

The Potential of Handheld Trauma Sonography in the Air Medical Transport of the Trauma Victim

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Introduction

Air medical evacuation is an important means of reducing the time to definitive care for the acutely injured and has been credited with saving or extending the lives of many people.¹ Out of necessity, medical care delivered during flight focuses on and is typically limited to correcting threats to physiologic stability. A review by Fisher² documented the most common life-threatening conditions in a medical helicopter to be cardiac arrest (19%), airway obstruction (5%), cardiac tamponade (3%), and tension pneumothorax (2%).

Trauma sonography has become an essential tool in trauma resuscitation. A body of controlled studies yields Level I recommendations for its use as the initial screening mode to rule out hemoperitoneum after blunt trauma.³ With technical developments and commercialization, portable handheld ultrasound is becoming increasingly available to clinicians and enhancing the way in which they examine patients.⁴⁻⁷ It is then intuitive that taking this extension of the physical examination outside of the hospital to the air medical environment has the potential to save lives.

The Advanced Trauma Life Support course of the American College of Surgeons focuses on reducing preventable deaths in the early postinjury phase. Preventable deaths may be addressed by preventing airway obstruction, promptly treating hemo/pneumothoraces, and identifying and addressing intra-abdominal and intracerebral bleeding.⁸⁻¹⁰ These are also conditions that may manifest and be worsened in the transport environment and are more difficult to detect in flight than anywhere else.

When faced with challenges, physicians historically have accepted new technology in a quest for better patient care. The first air medical mission was reportedly during the siege of Paris in 1870, when wounded soldiers were air-lifted out of the besieged city by balloon.^{11,12} Whether true or not, this spirit has transcended to the current day, where the trauma ultrasound has been used on the International Space Station in the absence of any other diagnostic imaging modes.^{13,14} The space station has no plan or capability for computed tomog-

raphy, no x-ray, no magnetic resonance imaging.¹⁵ This limitation has necessitated looking outside the traditional ultrasound boxes to consider novel indications that might provide diagnostic information.¹⁵⁻¹⁸

Despite the catastrophic consequences a serious medical event in space would have for both the individual and the mission, there is only a relatively small number of potential victims. Many more lives are at stake considering air medical transport on earth, and we suggest that novel additions to the role of ultrasound might benefit the air medical transport environment, ultimately providing the greatest benefit to the most people.

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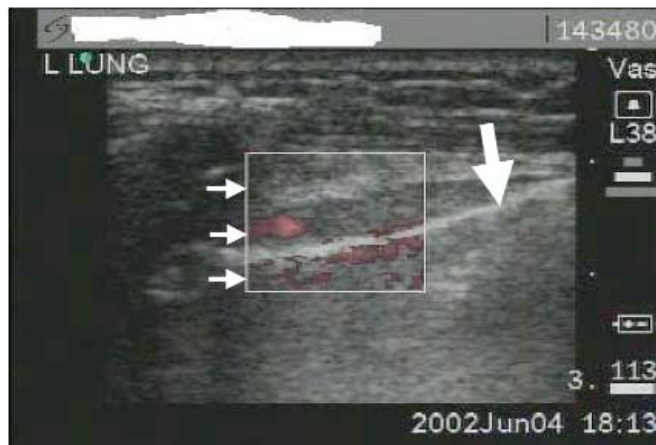
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Figure 1. Sonographic image of normal lung illustrating comet-tail artifacts (small arrow) originating from the visceral-parietal pleural interface (large arrow). The color-power Doppler interrogation box (3 arrows) illustrates a positive signal centered over the pleural interface.



Figure 2. Sonographic image of left lung of pedestrian struck by a car illustrating the visceral-parietal pleural interface (large arrow). Lung sliding was seen at this location during real-time imaging. The color-power Doppler interrogation box (3 arrows) illustrates a positive signal centered over the pleural interface.



