TOPIC HIGHLIGHT

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Portable ultrasonography in mass casualty incidents: The CAVEAT examination

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Abstract

Ultrasonography used by practicing clinicians has been shown to be of utility in the evaluation of time-sensitive and critical illnesses in a range of environments, including pre-hospital triage, emergency department, and critical care settings. The increasing availability of light-weight, robust, user-friendly, and low-cost portable ultrasound equipment is particularly suited for use in the physically and temporally challenging environment of a multiple casualty incident (MCI). Currently established ultrasound applications used to identify potentially lethal thoracic or abdominal conditions offer a base upon which rapid, focused protocols using hand-carried emergency ultrasonography could be developed. Following a detailed review of the current use of portable ultrasonography in military and civilian MCI settings, we propose a protocol for sonographic evaluation of the chest, abdomen, vena cava, and extremities for acute triage. The protocol is two-tiered, based on the urgency and technical difficulty of the sonographic examination. In addition to utilization of well-established bedside abdominal and thoracic sonography applications, this protocol incorporates extremity assessment for long-bone fractures. Studies of the proposed protocol will need to be conducted to determine its utility in simulated and actual MCI settings.

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Key words: Focused Assessment with Sonography in Trauma; Chest, abdomen, vena cava, and extremities for acute triage; Ultrasonography; Disaster; Field triage; Pre-hospital care; Mass casualty incident

INTRODUCTION

Bedside ultrasonography performed by practicing clinicians has gained widespread acceptance over the past two decades[1]. Its use has been described as an adjunct in a wide variety of commonly encountered clinical settings[2-8]. In fact, the use of ultrasonography has been described at almost every tier of emergency and critical care management from field evaluation and triage, to transport, emergency departments, surgical suites, and critical care units[9-18]. Ultrasound has also been shown to be of utility to providers with differing levels of training, background, and clinical focus[19-26]. One of the areas in which its use has been most extensively investigated is Traumatology[27,28]. The Focused Assessment with Sonography in Trauma (FAST) examination has become the standard of care for the diagnosis of post-traumatic pericardial tamponade and intraperitoneal bleeding, which essentially eliminates diagnostic peritoneal lavage from most trauma care protocols[29]. More recently described applications allow emergency personnel to use ultrasound in the diagnosis of chest and extremity trauma, as well as in the evaluation of shock states, particularly intravascular volume depletion[4,30-34].

Mass casualty incidents (MCIs) are unique clinical situations that call for quick and reliable triage of large numbers of injured patients, usually in a setting of severely limited resources[35]. A rapidly deployable, flexible, resource-sparing emergency medical response might be the key element to improve the chance for survival of victims during MCIs[6,36-39]. In MCIs, the ability to identify injured patients who could benefit from early intervention is often undermined by the relative lack of healthcare personnel, a chaotic environment, and the lack of a stable social infrastructure (structural integrity, shelter from the elements, sanitation, electricity, skilled technical personnel)[6,7]. This severely limits the availability of most modern diagnostic tools, especially imaging modalities, because they are resource intensive, and require a high degree of infrastructural integrity[35]. Thus, in an MCI, responders could be forced to rely solely on traditional clinical evaluation based mainly upon the history and physical examination - a relatively time-consuming and often inaccurate approach in this setting[40-43].

Technological advances have made modern ultrasound equipment increasingly portable, robust, easy to use, and inexpensive[44,45]. These advances allow ultrasound to be brought to the patient to obtain diagnostic information in real time[4,46-48]. Clinician-performed ultrasonography obviates the need for specially trained technicians to obtain images, facilities to process and store them, and for specialist physicians to interpret them[4,47]. There is extensive literature that describes the use of ultrasound by clinicians with diverse backgrounds and training who are managing a variety of diseases at all levels of the healthcare system[5,44,49,50]. In addition, a number of reports have described its use in remote, austere, and resource-poor settings, including outer space, high altitudes, areas of extreme poverty, and combat settings[10,21,51-54]. These qualities of ultrasonography make it uniquely suited for deployment in the care of patients in the setting of a MCI.

In this review, we discuss current uses of ultrasound in disaster and MCI settings. We then present the concept of a comprehensive sonographic examination in the evaluation of chest, abdomen, vena cava, and extremities in acute triage (CAVEAT). We conclude with a description of the proposed CAVEAT protocol for the use of ultrasound in civilian and combat disaster casualty triage.

