Screening Ultrasound in Blunt Abdominal Trauma
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J Intensive Care Med 2003 18: 253
DOI: 10.1177/0885066603256103
The online version of this article can be found at: http://jic.sagepub.com/content/18/5/253
Ultrasound is used worldwide to evaluate patients with blunt abdominal trauma. Sometimes referred to as an extension of the physical exam, ultrasound can rapidly help distinguish patients with injury requiring computerized tomography (CT) or surgery (typically 5%-10%) from those with no abdominal injury (>90%). Ultrasound has several advantages in the setting of trauma. It is portable, integrates easily into the resuscitation of trauma victims without causing delay in therapy, is noninvasive, and has no associated morbidity. Limitations of ultrasound include its dependence on operator skill and technique, poor image quality in patients with morbid obesity or extensive subcutaneous gas, limited visualization of the retroperitoneum, and less reliable localization of visceral injury compared to CT. Successful use of abdominal ultrasound in the setting of trauma can be maximized with adequate sonographer training, appreciation of technical limitations, and adherence to an appropriate trauma ultrasound protocol.

Key words: ultrasound, trauma, abdomen, injury, diagnosis

The rapid detection of abdominal injury is among the most important goals of trauma care. Prompt recognition of injuries requiring laparotomy can greatly decrease preventable deaths in trauma victims. Before the advent of current diagnostic modalities for evaluation of the abdomen, as many as 17% of patients died from undetected abdominal injury [1]. Physical exam is known to be unreliable, particularly in patients with head injury, decreased sensorium, or significant concomitant thoracic or orthopedic injuries [1,2]. In 1971, Olsen and Hildreth [3] reported a clinical accuracy as low as 42%, underscoring the need for more objective means of evaluation.

Diagnostic Peritoneal Lavage

In 1965, Root et al [4] introduced diagnostic peritoneal lavage (DPL), a simple, inexpensive, reliable procedure for detecting hemoperitoneum. Shortly thereafter, DPL became the primary diagnostic tool for objective evaluation of the abdomen after blunt trauma, and it remained so for the next 20 years. Investigators have reported high accuracy (97%-99%) with a low complication rate of 1% to 2% [5,6]. However, DPL has several relative contraindications, including coagulopathy, prior abdominal surgery, morbid obesity, and third-trimester pregnancy. Moreover, although DPL is highly sensitive and specific for the presence of hemoperitoneum, it is less specific for determining the need for intervention. Positive tests can lead to nontherapeutic laparotomy, and significant parenchymal and retroperitoneal injuries may exist despite negative results.

Computed Tomography

In the early 1980s, computed tomography (CT) became widely available for the evaluation of abdominal trauma. CT was associated with a decrease in nontherapeutic laparotomies performed in trauma patients [7,8]. Furthermore, CT provided the first means of defining the location and extent of injury, making nonoperative management feasible for many patients. Although CT is extremely accurate, it requires patient transportation that may not be suitable for unstable patients. Because of the associated radiation, CT is used
with caution in children and pregnant women. Finally, the use of intravenous contrast poses a small but real risk of allergic reaction and nephrotoxicity.

Ultrasound

Ultrasound has been used in Europe to evaluate abdominal trauma for many years. In 1971, Kristen-sen et al [9] reported a case of splenic injury detected by ultrasound. Several reports of sonographic detection of abdominal injuries followed. In the first prospective American study, published by Tso et al [10] in 1992, ultrasound exams were performed by trauma fellows after 2 hours of training. Ultrasound was found to be 91% sensitive for hemoperitoneum. In the past decade, the use of ultrasound in trauma has increased in the United States. Many studies have now been published, and there is great variability in the reported technique and diagnostic performance of ultrasound. Table 1 summarizes the results of a representative sampling of studies published over the past decade [11-18].

