Blunt Abdominal Trauma: Diagnostic Performance of Contrast-enhanced US in Children—Initial Experience

To prospectively compare the sensitivity and specificity of ultrasonography (US) with those of contrast material–enhanced US in the depiction of solid organ injuries in children with blunt abdominal trauma, with contrast-enhanced computed tomography (CT) as the reference standard.

The study protocol was approved by the ethics board, and written informed consent was obtained from parents. US, contrast-enhanced US, and contrast-enhanced CT were performed in 27 consecutive children (19 boys, eight girls; mean age, 8.9 years ± 2.8 [standard deviation]) with blunt abdominal trauma to determine if solid abdominal organ injuries were present. Sensitivity, specificity, agreement, accuracy, number of lesions correctly identified, and positive and negative predictive values were determined for US and contrast-enhanced US, as compared with contrast-enhanced CT.

In 15 patients, contrast-enhanced CT findings were negative. Contrast-enhanced CT depicted 14 solid organ injuries in 12 patients. Lesions were in the spleen (n = 7), liver (n = 4), right kidney (n = 1), right adrenal gland (n = 1), and pancreas (n = 1). Contrast-enhanced US depicted 13 of the 14 lesions in 12 patients with positive contrast-enhanced CT findings and no lesions in the patients with negative contrast-enhanced CT findings. Unenhanced US depicted free fluid in two of 15 patients with negative contrast-enhanced CT findings and free fluid, parenchymal lesions, or both in eight of 12 patients with positive contrast-enhanced CT findings. Overall, the diagnostic performance of contrast-enhanced US was better than that of US, as sensitivity, specificity, and positive and negative predictive values were 92.2%, 100%, 100%, and 93.8%, respectively.

Contrast-enhanced US was almost as accurate as contrast-enhanced CT in depicting solid organ injuries in children.

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Ultrasoundography (US) has been shown to be a cost-effective modality in the evaluation of blunt abdominal trauma in children (1–8). This modality is widely accepted in Europe, and it is becoming more widely accepted in the United States as a triage tool in patients with blunt abdominal trauma whose condition is unstable (9,10). However, US is not a reliable screening tool in the evaluation of hemodynamically stable children with blunt abdominal trauma since the lack of free intraperitoneal fluid on US images does not necessarily enable serious organ injuries to be excluded (11–15).

In two pediatric series involving children with blunt abdominal trauma, 34%–37% of patients with computed tomography (CT)-proved injuries did not have free fluid at CT or US (11,15). In several studies, US was found to be specific but only moderately sensitive, and the use of special US contrast agents was reported to enhance parenchymal abnormalities in the emergency setting (5,16).

The findings of studies have shown that contrast-enhanced US is almost as sensitive as CT in the detection of traumatic abdominal organ injuries and that contrast-enhanced US can be a useful tool in the assessment of trauma (17–22). Thus, the purpose of our study was to prospectively compare the sensitivity and specificity of US with those of contrast-enhanced US in the depiction of solid organ injuries in children with blunt abdominal trauma, with contrast-enhanced CT as the reference standard.

Patients

This study was conducted at a large university hospital in northern Italy that serves as a regional center for pediatric trauma. A total of 108 consecutive children (60 boys, 48 girls; mean age, 8.1 years ± 3.3 [standard deviation]; age range, 2–13 years) who presented to the emergency department between September 2003 and August 2006 were suspected of having acute blunt abdominal trauma and were prospectively evaluated for study eligibility.

When patients arrived in the emergency department, they underwent vital sign recording, laboratory tests, and standardized US to detect free abdominal fluid as part of a routine trauma protocol. Five patients with US-proved hemoperitoneum and unstable vital signs (Glasgow coma scale score ≤ 14, pulse < 60 beats per minute or > 100 beats per minute, systolic blood pressure < 90 mm Hg after a 2-L crystalloid fluid challenge, respiratory rate < 24 breaths per minute, poor gas exchange with oxygen saturation < 90%, inability to talk, and severe pain) were immediately referred to surgery and were excluded from the study. Seventy-six patients with a minor injury according to the Abbreviated Injury Scale (23) and negative US findings, normal hematocrit levels, and normal hepatic and pancreatic enzyme levels were discharged after 12–24 hours of observation without undergoing further abdominal imaging.