PORTABLE ULTRASONOGRAPHIC TECHNOLOGY

As noted previously, technological advances have increased the clinical utility of ultrasound in a variety of ways. Among these advances is miniaturization[9,55]. Many battery-powered devices with excellent imaging quality and Doppler capabilities weigh less than 5 kg. Several have been designed to meet stringent military specifications for durability. Some models that weigh as little as 500 g have appeared on the market[9,55]. The use of digital hand-held sonographic units allows for early performance of FAST and extended-FAST (E-FAST, incorporating thoracic windows for the assessment of pneumothorax) examinations and can accurately and safely improve the traditional clinical evaluation[56-58]. Portable ultrasound has also been found to be of benefit during ground/aeromedical trauma transport, as well as in forward deployed medical/surgical teams and combat support where it has been reported to be a useful adjunct in the field triage of injured soldiers[9,10,18,59,60].

In MCIs caused by a natural disaster, the deployment of portable ultrasound with its ability to identify life-threatening injuries in the field or in pre-designated staging areas could help to increase triage accuracy, and enhance the efficiency of scarce personnel utilization, patient transport, and directing medical resources to patients who stand to most benefit from these resources[6,17].

Recent technological advances in telesonography could probably extend the usefulness of ultrasonography in MCIs. Recent studies have shown how portable ultrasound images can be safely transmitted for remote viewing by experts[20,21,51,61-63]. With this technology, it might be possible for mobile triage units equipped with portable ultrasound equipment, basic medical supplies, and limited medical training to be deployed to a remote MCI site, to obtain sonographic images for transmission to experts who could interpret them and make decisions about triage, *in situ* treatment, and/or evacuation. Commercial satellite[33] and low-bandwidth internet links[64] have been used to transmit ultrasound images for real-time interpretation, and have also been transmitted from the International Space Station to Earth for interpretation at the Mission Control Center[21].

DISASTER TRIAGE

Disasters that result in large numbers of deaths and injuries

Table 1 Classification of multiple casualty incidents

Natural disasters	Man-made disasters
Causes of large scale physical destruction to manmade objects and infrastructure	Hazardous material incidents and Industrial accidents
Earthquakes	Radiation exposure
Volcanoes	Chemical exposure
Mudslides	Inhalation injury
Avalanches	**Explosive disasters**
Floods	
Tsunami	**Transportation accidents**
Tropical storms, hurricanes, tornadoes	**Aircraft**
	Marine
Climatic	**Railroad**
Extreme heat, cold	**Highway**
Famine	
	War related
Fire related	**Military casualties**
Thermal injury	**Civilian casualties**
Inhalation injury	**Innocent bystanders**
Infrastructure, agriculture, and	**Military targets**
domiciliary damage	Terrorism
	Mass casualty
Epidemics	Bioterrorism
	Genocide
	Major societal dislocations
	and refugee populations
	Malnutrition, epidemics

Disasters that cause gross physical damage (most likely to cause injuries identifiable by ultrasound) are in bold: There can be a certain degree of overlap between the two categories ("gross physical trauma" and "no gross physical trauma"). Detailed history of the incident should be gathered to determine whether "physical trauma" is present alone, in combination with other factors, or not at all.

can be categorized in several ways (Table 1). Ultrasound images provide diagnostic information about anatomical structures, therefore, their utility is primarily in MCI settings with gross physical trauma. However, ultrasound is also of utility in diagnosis and management of secondary conditions such as volume depletion or visceral changes caused by sequelae of some types of MCI (e.g. pleural effusion, pulmonary consolidation, or ascites)[4,5,46,65].

By definition, an MCI is an event in which two or more patients are injured and present with a severity of illness that exceeds the resources of the treatment facility[22,66,67]. This categorization depends solely on an imbalance between patient needs and available resources. Thus, by this definition, the terrorist attack on the World Trade Center in 2001 was not an MCI, because the rescue and hospital resources exceeded the numbers of injured survivors[23]. Triage and medical care during MCIs require a significant deviation from customary medical prioritization in which the goal for each patient is definitive care, with delivery prioritized by severity of illness[6,66,67]. During MCIs, the available medical resources are allocated with the goal of salvaging the greatest number of victims, with the understanding that this will result in the loss of some patients with extreme, complex, and/or resource-intensive injuries[38-40,66]. In such situations, critically ill patients receive lower priority than those with less severe, but more easily treated injuries.