After examining more than 4000 trauma patients with abdominal ultrasound, we have found ultrasound to be an effective screening test for abdominal trauma. Ultrasound is safe, rapid, and easily repeated, and it may be less expensive than CT for screening trauma patients. Ultrasound is also portable; it can be used in the trauma suite or operating room for unstable patients, without interrupting resuscitative measures. The present review addresses the technique, interpretation, limitations and pitfalls, appropriate utilization, and potential future role of abdominal ultrasound in the setting of trauma.

Ultrasound Technique in Abdominal Trauma

Review of the literature reveals that ultrasound technique varies widely among practitioners. The examination may be performed by a surgeon, radiologist, registered sonographer, or emergency physician. According to most early reports of ultrasound in trauma, exams were performed by surgeons and were based solely on the detection of intraperitoneal fluid in one or more regions of the abdomen. In 1993, Jehle et al [19] described 44 patients with blunt abdominal trauma in whom ultrasound was performed by emergency physicians after 2 weeks of training. The exam consisted of a single view of Morison’s pouch. Other investigators performed a more detailed exam, most commonly a survey for fluid. This survey includes the right and left upper quadrants, the paracolic gutters, and the pelvis [20,21]. This surgeon-performed ultrasound technique is referred to as focused abdominal sonography for trauma (FAST) and is currently used in several trauma centers.

Although the primary goal of ultrasound in abdominal trauma is the detection of hemoperitoneum, some examiners evaluate organ parenchyma in addition to screening for fluid because abdominal injury can occur without hemoperitoneum. In a 1997 study, Chui et al [22] found that 29% of patients with abdominal injuries had no hemoperitoneum. Surgeon-performed FAST was interpreted as negative in all of these patients. In a subsequent study by Shanmuganathan et al [23], 34% of abdominal injuries from blunt trauma had no hemoperitoneum at CT. All patients without hemoperitoneum on CT who underwent FAST had negative studies because the examiners considered only free fluid to be a positive finding. Consideration of findings other than free fluid may increase sensitivity. In 2001, Brown et al [24] found that 26% (45/172) of patients with abdominal injury who underwent screening ultrasound had no hemoperitoneum at CT. All patients without hemoperitoneum on CT who underwent FAST had negative studies because the examiners considered only free fluid to be a positive finding. Consideration of findings other than free fluid may increase sensitivity. In 2001, Brown et al [24] found that 26% (45/172) of patients with abdominal injury who underwent screening ultrasound had no hemoperitoneum. In that study, screening ultrasound was performed by experienced sonographers and included evaluation of organ parenchyma. Of the 45 injured patients without hemoperitoneum, 19 had positive screening ultrasound due to findings other than free fluid. The overall sensitivity of ultrasound was 84%, but if ultrasound had been used to screen for fluid alone, sensitivity would have decreased to 65% for detecting abdominal injury.

At our institution, ultrasound examinations are performed by experienced sonographers and routinely include a survey for fluid in the following regions: the pericardium, epigastrium, upper quad-

Table 1. Ultrasound Detection of Abdominal Injury [11-18]

<table>
<thead>
<tr>
<th>Number of Subjects</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffman et al 1992</td>
<td>291</td>
<td>89</td>
</tr>
<tr>
<td>McKenney et al 1996</td>
<td>1000</td>
<td>88</td>
</tr>
<tr>
<td>Healy et al 1996</td>
<td>796</td>
<td>88.2</td>
</tr>
<tr>
<td>Yoshii et al 1998</td>
<td>1239</td>
<td>94.6</td>
</tr>
<tr>
<td>Rozycki et al 1998</td>
<td>1540</td>
<td>83.3</td>
</tr>
<tr>
<td>Bode et al 1999</td>
<td>1671</td>
<td>88</td>
</tr>
<tr>
<td>Brown et al 2001</td>
<td>2693</td>
<td>84</td>
</tr>
<tr>
<td>Richards et al 2002</td>
<td>3264</td>
<td>67</td>
</tr>
</tbody>
</table>
Ultrasound Findings in Abdominal Trauma

Free Fluid

The utility of ultrasound in blunt abdominal trauma is based on the detection of hemoperitoneum. Most hemoperitoneum appears black, similar to other fluids. It is well depicted and easily recognized using ultrasound (Figure 1). Hemoperitoneum is commonly the only indication of injury on ultrasound, and its presence requires further evaluation. When using ultrasound as a screening test to help triage patients to laparotomy, CT, or observation, it is of primary import to recognize the presence, not necessarily the source, of bleeding. Although the site of injury may not be visible with ultrasound, the pattern of fluid and the number of fluid pockets can help predict the location and severity of injury.