The Current Status of Air Medical Trauma Sonography

Abdominal trauma sonography, or the focused assessment with sonography for trauma (FAST), is a simple test that looks for free intraperitoneal fluid. It is repeatable and can be completed in seconds to minutes.¹⁹⁻²¹ This form of trauma sonography has been subjected to a limited degree of investigation in the air medical environment. Price and colleagues²² performed 21 examinations on 14 patients, 9 of whom were “simulated” aboard a helicopter in flight. They spent 10 hours training those examiners who were not experienced in ultrasound. They thought it was easy to perform an evaluation and commented that there was no interference with the helicopter avionics.

Polk and colleagues²³ examined 84 patients. They had an overall accuracy of 96.4% in these patients with a sensitivity of 81% and a 100% positive predictive value. They had 3 false negatives, though. They thought the ultrasound studies obtained in flight were similar in quality and consistency to those obtained in the emergency department and predicted that trauma ultrasound in flight could change traditional algorithms of prehospital care. This same group²⁴ also used their helicopter-borne ultrasound to prevent an air medical transport in a patient who had suffered blunt cardiac arrest by ruling out major abdominal trauma and any evidence of tamponade.

Not all the initial evaluations have been so optimistic, however. Melanson²⁵ evaluated 71 patients in flight and found the FAST could not be performed in almost half (48%) because of insufficient time, inadequate patient access, or patient combativeness. They thought that significant advances were still required before the FAST could be accepted as a standard of care in the air medical role.

The essential lessons from the limited data appear to be that examiner skill level is crucial. False negatives may be a concern as a result of earlier scanning that occurs before fluid

can accumulate in a large enough quantity for easy detection. The inability to perform a FAST because of hemodynamic instability in itself may be a clinically significant marker that should raise the attention of resuscitating clinicians.

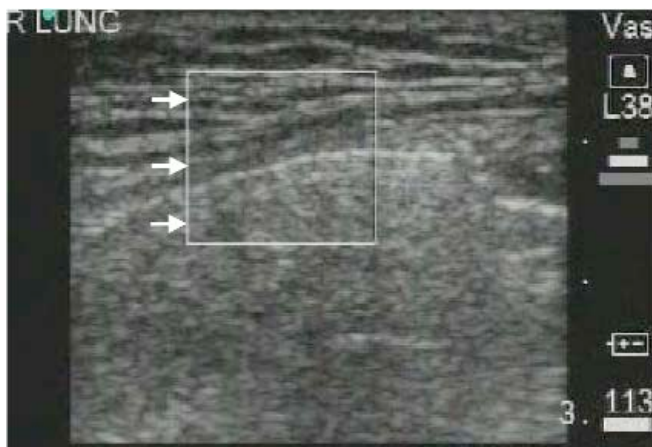
Evaluating abdominal sonography during flight may not exploit the full potential of this mode, though. The FAST can be considered the noninvasive equivalent of a diagnostic peritoneal lavage, having essentially replaced it for the initial assessment of hemoperitoneum after blunt trauma.²⁶ A diagnostic peritoneal lavage should not be performed, except for exceptional circumstances, in a setting where interventions (typically meaning a laparotomy) cannot be offered in the event of a positive result, such as on board a transport aircraft. Whereas the FAST examination provides information to triage patients, other forms of focused sonography may further direct in-flight care in the future. These potential roles are outlined below.

The Potential of Trauma Sonography in Air Medical Transport

Pneumothoraces

Not only are pneumothoraces a preventable cause of death after trauma, but they have been considered a contraindication to air medical transportation.^{12,27} Pneumothoraces are common, occurring in a fifth of the major trauma victims found alive, and they cause disproportionate cardiopulmonary derangements compared with other thoracic injuries of comparable anatomic severity.²⁸ The importance of this condition and the difficulty in diagnosing it in a prehospital setting is further complicated by the recent appreciation that the portable supine chest x-ray is a very insensitive diagnostic tool for pneumothoraces.²⁹⁻³¹ Occult pneumothoraces not seen on chest x-ray but seen on computed tomography scan have been reported to constitute up to 70% of all the pneumothoraces detected in some series.³²⁻³⁴