Current disaster triage schemes rely on information obtained by history (medical and mechanistic) and the physical examination to make triage decisions[68,69]. The most commonly used MCI triage classification in the United States involves assignment of patients to one of the four color-coded categories based on his or her vital signs and ability to breathe, talk, and walk (Table 2)[68]. Red category indicates patients who require immediate medical attention and can probably be stabilized and survive with immediate limited interventions. Yellow designation pertains to patients who require medical attention within 1 h. Green indicates patients who are deemed medically non-urgent. Patients who are placed into the black (expectant or dead) category are treated last[41,42,71].

The benefit of such disaster triage classifications is that they can be easily and rapidly applied in adverse circumstances. However, because they are based on somewhat crude clinical parameters, it is likely that they could result in inappropriate triage. Over-triage can be defined as allocation of medical resources for a patient who is eventually found to be without significant injuries[72,73]. Under-triage occurs when a patient does not receive medical resources for injuries that without treatment will lead to deterioration of his or her condition[73]. Both over- and under-triage are difficult to study scientifically in the MCI setting because detailed data and outcomes are difficult to obtain and/or record. One report has identified an over- and under-triage rate of 12% and 4% for trauma patients transported to a major trauma center[74]. In a recent simulation study of FAST ultrasound used as an adjunct to triage using the START (simple triage and rapid treatment) mass casualty system, it was estimated that secondary triage using ultrasound technology might have identified nearly 7% of patients with evidence of delayed hemoperitoneum[37]. Any rapidly and easily deployable tool that could be used to increase the accuracy of triage decisions probably could, for a priori reasons, enhance patient care in the MCI setting.

CIVILIAN DISASTER EXPERIENCE

Despite numerous recent natural MCIs, there is scant literature to describe the specific role of ultrasonography during the medical response to these events[17,36,38]. This might be due to the inherent difficulties of studying any aspect of medical care in the MCI setting, or due to the relative novelty of both clinician-performed ultrasonography and of portable ultrasound equipment[17,18,58]. In one study, ultrasound was performed by relief teams after the 1988 Armenian earthquake as a primary screening procedure in 400 of 750 injured MCI patients admitted to a large hospital within 72 h of the event[17]. The average time spent on evaluation of a single patient was approximately 4 min. Traumatic injuries of the abdomen were detected in 12.8% of the patients, with few false-negative (1%) and no false-positive examinations[17]. In another study, ultrasonography was used after an MCI in Guatemala in which the dead far outnumbered the injured. In that setting, ultrasound was useful for excluding internal trauma, and the

Priority	Need for treatment	Color code	Characteristics
1	Immediate	Red	Life-threatening shock or hypoxia is present or imminent, but the patient can be likely stabilized and will probably survive if given immediate care
2	Urgent	Yellow	Injuries have systemic effects or implications, but the patient is not yet in life-threatening shock or hypoxia. Despite the chance that systemic decline may ensue, this group can likely withstand a 45- to 60-min wait without immediate risk. Patient likely to survive if given appropriate care
3	Non-urgent	Green	Localized injuries without immediate systemic implications. With minimal care, these patients are unlikely to deteriorate for several h (or not at all)
4	Expectant	Black	Most severely injured patients who have poor chance for survival regardless of care rendered. No distinction is made between clinical and biological death. In multiple casualty incidents, any patient who is unresponsive or who has no spontaneous ventilation or circulation is classified as dead

Table 2 Commonly accepted triage coding categories

Modified from[70].

preponderance of conditions identified were concurrent problems that were not directly caused by the physical trauma of the natural disaster (e.g. pregnancy and non-traumatic causes of abdominal pain)[75]. The current consensus seems to support sonographic screening of mass casualties as a quick and effective means for detection of internal evidence of truncal injuries[17,36,38,75].