Fluid Pattern

Sirlin et al [25] reported patterns of fluid accumulation observed in patients with specific injuries. For example, in patients with splenic injury, fluid accumulates in the left upper quadrant, in both upper quadrants, or diffusely throughout the abdomen. Hepatic injuries are associated with fluid in the right upper quadrant and lower recesses but not in the left upper quadrant. Recognition of these fluid patterns may help expedite appropriate therapy in unstable patients.

Fluid Scoring

Although the pattern of fluid accumulation may suggest the site of injury, the number of fluid pockets predicts the likelihood and severity of injury as well as the need for laparotomy. Sirlin et al [26] developed a simple scoring system from 0 to 4 depending on the number of fluid pockets found on screening ultrasound. Of the patients with no fluid, 1% had injury; of those with 1 pocket of fluid, 59% had injury; of those with 2 pockets, 83% had injury; and of those with 4 or more pockets, 93% had injury. The number of injuries requiring surgery and injuries causing death also increased significantly with the number of fluid pockets in the abdomen.

Using a more complex scoring system, McKenney at al [27] found that the hemoperitoneum score accurately predicts the need for laparotomy in trauma patients. In 100 trauma patients who had ultrasound positive for hemoperitoneum, fluid score was a better predictor of therapeutic laparotomy than initial blood pressure or base deficit.

Nontraumatic Fluid

Patients with abdominal fluid that is not traumatic (eg, ascites or peritoneal dialysate) typically require evaluation with CT because ultrasound cannot always distinguish blood from other fluid. Women of reproductive age normally have small amounts of fluid in the cul-de-sac. Early in our experience, we found interpretation of pelvic fluid in these women to be problematic in the setting of trauma. Sirlin et al [28] reviewed 1047 female trauma patients of reproductive age. Fluid limited to the cul-de-sac and paraovarian recesses was not associated with injury, but fluid in any other location...
was highly associated with injury. Physiologic fluid alone does not require further evaluation with CT.

Complex Fluid

Although simple fluid is easily recognized at ultrasound as an anechoic area, hemoperitoneum often presents as complex fluid, which may be intermediate in echotexture or even hyperechoic. Initially after traumatic injury, blood is hypoechoic. As coagulation occurs, the hematoma becomes echogenic. As clot lyases, blood products become sonolucent again. Because hematoma may be similar in echotexture to adjacent parenchyma, fluid screen alone may miss this stage of hemorrhage. Moreover, the echogenic hematoma is likely to be at the site of injury, whereas anechoic lysed blood, if present, may be remote from the injury (Figure 2). This ultrasound finding has been described by Sirlin et al [29] as analogous to the CT “sentinel clot,” which is an acute high-attenuation hemorrhage indicating the site of injury in patients who may have diffuse hemoperitoneum [30].

Parenchymal Findings

In addition to hemoperitoneum, parenchymal findings may herald injury. Because as many as 34% of injuries occur without hemoperitoneum [23], it is important to recognize traumatic parenchymal abnormalities. Moreover, in hemodynamically unstable patients with positive ultrasound, parenchymal findings can be helpful in revealing the site of injury prior to emergent laparotomy.
Lacerations may appear as a contour irregularity or hyper- or hypoechoic regions within the viscer- al organ. Richards et al [31-33] have found that the ultrasound appearance of parenchymal injury depends on the injured organ. Splenic injuries are most commonly seen as a diffuse heterogeneous pattern [31], but liver injury is more likely to appear as a focal hyperechoic lesion [32], with or without hemoperitoneum (Figure 3). Retroperitoneal injuries frequently cause no hemoperitoneum; adrenal injury may present only as a mass or collection above the kidney, and renal injury may appear only as a focal lesion or as heterogeneity of the renal parenchyma. Severe renal injuries tend to cause a disorganized pattern replacing normal kid- ney in the renal fossa [33].