Figure 3. Sonographic image of right lung revealing absence of color power Doppler signal (3 arrows) from presumed pleural interface. No lung sliding was seen at this location in real-time scanning. *Reproduced with permission from Kirkpatrick et al. J Trauma 2004;57:288-95.*



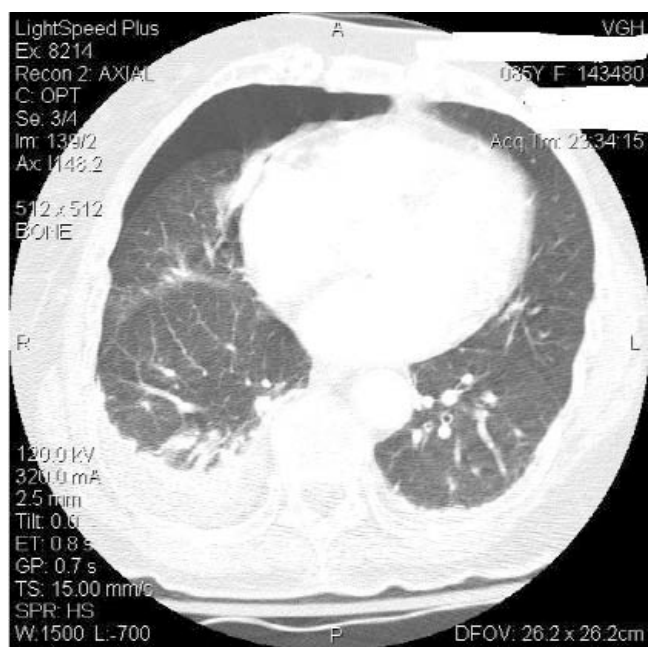
In direct observance of Boyle's Law, pneumothoraces will increase in size if there is any ascent to altitude in a nonpressurized or semipressurized aircraft. Although pneumothoraces are dynamic and may undergo life-threatening exacerbations spontaneously, the size of pneumothorax also will increase by 33% at an altitude of 8000 feet (compared with sea level).³⁵

Despite the admonitions of the Advanced Trauma Life Support course, pneumothoraces frequently are untreated in prehospital transportation.³⁶ Interventions such as needle decompressions often are performed in the air medical environment when changes in chest symmetry are noted or unexplained hypotension or increases in peak airway pressure occur, without certain knowledge of what the etiology is. Focused ultrasound might assist with quickly differentiating the cause. Thus, there is an impetus to consider other methods of diagnosing pneumothoraces before committing a patient to the air medical transport environment.

Sonography may have an important role in the thoracic examination of the traumatized patient. Initial reports have found sonography to be more accurate than the anteroposterior supine x-ray in detecting pneumothoraces.^{33,37,38} Further, hand-held ultrasound can be transported to the scene of resuscitation, whereas portable radiography equipment cannot.³⁹ Thoracic sonography infers a presence of pneumothorax by evaluating for the physiological "sliding" or "gliding" movement of the parietal on the visceral pleura.^{40,41} This movement can be well seen with high-frequency linear transducers. Even small amounts of air between the visceral and parietal pleura prevent this physiological movement from being detected and thus imply either subcutaneous emphysema or a pneumothorax.

Comet tail artifacts are believed to be visceral pleura-based densities, the equivalent of the radiographic Kerley B lines, which, when detected, enhance sensitivity in ruling out pneumothoraces.⁴² This physiological sliding movement can be ac-

Figure 4. Computed tomographic study of same patient in figures 2 and 3, revealing a pneumothorax that was "occult" to the anterosuperior supine chest radiograph but inferred by the lack of sliding, moving comet-tail artifacts, and an absent color-power Doppler signal on ultrasound.



centuated in the examiner's eyes through the use of the color power Doppler function, the "Power Slide" sign (Figures 1 and 2).⁴³ A pneumothorax thus is inferred by the inability to detect lung sliding, the absence of comet tail artifacts, and the absence of the color-Power Doppler depiction (Figure 3). Initial studies from Vancouver^{33,37,38} have shown the thoracic ultrasound examination to have an enhanced accuracy and sensitivity compared with the supine chest x-ray (Figures 3 and 4).