MILITARY EXPERIENCE

Ultrasound has been utilized in military deployments in Kosovo, Afghanistan and Iraq[59,60,76]. The British Air Assault Surgical Groups deployed to Kuwait during 2003 included the use of a hand-held ultrasound scanner by the forward medical units[76]. FAST examinations performed by trained emergency physicians using portable equipment at a large military combat hospital in Iraq had very high sensitivity (100%), specificity (99%), and negative predictive value (100%), as confirmed by subsequent operative reports and computed tomography (CT) imaging[60]. In that particular experience, ultrasonography was performed in patients who sustained blunt, blast, and penetrating trauma[60].

In a review of the Unites States Army Forward Surgical Team experience, one of the benefits of FAST was in its ability to identify occult blood loss in young, highly conditioned patients whose physiological reserve undermined the reliability of vital signs until late stages of shock[10]. A recent report from the Madigan Army Medical Center in Tacoma (WA, USA) highlights the prospects of utilization of ultrasonography in austere and remote environments for detection and triage of patients with pneumothoraces[50]. The advantages of telesonography are likely to be particularly useful in combat environments, and its use in military settings is under ongoing investigation[20,50,64,77].

PRE-HOSPITAL EXPERIENCE

Effective pre-hospital use of sonography in triage relies on pre-hospital personnel trained in basic ultrasound techniques. Several studies have suggested that non-physicians are able to perform the FAST examination reliably[9,21,49,78]. In one, flight nurses, technologists, emergency physicians and emergency medicine residents were assessed for their ability to evaluate real and simulated patients with the FAST examination under different aeromedical conditions[78]. No significant obstacles in accomplishing sonographic examinations were noted, and the pilots did not report any adverse effect of in-flight sonography on flight safety. Conversely, several studies have suggested that, in 16%-34% of cases during aeromedical transport, significant impediments to ultrasonography could exist due to technological, environmental, or operator problems[9,49,79,80]. In experimental weightlessness simulated *via* parabolic-flight patterns, 80% of images obtained by in-flight sonographers were considered determinate[79]. Similarly, FAST examinations that have been successfully performed by non-physician crew members of the International Space Station under the direction of a ground-based sonographer, suggest that appropriately trained non-physicians could perform guided sonography in remote locations[21].

COMPONENTS OF THE CAVEAT EXAMINATION

In view of the extensive literature that describes the utility of ultrasonography in a variety of austere, remote, and MCI situations, we propose a protocol for the evaluation of the CAVEAT in such settings. The sonographic assessments of each of the four anatomical regions are presented individually, and then an integrated algorithm is suggested.

Chest

Ultrasonographic imaging of the chest allows for the identification of many of the most time-critical internal injuries associated with blunt truncal trauma, including pericardial tamponade, massive hemothorax, pneumothorax, and tension pneumothorax[34,50,81]. Its accuracy in the diagnosis of these conditions might exceed that of plain-film roentgenography, which is not usually available in MCI settings[34,50]. Timely chest sonography probably allows for more rapid triage and performance of life-saving procedures including tube thoracostomy, pericardiocentesis, evacuation, and/or operative intervention for chest injuries[31,82]. In addition to the traditional FAST and E-FAST studies,
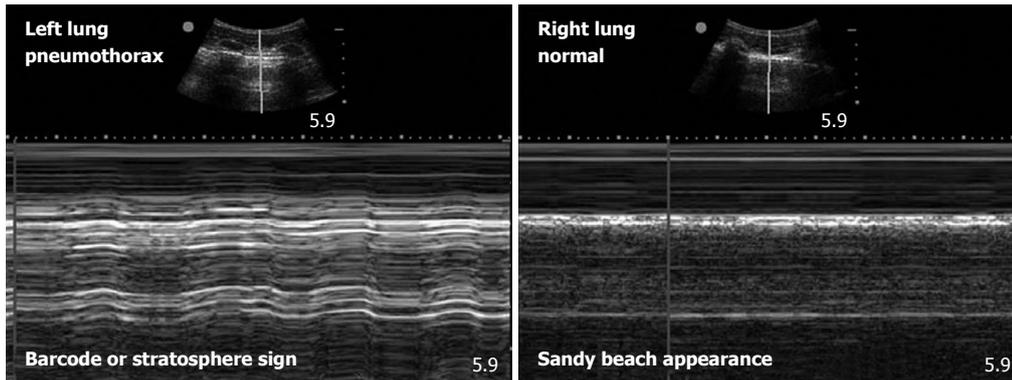
Figure 1 Pneumothorax on bedside ultrasonography. These two images utilize M-mode echography to gather more information on the pleural interfaces seen as a hyperechoic line in the B-mode images above. The M-mode tracings below represent a single line of sight through the B-mode images. Over time, the gray-scale appearance of M-mode images changes with the movement of the tissue. In normal lungs the pleurae slide across each other and this movement takes on a "granular" or "sandy beach" appearance (image on the right). As a result of the lack of pleural sliding in the presence of pneumothorax, a pattern of horizontal striations that do not demonstrate the granular appearance of movement is present. This M-mode pattern that is characteristic of pneumothorax has been described as a "barcode" or the "stratosphere" sign (image on the left).
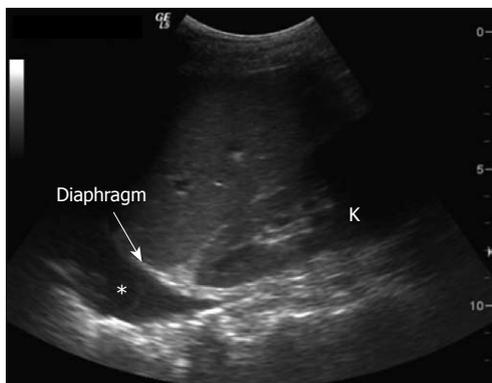