Even with attention to organ parenchyma, however, some parenchymal injuries are difficult to visualize with ultrasound because the acute laceration or hematoma may be isoechoic [24]. A traumatic pseudo-aneurysm may appear as an anechoic mass within an organ, similar to a cyst. These lesions are easily differentiated using Doppler to demonstrate flow within the pseudo-aneurysm. This type of injury emphasizes the importance of using modern equipment with Doppler capabilities when performing ultrasound for abdominal trauma. Detection of parenchymal injury may also be improved by using a higher frequency probe. Stengel et al [34] found better detection with a 7.5-MHz linear array probe compared to a 3.5-MHz convex probe. Development of ultrasound contrast agents may facilitate the detection of parenchymal injury with ultrasound, similar to intravenous iodinated contrast used for CT.

**Limitations and Pitfalls of Ultrasound in Abdominal Trauma**

**False-Negative Ultrasound**

Ultrasound is of limited value in patients with morbid obesity or severe subcutaneous emphysema. Without a full bladder to provide an acoustic window, hemoperitoneum in the pelvis can be missed [35]. Another potential limitation of ultrasound is its operator dependency, which limits reliability when performed by those with relatively little experience. Although sensitive to hemoperitoneum, ultrasound is insensitive to certain types of injury, including retroperitoneal injury, bowel or mesenteric injury, and any injury occurring without hemoperitoneum. In our experience, ultrasound missed 31% of isolated retroperitoneal injuries, 14% of bowel or mesenteric injuries, and 58% of injuries not associated with hemoperitoneum [17].

**False-Positive Ultrasound**

In addition to potential false-negative studies due to the above limitations, certain nontraumatic findings may lead to false-positive studies. Awareness of specific pitfalls can help limit false-positive results and avoid unnecessary follow-up tests. We have found that fluid-filled bowel, especially stom-
ach, can mimic free fluid on ultrasound. If the examiner is unsure, the stomach can be identified by injecting air or fluid through a nasogastric tube under real-time ultrasound observation. A slip of diaphragm may be hypoechoic, similar to perisplenic or perihepatic fluid. Physiologic pelvic fluid in women can be misinterpreted as hemoperitoneum. Parenchymal lesions such as hemangiomas or metastases may be indistinguishable from lacerations and hematomas. An adrenal adenoma may appear as an echogenic mass, identical to hemorrhage. Abdominal fat can be confused with hematoma due to unusual echotexture and configuration. Simple cysts can usually be identified with confidence on ultrasound, but if poorly visualized for technical reasons, a cyst may also mimic free fluid or a traumatic fluid collection. With experience, many pitfalls can be avoided, but some lesions have a nonspecific ultrasound appearance, and CT may be necessary to confidently exclude injury.