Ideally, experienced operators, or novices remotely directed by experts, would be able to quickly recognize intrapleural abnormalities and offer corrective interventions before physiological distress or clinical deterioration. Further study is required to validate this approach. Draining the chest by performing either a needle or tube thoracostomy is not without complications^{44,45} but is greatly preferred to leaving a tension pneumothorax untreated. The standard approaches to treating any suspected tension pneumothorax solely on the basis of clinical suspicion should continue until further data are accumulated.

Airway Management

Establishment and protection of a patent airway is of the highest priority in emergency trauma care.⁹ Failing to ensure this is a leading cause of preventable trauma deaths. The most definitive airway protective maneuver is to place an endotracheal tube through the vocal cords into the trachea. A further concern is the increased risk of tube malposition in operational medicine. Rates of tube malposition double in the emergency situation,⁴⁶ and prehospital personnel cannot be

expected to maintain the same skills as in-hospital anesthesiologists. Success rates for first-time intubations in the field by basic emergency medical technicians were found to be only 51%, with a 25% recognized and 3% unrecognized esophageal intubation rate in one study.⁴⁷

Confirmation of correct tube placement relies on a number of different modes, including direct observation at laryngoscopy, auscultation of equal air entry bilaterally, observation of chest wall excursion, capnography, and ensuring adequate oxygenation (although hypoxemia is a late and ominous finding of tube malposition). Unfortunately, even in the best of settings, clinical examination is notoriously inaccurate. Sixty percent of right stem intubations occur with equal breath sounds documented, and 70% occur despite the observation of apparent symmetric chest excursion.^{48,49} Capnography has been considered the gold standard but relies on an adequate cardiac output to deliver carbon dioxide and thus may be inaccurate in a cardiac arrest setting or simply not available in many prehospital settings.

It is extremely difficult if not impossible to auscultate in an air transport vehicle because of noise and vibration.^{50,51} We believe that portable ultrasound could help rule out pneumothoraces before air transport and thus reduce in-flight medical events. Studies are being designed to address these issues.

The in-flight use of thoracic sonography may provide another means to corroborate correct endotracheal tube placement in an environment where a stethoscope is symbolic rather than functional. Lung sliding, the movement of comet-tail artifacts, and the color power Doppler sign signal ventilation in paralyzed or apneic patients. These signs can be noted with a simple view of the left lung and can ensure flight personnel that the left lung is moving. This simple fact rules out an esophageal intubation and a right main stem intubation, the 2 most common significant tube malpositions. This does not correlate the adequacy of ventilation but provides a means of assessing tube position.

Initial studies have been carried out in both elective, surgical, and trauma patients at the Vancouver Hospital.⁵² These studies found ultrasound to be a feasible method of simply examining the left lung behavior. Further studies are planned for the air ambulance to extend these findings to the prehospital environment.

Abdominal and Pericardial

Major and internal hemorrhage is another frequent cause of preventable trauma death and one of the most common causes early in hospital death.^{53,54} Bleeding to death accounts for more than 80% of operating room deaths,⁵⁵ with intra-abdominal injuries accounting for more than 50% of these.⁵⁶ Although surgical intervention would not be possible in air medical transport, the simple determination of a major hemo/peritoneum before evacuation might allow a damage control intervention at a referring hospital and thus prevent exsanguination during flight in a patient that otherwise might be transported prematurely.

The absence of such a major hemoperitoneum would reassure the physicians involved in treating a hemodynamically

unstable patient with major pelvic trauma that a laparotomy is not indicated and early referral to a definitive center with orthopedic and interventional radiologic capabilities is appropriate. The rapid detection of pericardial fluid with a screening trauma ultrasound is considered part of the FAST examination and has been found to be very accurate.¹⁹

Emergency department studies have demonstrated the use of hand-held sonography in quickly examining trauma victims.^{4,7} Overall this technique was found to have a 95% accuracy in detecting interperitoneal free fluid and was very accurate in detecting major hemoperitoneum in those patients requiring intervention.⁵⁷ The technique had a lesser sensitivity of 65% with an overall accuracy of 90% detecting all injuries. This is because many injuries consist of low-grade solid organ injuries without free fluid that did not require clinical intervention. The ultrasound examination thus will not detect all injuries and should be supplemented with computed tomography scanning at the definitive care center, when available, but can be very useful in resuscitating the most critically injured and unstable patients.