Twenty-seven hemodynamically stable patients (19 boys, eight girls; mean age, 8.9 years ± 2.8; age range, 4–13 years) with moderate or severe injuries according to the Abbreviated Injury Scale and with or without abnormal laboratory test results, positive US findings, or both were evaluated with contrast-enhanced US and CT. Blunt abdominal trauma stemmed from a fall from a bicycle (n = 15 [56%]), involvement in a car crash as a passenger (n = 5 [18%]), a school accident (n = 4 [15%]), or being struck by a car as a pedestrian (n = 3 [11%]).

The main vital signs (blood pressure, heart and pulmonary rates, and percentage of oxygen saturation in the blood) and the results of biochemical liver and kidney laboratory tests (transaminase and creatinine levels) were recorded to evaluate any adverse effects due to contrast agent administration.

Each imaging technique was performed by the same individual who later interpreted the results. One sonologist (C.S., 13 years of experience) performed US, another sonologist (M.V., 14 years of experience) performed contrast-enhanced US, and a radiologist (L.B., 22 years of experience) performed contrast-enhanced CT. The operators were blinded to the results of the other examinations.

US and Contrast-enhanced US

Two US scanners (ATL HDI 5000, release 10.4; Philips, Bothell, Wash) equipped with a 5–2-MHz curved-array probe and contrast-specific software that operated in real time at a low mechanical index (pulse inversion technology) were used. The tissue harmonic imaging mode was used to maximize the diagnostic effectiveness of baseline US. US examinations, which were performed to detect free fluid, consisted of evaluation of the (a) right upper quadrant, including the hepatorenal fossa and the pleural space; (b) left upper...
quadrant, including the perisplenic region and the pleural space; (c) epigastrium, including the pericardial space; (d) right and left paracolic gutters; and (e) pelvis.

In all patients, a complete study of the entirety of the abdominal parenchyma was performed. US findings were considered positive when free fluid or parenchymal lesions were detected. A parenchymal lesion was defined as a hypo- or hyperechoic area in a solid organ or a distortion of the normal echotexture of a solid organ (Fig 1).

Contrast-enhanced US was performed immediately after unenhanced US. We used a second-generation blood pool contrast agent that was commercially available in Italy (SonoVue; Bracco, Milan, Italy) and was previously reported to be useful in the detection of injuries due to abdominal trauma (17–22). The contrast agent was injected as a bolus with a 22-gauge catheter placed in an antecubital vein and was immediately followed by a 10-mL saline solution flush (0.9% NaCl). Two 2.4-mL bolus contrast agent injections were administered: The first was administered to investigate organs in the left upper quadrant (left kidney, adrenal gland, and spleen), whereas the second was administered to evaluate organs in the right upper quadrant (right kidney, adrenal gland, pancreas, and liver). The complete contrast-enhanced US examination lasted no more than 6 minutes and comprised the acquisition of static and moving images (Fig 2) (Movie 1, http://radiology.rsna.org/cgi/content/full/2463070652/DC1).

On contrast-enhanced US images, organ injuries appeared as strongly hypoechogenic areas against the homogeneous echogenicity of the parenchyma with or without interruption of the anatomic profile (Fig 3). Microbubbles within the lesion were identified as active bleeding and were referenced in the report (Fig 4) (Movie 2, http://radiology.rsna.org/cgi/content/full/2463070652/DC1).

**CT Examinations**

Unenhanced and contrast-enhanced CT examinations were performed immediately after US. CT examinations were performed with a single-detector row scanner (Somatom; Siemens, Berlin, Germany) in eight patients and with a multidetector scanner (Emotion 6; Siemens) in 19 patients. The scanning parameters were as follows: 5-mm collimation, 7.5 mm/sec table speed.
and 5-mm reconstruction interval for the single-detector row scanner and 2-mm collimation, 12 mm/sec table speed, and 2.5-mm reconstruction interval for the multidetector scanner. A dose (2 mL per kilogram of body weight) of a nonionic contrast medium (Iomeron; Bracco) was injected at a rate of 1.5 mL/sec with an acquisition delay of 60 seconds. Contrast material was not administered orally. CT lesions were scored with the Organ Injury Scale of the American Association for the Surgery of Trauma (24). All of the findings were recorded on a radiologic archive system.