Utilization of Ultrasound in Abdominal Trauma

Clinical Algorithm

Several authors have suggested algorithms for the use of ultrasound in patients with abdominal trauma, and most are quite similar. Figure 4 describes the algorithm used at our institution. Because ultrasound is a screening exam, we attempt to maximize sensitivity. Sensitivity is optimized by using only experienced personnel and current equipment, by evaluating organ parenchyma and filling the bladder when indicated, and by pursuing any questionable finding with CT, repeat ultrasound, or DPL. Limitations of the exam must be recognized; retroperitoneal and enteric injuries are difficult to detect with ultrasound. Results must be considered together with all clinical data. A negative ultrasound should not discourage CT if there is unexplained hypotension, decreasing hematocrit, suspicion of retroperitoneal injury (gross hematuria, fractures of the pelvis or spine), or suspicion of enteric injury (persistent or increasing abdominal pain). However, we have found that most trauma patients with negative screening ultrasound require no further tests to exclude abdominal injury. In our experience, 93% of patients with negative screening ultrasound required no further tests, and CT was avoided in these patients [36]. Of patients with false-negative screening ultrasound, 89% had injuries identified within 24 hours. In these patients, further evaluation of the abdomen was performed for clinical indications such as pain, hematuria, hypotension, and decreasing hematocrit. A trauma protocol involving screening abdominal ultrasound should include a period of clinical observation.

Hemodynamically Unstable Patients

Ultrasound plays a particularly important role in the management of hemodynamically unstable patients. These patients frequently cannot undergo transportation to CT. Ultrasound can detect hemothorax rapidly, often within minutes of the patient’s arrival, allowing the surgeon to determine immediately if the patient requires laparotomy. Sirlin et al [37] reviewed 108 patients with systolic blood pressure below 90 mmHg on admission or during resuscitation. Ultrasound was positive in all patients requiring laparotomy and had an overall sensitivity of 89% for detecting injury.

Pregnant Patients

Another population of patients uniquely suited to ultrasound is pregnant women. Pregnancy is a relative contraindication to DPL, and CT is avoided if possible in pregnant patients because of potential teratogenic effects of radiation. In our experience, the use of ultrasound successfully prevented CT in 93% (74/80) of pregnant trauma victims who were felt to require objective evaluation of the abdomen [38].
Cost Considerations

Other factors that influence the use of ultrasound in trauma depend on the individual trauma center. The physical layout of the emergency department, radiology department, and trauma resuscitation area will determine ease of transport to CT. The availability of equipment, technologists, or adequate training for surgeons may affect the use of ultrasound. Cost is an increasingly important factor in all hospital environments, and further investigation is needed to determine whether screening ultrasound is more cost-effective than CT. There are numerous indications for objective evaluation of the abdomen, and typically only 5% to 10% of those evaluated in a busy trauma center will have abdominal injuries. Intuitively, it seems that ultrasound would be cost-effective if only a fraction of those CT exams could be avoided. McKenney et al [39] found that efficient use of ultrasound in a trauma protocol can result in significant cost savings, primarily due to decreased use of CT and DPL.

Future Directions of Ultrasound in Abdominal Trauma

As technology rapidly advances, the role of ultrasound in abdominal trauma will evolve. Ultrasound contrast agents will soon be widely available, and these media may increase sensitivity of ultrasound for detecting parenchymal injuries. Small handheld ultrasound machines will enable paramedics to use ultrasound in the field as a tool for patient triage. With recent advances in multidetector-row CT, all but the most unstable trauma patients may soon undergo full-body CT as a routine part of the trauma protocol. As a result, although ultrasound remains the study of choice in parts of the world where CT is less available, the use of ultrasound in the United States may focus on unstable patients, pregnant women, and prehospital evaluation of abdominal trauma. In addition, ultrasound would be an excellent screening tool for large numbers of patients in the setting of mass trauma due to natural catastrophe or terrorist attack.

Conclusions

When used in the proper clinical setting, ultrasound is a safe, rapid, and portable means of evaluating the abdomen in patients with blunt trauma. To be used to its full advantage, ultrasound should be performed by experienced examiners trained to identify more than just free fluid. The limitations and pitfalls of ultrasound must be appreciated, and imaging with CT should be performed in stable patients with indeterminate or positive ultrasound. After negative ultrasound, patients should undergo a period of clinical observation; further investigation is required should suspicion of abdominal injury arise. As with any diagnostic test, ultrasound results must be interpreted in conjunction with all clinical data to guide appropriate management decisions. Although clinical algorithms may change in the future, ultrasound will likely maintain a significant role in the evaluation of abdominal trauma.

References

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