The goal of prehospital examination would not be to diagnose all injuries but to detect patients with major injuries that would either be prioritized in normal emergency settings or potentially deferred in disaster settings. This technology originally was developed through a joint civilian/military initiative to provide a portable capability for the battlefield or mass casualty situation.⁵⁸ Ultrasound screening of 400 earthquake victims was carried out with a 1% false positive and negative rate after the 1998 Armenian earthquake.⁵⁹ Though we are not aware of the reported use of hand-held ultrasound technology in this capability as yet, this use appears intuitive for the future, especially given the increased concerns for homeland security and disaster management.

The Potential for Extremity Examination in Flight

Although not life threatening, fractures of the long bones quite often are disabling and significantly affect rehabilitation if not addressed properly. Initial experiences have found sonography accurately depicts breaks in the cortical surfaces of the long bones.^{60,62} Portable ultrasound thus can confirm suspected fractures without radiation and also can be used to anatomically realign fractures when they are splinted for flight.

Telemedical Developments

The use of remote experts would greatly simplify the training of flight personnel by obviating the need to interpret sonograms in flight. Nonphysician astronauts in low Earth's orbit aboard the International Space Station have been remotely mentored to acquire meaningful ultrasound images under the direction of ground-based experts.⁶³ Protocols are being refined to allow remote direction of nonexperts by expert sonographers using telephone, internet, or wireless technology.⁶³ If these technologies may benefit the injured or ill astronaut in space, they also may aid terrestrial victims of the same maladies. On Earth, examinations of both healthy volunteers and chronically ill patients using portable hand-held ultrasound have been transmitted using combinations of

wireless and satellite technologies to remote experts.^{64,65}

Three-dimensional ultrasound is another technological advance that has much improved the ability to quantify volumes compared with 2D, especially for irregular-shaped volumes.⁶⁶⁻⁶⁸ The quantification of pleural motion using the color-power Doppler signal simplifies this physiologic process to a single digital measurement. With advances in decision support software, it is conceivable that autonomous diagnoses of increasing blood loss or a significant pneumothorax might even be made in the future.

Conclusion

Trauma ultrasound is becoming an indispensable tool in trauma care. Newer portable devices have the potential to enhance almost every aspect of the physical examination and provide an additional examining sense. As a digital technology, images are transmissible through information technology, supporting archiving, telemedicine, and potentially even remote interpretation.

All ultrasound examinations are very user-dependent, and much remains to be learned regarding the physical limitations of vibration and turbulence on in-flight imaging. As with all ultrasound exams performed by nonexperts, we believe that a positive examination provides extremely important diagnostic and clinical information, whereas negative examinations must be treated with extreme caution and not used as primary determinants of care. We further believe this mode will play a major role in both future trauma care and air medical transportation. Controlled studies to explore this potential should proceed.

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7. And for the first time - a Medical Transport Educator's Track Offering on Thursday, March 17th!

One unique and exciting aspect of this conference is when attendees visit Capital Hill and visit with Senators and Congressmen to rally for the needs of the medical transport community.



New for 2005!

When you register for the AAMS Spring Conference, we will provide you with an extensive "How-To" Guide to help you locate your congressional representatives and make crucial contacts prior to your arrival in the Nation's Capital. Don't be intimidated! Grassroots lobbying is one of the most effective ways to get issues addressed by your representatives! Come, have a presence and make a difference in the air medical community!



2005 AAMS Spring Conference ***"Leadership and Advocacy"***

March 16 - 19th
Hilton Embassy Row
Washington, DC

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