Figure 2 Hemothorax on bedside ultrasonography. Hemothorax can be seen as hypoechoic area (asterisk) above the liver. Of note, movement of the lung within the pleural fluid can often be appreciated during the progression of the respiratory cycle. The kidney (K) and the diaphragm (arrow) can be easily seen, with the wedge of the liver located above.

portable ultrasound technology has also been successfully utilized in diagnosis of traumatic hemothorax[81,83]. In a study of 61 patients with thoracic trauma, the sensitivity of ultrasound examination in detection of hemothorax was 92%, with specificity of 100%[83]. Others have reported successful sonographic visualization of hemothorax, even in the absence of any clinical or roentgenographic findings[84]. Sonographic examples of pneumothorax and hemothorax can be found in Figures 1 and 2, respectively.

Abdomen

The FAST examination is based on the assumption that the majority of clinically significant abdominal injuries result in hemoperitoneum. The standard FAST protocol is directed to detection of fluid in the pericardial and peritoneal spaces. With regard to the CAVEAT protocol, the current section is limited to the discussion of intraperitoneal hemorrhage. Although frequently described in terms of four "windows", the FAST is more accurately conceptualized as the interrogation of the potential spaces where abnormal fluid collections tend to accumulate in a supine patient. Excluding the three spaces in the chest (bilateral pleural spaces and the pericardium), there are a total of seven potential spaces in the peritoneum. The three in the right upper quadrant (from superior to inferior) are the subphrenic, the hepatorenal, and the space around the inferior pole of the kidney (continuous with the hepatorenal space). In the left upper quadrant, the three analogous spaces are: the subphrenic, the splenorenal, and the space around the inferior pole of the kidney (continuous with the splenorenal space). The seventh potential space is in the pelvis (rectouterine in the female; rectovesicular in the male).

The sonographic threshold for detection of hemoperitoneum is subject to dispute. Some studies have shown that as little as 30-70 mL of blood can be detected ultrasonographically[85-87]. Other studies have suggested that a small anechoic stripe in the Morison's pouch represents approximately 250 mL of fluid, while 0.5 and 1 cm stripes represent approximately 500 mL and 1 L of free fluid, respectively[85]. McKenney *et al*[88] have proposed a clinically practical hemoperitoneum score that helps predict the need for abdominal surgical intervention, and appears to be a better predictor of a "positive" laparotomy than initial blood pressure and/or base deficit. To increase the diagnostic yield of FAST, the examination can be performed serially, which allows for reassessment of patients with unanticipated changes of condition, or those who are being managed non-operatively[89-91].

