound should ideally meet the following expectations: negative ultrasounds should reliably exclude those requiring intervention, and positive interpretations should identify those requiring intervention, but may include those with the presence of injury.

For the abdominal component, while negative interpretations were correct the vast majority of the time, approximately one third of patients requiring intervention had false-negative interpretations. Patients with operative hemoperitoneum were roughly 10 times more likely to have a positive test than those without; however, a positive interpretation was just as likely to be false as true.

Positive interpretations significantly raised post-test probability of injury (positive likelihood ratio for required intervention was 10.7 [95% CI 5.5–21]), but the false-positive rate was not insignificant. Although we did not study management strategies based on HEMS ultrasound, we believe hypotheses can be generated from our data. In our opinion, the activation of a trauma surgery team seems like a reasonable response to a positive HEMS ultrasound, considering the risk of serious injury. Negative HEMS interpretation have limited value due to low sensitivity and, based on our findings, should not affect triage, imaging, or management decisions in the emergency department. This viewpoint may change as novices gain experience, training protocols evolve, and larger studies provide more generalizable results. However, even the appropriate course of action after a negative FAST performed in the ED is controversial, and several authors have suggested FAST as a single test is inadequate for ruling out intra-abdominal injury (20,21). In this regard, our findings for ultrasound performed by HEMS providers may be consistent with those performed in hospital.

With regard to lung ultrasound, sensitivity for pneumothorax was poor, although improved for required thoracotomy. Right lung ultrasound had higher sensitivity than left, which may be explained by difficulty navigating around the left-sided heart. Several studies have demonstrated very high sensitivity for lung ultrasound in diagnosing pneumothorax, but this was not replicated in our study (2,22). This might be explained by our use of a large pool of novice sonographers and the difficult conditions in which they had to scan, notably in trying to assess lung slide with helicopter vibration. Additionally, the vast majority (76.7%) of pneumothoraces in our study could not even be visualized by chest radiography. However, a positive HEMS interpretation dramatically increased post-test probability of pneumothorax (positive likelihood ratio = 41.5; 95% CI 9–189.2) and required intervention (positive likelihood ratio = 235; 95% CI 31–1758) and, in contrast to the abdominal component, the PPV was high. Therefore, a positive lung ultrasound interpretation was reliably specific and predictive.

Early reports demonstrated that trauma ultrasound could be performed on helicopters (14–17). Melanson and colleagues first evaluated the ability of a novice crew of HEMS providers to perform trauma sonography in the United States (13). Ultrasound was either not at- tempted or mechanical difficulties prevented scanning in most patients. In only 2 of 71 patients were all three conditions in which they had to scan, notably in trying to assess lung slide with helicopter vibration. Additionally, the vast majority (76.7%) of pneumothoraces in our study could not even be visualized by chest radiography. However, a positive HEMS interpretation dramatically increased post-test probability of pneumothorax (positive likelihood ratio = 41.5; 95% CI 9–189.2) and required intervention (positive likelihood ratio = 235; 95% CI 31–1758) and, in contrast to the abdominal component, the PPV was high. Therefore, a positive lung ultrasound interpretation was reliably specific and predictive.

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Two other studies have contributed most significantly to our understanding of prehospital FAST (6,9). Heegaard and colleagues found that ground-ambulance paramedics performed FAST with 100% proportion of agreement with physician over-read of the imaging (6). The greater
accuracy than that found in our study may be explained by a number of factors. Physician over-read is a limited criterion standard in that the capacity to over-read is dependent on the adequacy of image acquisition, a component of the test itself, and physician over-read may not correspond with the presence of injury. In Heegaard et al.’s study, 17% of available paramedics participated, likely a selection bias of the most motivated providers. Additionally, imaging during helicopter transport may be complicated by factors such as turbulence, vibration, lighting, tighter confinement, shorter transport times, and higher severity of injury. Our HEMS providers evaluated cardiac and lung spaces and, in retrospect, focusing on a single component, such as abdominal scanning, may be more practical for novice prehospital providers.

Walcher and colleagues aimed to determine the extent of management changes based on FAST performed by German emergency surgeons, physicians, and paramedics at the scene, in ground ambulances, and in helicopters (9). Accuracy of prehospital FAST was 99%, with a change in prehospital management seen in 30% of patients. In comparison, HEMS providers in our study were all nonphysician novices and performed studies only in flight. The compelling findings of these studies offer hope for improved diagnostic accuracy asprehospital providers in the United States gain experience.

Limitations

External validity is limited by the fact that this study was conducted at a single institution with one crew of HEMS providers. All were novices, which may not represent the skill level of other prehospital crews. Our protocol, which dictated ultrasounds be performed only after stabilization, may have limited the opportunities to scan or allowed for selection bias. For example, patients with positive findings may have required greater stabilization and been less likely to be imaged.

We did not determine the rate of EFAST performance because we could not accurately establish the denominator of eligible patients. If we were to use the number of adult trauma patients transported from scene (n = 833), the rate of any imaging for patients would have been 35% and for complete EFAST 25%. However, our protocol dictated imaging only after all stabilization tasks, and we did not ascertain the number of patients this excluded. In actual practice, HEMS providers might image unstable patients concurrently with other tasks, as in the ED. Additionally, we did not determine the number of patients transported for isolated limb or head trauma that might not have inspired imaging. Other barriers to scanning included short flights, limited patient access, patient combative ness, lighting, and other technical and mechanical difficulties.

Sonographers were not blinded to physical examination when interpreting ultrasound studies, nor were they blinded to the study hypothesis, allowing for the possibility of the Hawthorne effect. Finally, the observational design of our study precludes definitive conclusions, particularly with regard to the value of prehospital ultrasound for clinical outcomes. A large multicenter trial could further explore the effect of prehospital trauma sonography on triage and patient outcomes.

CONCLUSIONS

The prospect of HEMS providers making early diagnoses with ultrasound in injured patients is enticing. During our study period, there were numerous cases in which hemothorax and pneumothorax were diagnosed in the helicopter with potential to expedite critical management for these life-threatening conditions. We demonstrated that a large crew of paramedics and flight nurses who had never used the technology could undergo training and incorporate ultrasound in flight. Positive interpretations significantly raised the probability of injury, more reliably so for lung ultrasound. Negative interpretations were predictive, but low prevalence limited the value of these results. Sensitivity was not sufficient for ruling out injury. We believe further study is needed to elucidate accuracy as providers gain experience, and to explore clinical outcomes that may be affected by prehospital trauma ultrasound.

Acknowledgments—The authors would like to thank R. Michelle Sauer, PhD, ELS and Angela Beeler for their editorial assistance. The authors would especially like to thank Memorial Hermann Life Flight for their participation and cooperation during this study.

REFERENCES


ARTICLE SUMMARY

1. Why is this topic important?
   Prehospital providers are beginning to use ultrasound for trauma patients, and little is known about the accuracy of the modality. Early diagnosis of traumatic injuries may expedite life-saving care.

2. What does this study attempt to show?
   This study attempts to demonstrate the accuracy of trauma ultrasound performed by prehospital aeromedical providers.

3. What are the key findings?
   Novice prehospital providers were moderately accurate with high specificity but poor sensitivity.

4. How is patient care impacted?
   Positive interpretations significantly increased the likelihood of injury, and potential benefits might include triage to the appropriate hospital, improved hospital preparation, and expedited life-saving interventions. Negative interpretations were not sensitive enough to factor into decision making.