Reported sensitivities for ultrasound in detecting the hemoperitoneum vary, with ranges of 42%-99%[91-95]. On a cautionary note, one study has found that 29% of patients with confirmed abdominal injury had no reported hemoperitoneum on FAST or CT scanning[93]. In another study, 27% of patients with negative FAST required laparotomy for intra-abdominal injuries[95]. Thus, the reliance of hemoperitoneum as the sole indicator of abdominal visceral injury limits the utility of FAST as a diagnostic screening tool in hemodynamically stable patients with blunt abdominal trauma[93,95]. To identify subsets of patients who would most benefit from the FAST examina-

tion, Rozycki *et al*[92] have found that ultrasound was most sensitive and specific in patients with penetrating chest wounds or in hypotensive blunt abdominal trauma patients (sensitivity and specificity nearly 100%).

Although CT imaging is optimal for stable patients with potential internal injury after trauma, this resource is rarely available in the MCI setting. In such situations, stable patients with a negative FAST examination should receive ongoing observation, serial abdominal examinations, and repeat FAST examination, tailored to available resources. Injuries that are commonly associated with false-negative FAST include retroperitoneal hemorrhage and hollow viscus perforation[96]. Few false-negative results have been reported with significant intraperitoneal bleeding[93,95,97]. Diagnostic options available in this situation include repeat FAST, diagnostic peritoneal lavage, laparoscopy, exploratory laparotomy, and CT, although of these, only the serial FAST is likely to be available in the setting of MCI[98].

EVALUATION OF INTRAVASCULAR VOLUME BY INFERIOR VENA CAVA ASSESSMENT

Intravascular volume status can be estimated by evaluation of the inferior vena cava (IVC). The vessel is usually evaluated in real-time in both the longitudinal and transverse planes. As a component of the CAVEAT examination, sonographic IVC evaluation is most probably directed towards the rapid identification of hypovolemia, which, with experience, can be quickly and effectively accomplished by a purely qualitative assessment of the size, shape, and collapsibility of the vessel. If measurements are made, they should be obtained in diastole (*i.e.* the moment when the IVC is smallest in the cardiac beat-to-beat cycle), and taken just inferior (1-3 cm) to the junction of the hepatic veins (Figure 3). The traditional window has been subxiphoid, although recent reports have suggested that equivalent results can be obtained using a right intercostal view with the liver as a sonographic window[99,100]. This approach is especially useful if the subxiphoid window is obstructed by bowel gas or dressings[101]. Longitudinal and transverse planes are equivalent for measurement of the IVC[102]; however, each has mutually complementary advantages and disadvantages, so the IVC should be assessed in both planes.

An extensive body of literature describes a relationship between the sonographic appearance of the IVC and intravascular volume and cardiac filling pressures[5,33,65,103-105]. Assessment of the IVC might be made qualitatively (shape), and quantitatively (absolute size and collapse index). There is strong evidence that, in any given patient, increasing intravascular volume results in an expanding IVC diameter and a diminution of the percentage variation in diameter related to the respiratory cycle (*i.e.* the IVC collapsibility index, Figure 3). Decreasing intravascular volume will have the opposite effects[33,65,103,106]. A wide range of normal and abnormal values for these parameters has been
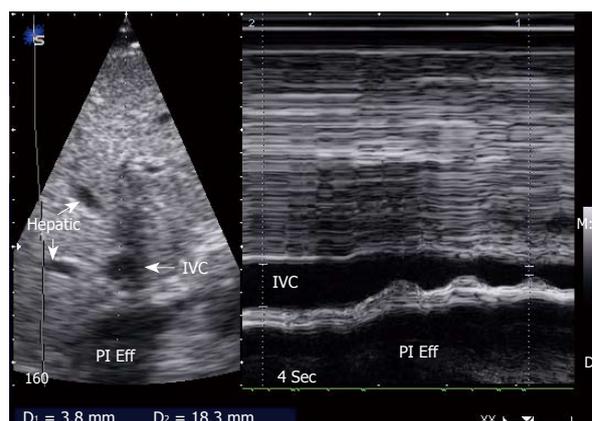

Figure 3 Inferior vena cava collapsibility index can be obtained from measurements of end-expiratory and end-inspiratory vena cava diameters. The inferior vena cava collapsibility index (IVCCI) can be derived by subtracting the end-expiratory IVC diameter (IVC$_{exp}$) from end-inspiratory IVC diameter (IVC$_{insp}$), and the dividing the difference by IVC$_{insp}$. The resultant fraction is then multiplied by 100% to produce a percentage IVC collapse. In this example, the IVCCI is [(18.3-3.8)/18.3] × 100% = 79.2%, which indicates hypovolemia. Pl Eff: Pleural effusion.

reported[33,107]. This is consistent with the role of the IVC as a capacitance vessel. Volume overload states are unlikely to be of concern in the MCI setting, and the key question to be answered in evaluation of the IVC is whether the vessel demonstrates adequate intravascular volume or not. Thus, the basic sonographic skill to be mastered by the sonographer who performs the CAVEAT examination is accurate identification of the vessel, and familiarity with the spectrum of IVC findings in normovolemic patients, to recognize the presence of a grossly collapsed or underfilled VC. If measurements are made, an adequate central venous pressure (CVP) can be predicted by an inspiratory IVC diameter > 10-12 mm, whereas an IVC diameter < 5 mm suggests abnormally low CVP[65]. Of note, IVC diameters in most normovolemic patients vary between 10 and 20 mm. Although the sensitivity and specificity of IVC assessment for estimation of intravascular volume are still poorly defined, an IVC collapsibility index of > 60%-70% predicts hypovolemia and helps identify patients who are likely to respond to intravascular volume expansion[4]. Finally, the correlation between IVC characteristics and vital signs traditionally used in triage (heart rate and blood pressure) is poor (our unpublished observations), which highlights the clinical challenges associated with failure to identify early compensated hypovolemic/hemorrhagic shock by heart-rate- or blood-pressure-based criteria. According to recent studies, bedside assessment of the IVC typically requires < 5 min[4,5,46].

Extremities

Ultrasonography has been used to identify fractures of the femur, humerus and ribs[18,31,32,108]. In a prospective study of 158 examinations performed on 95 patients, 94% of patients with extremity injuries were accurately identified, with no false-positive results[31]. Portable ultrasound is more accurate in the recognition of fractures in midshaft locations and less so in the metacarpal and
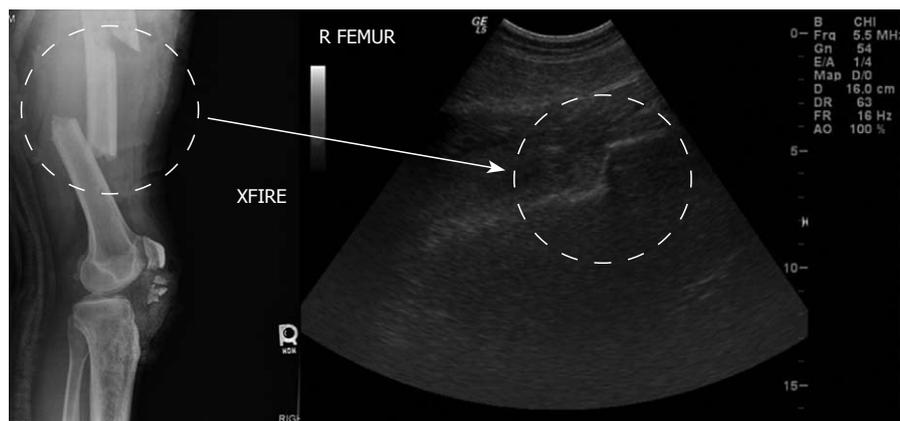
Figure 4 Bedside sonographic appearance of a displaced femoral fracture. A correlation to plain radiography is shown. Bedside sonography provides a viable tool for quick and reliable assessment of suspected long-bone fractures. R FEMUR: Right femur; XFIRE: Cross table film.

Table 3 The chest, abdomen, vena cava, and extremities for acute triage protocol summary

Description	Identification of immediately and potentially life-threatening injuries (FAST + pneumothorax)	Intravascular status evaluation (IVCCI)	Hemothorax assessment	Extremity assessment (lower → upper extremity sonography)
Skill level	Easy	Intermediate		Difficult
Urgency	Primary triage & assessment (Mandatory)	Secondary triage & assessment (Optional)		

The protocol is divided into two-tiered system of urgency (primary and secondary) and three skill levels (basic, intermediate, and advanced). Note that the chest, abdomen, vena cava, and extremities for acute triage examination can be performed after the primary survey, with the serial assessment performed, as indicated at a later time. FAST: Focused Assessment with Sonography in Trauma; IVCCI: Inferior vena cava collapsibility index.

metatarsal anatomical areas[59]. Ultrasonography can also demonstrate occult fractures that are not readily identifiable by traditional radiography[109,110]. Rapid ultrasound assessment of the extremities as a component of the CAVEAT examination is likely to result in more accurate reduction and stabilization of major fractures, prioritized utilization of radiographic resources, and more accurate triage of multiply injured patients[18,111]. Of note, extremity assessment should be considered an optional part of the sonographic assessment paradigm and should be utilized mainly as a secondary (versus initial/primary) triage tool. Figure 4 demonstrates the appearance of a midshaft, displaced femoral fracture, along with correlation to plain extremity radiograph.

CAVEAT protocol

The CAVEAT protocol is an integrated sonographic survey to be used as an adjunct in disaster and combat care triage and diagnosis. The suggested order of the component parts of the ultrasound examination are listed in rough order of clinical priority of diagnosis and by required skill level (Table 3). With increasing skill, the sonologist will be able to deviate from this suggested order based on the individual patient's injuries[112]. The authors anticipate that the completion of the entire CAVEAT protocol by a proficient sonologist will take approximately 5 min longer than the performance of the traditional FAST examination. Additional time might be spent, at the discretion of the sonographer, during the secondary triage assessment. However, such secondary examinations (including detailed extremity scans) are optional and based on resource/time availability.

The examination begins with a sonographic evalua-

tion of the pleura to identify the presence of pneumothorax. The examiner then performs a complete FAST examination, to include assessment of the costophrenic recesses bilaterally for identification of hemothorax. After the FAST examination, the IVC is assessed to determine gross perturbations of intravascular volume; in particular, volume depletion (see previous section). The theoretical possibility of identifying retroperitoneal injuries with sonographic contrast material is not practical in the MCI setting[113]. The CAVEAT examination concludes with an ultrasound examination of the long bones, with particular attention to regions of pain, tenderness, or deformity. Of note, the extremity assessment is not mandatory, and has been included in the proposed protocol mainly as an adjunct to secondary patient assessment (Table 3). In this role, extremity sonography could be performed as a secondary triage tool at a later time to help direct appropriate resources to orthopedic injuries that are not immediately life threatening but require prompt attention, and might be otherwise undetected in a resource-limited environment.

LIMITATIONS AND NEED FOR FURTHER STUDIES

The CAVEAT examination will not detect most intracranial, pulmonary, retroperitoneal, or pelvic injuries. Except in the hands of the most experienced sonologists, it will miss most solid organ and great vessel injuries that do not cause frank internal hemorrhage. Although the benefit of the CAVEAT protocol is yet to be established, as this review suggests, there is extensive scientific literature to

support the utility of its component parts. Studies are needed within the pre-hospital and emergency department environments to establish the feasibility of the CAVEAT protocol, and whether the addition of sonographic information improves triage accuracy. A significant potential impediment to the CAVEAT protocol, shared with other applications of clinician-performed ultrasonography, is the need for sonologist training. It is hoped that as ultrasonography is incorporated in both undergraduate and graduate medical training, care providers in MCI settings will increasingly possess the skills needed for the CAVEAT examination.

CONCLUSION

Ultrasonography has a wide range of applications in diagnostic imaging and procedural guidance, without the deleterious effects of ionizing radiation. Recent technological advances have resulted in increasingly affordable, robust, portable, and user-friendly equipment. Many modern ultrasound units are battery-powered, and store images digitally, which allows for electronic and/or wireless data transfer. These advances make ultrasound increasingly suited to the rapid evaluation of the critically ill, particularly in remote, austere, and resource-poor settings. We have reviewed applications of portable ultrasonography in military and civilian mass casualty settings. Similar to other algorithms for the use of ultrasound in the assessment of the critically ill, the CAVEAT protocol seeks to integrate diverse uses of ultrasonography in a systematic coordinated way. The CAVEAT protocol proposes a graduated approach based on a combination of urgency, sonographic skill-sets, and technical difficulty of the examination.

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