**Statistical Analysis**

Means, standard deviations, ranges, and frequencies were used as descriptive statistics. To compute the sensitivity, specificity, positive and negative predictive values, and frequency of lesions correctly identified, contrast-enhanced CT was considered the reference standard. The accuracy and agreement of both US and contrast-enhanced US and their agreement with contrast-enhanced CT were determined with the area under the receiver operating characteristic curve and the \( \kappa \) statistic, respectively. The standard errors of these estimates were also calculated. The McNemar test and \( z \) distribution were used to compare the diagnostic capability of US with that of contrast-enhanced US. Spearman rank correlation analysis also was used. Statistical analyses were performed on a personal computer with the SPSS statistical package (version 13.0 for Windows; SPSS, Chicago, Ill). Two-tailed \( P \) values of less than .05 were considered to indicate a significant difference.

Since this study was an initial experience, it was designed to allow us to obtain preliminary information about the accuracy of contrast-enhanced US compared with that of US; therefore, we did not compute an a priori size estimation, but we did examine all patients admitted during a 3-year period. Post hoc power calculation was performed with statistical software (PS, version 2.1.31; Department of Biostatistics, Vanderbilt University, Nashville, Tenn) that can be accessed at [http://biostat.mc.vanderbilt.edu/twiki/bin/view/Main/PowerSampleSize](http://biostat.mc.vanderbilt.edu/twiki/bin/view/Main/PowerSampleSize) and is based on the approach of Dupont and Plummer (25,26).

**Results**

Twelve (44%) of the 27 patients had 14 solid organ injuries depicted on contrast-enhanced CT images. Two of these patients each had two lesions. There were seven splenic lesions, four hepatic lesions, one renal lesion, one adrenal gland lesion, and one pancreatic lesion (Fig 5). Fifteen (56%) of the 27 patients did not have organ lesions at contrast-enhanced CT and were considered to have negative CT findings. Thus, contrast-enhanced CT was the reference standard for 14 lesions in 12 patients and for 15 examinations with negative results in 15 patients.

**US Findings**

US findings were positive in 10 patients. Eight patients had positive contrast-enhanced CT findings. Two patients had negative contrast-enhanced CT findings; however, free fluid was detected at US. For US, sensitivity, specificity, and positive and negative predictive values were 57.1%, 86.7%, 80.0%, and 68.4%, respectively (Table 1). There was fair agreement between US and contrast-enhanced CT findings (mean \( \kappa = 0.442 \pm 0.161 \) [standard error]). Twenty-one (72.4%) lesions were correctly identified with US; thus, the mean accuracy of US was 71.9% ± 9.9.

**Figure 4**

(a) Transverse oblique contrast-enhanced US image of the liver shows a markedly hypoechoic area with extravasation of microbubbles within the hematoma (arrows). (b) Transverse contrast-enhanced CT enabled us to confirm the lesion (arrow).

**Figure 5**

Flow diagram. CE-CT = contrast-enhanced CT, CE-US = contrast-enhanced US, O.R. = operating room, TP = true-positive findings.
Contrast-enhanced US Findings

Contrast-enhanced US depicted 13 of the 14 lesions depicted with contrast-enhanced CT. A right adrenal gland contusion was missed in a patient who also had a lesion in the spleen. All 15 patients with negative contrast-enhanced CT findings also had negative findings at contrast-enhanced US. The sensitivity, specificity, and positive and negative predictive values of contrast-enhanced US were 92.9%, 100%, 100%, and 93.8%, respectively (Table 1). Fair agreement between US and contrast-enhanced US was observed (mean \( \kappa = 0.359 \pm 0.172 \)). In comparison with US, contrast-enhanced US showed significantly higher values for the number of lesions correctly identified (\( P = .039 \)), agreement (\( P = .005 \)), and accuracy (\( P = .022 \)) evaluated. In addition, there was a close relationship (\( r_s = 0.907, P < .001 \)) between the size of the 13 lesions measured with contrast-enhanced US and the size of the lesions measured with contrast-enhanced CT (Table 2).

Power Calculation

Post hoc power analysis of the accuracy values obtained with the two techniques was performed. A power value of 0.876 was obtained by taking into account the following values: \( \alpha = .05 \), 58 cases, difference of 0.245, and standard deviation of 0.420 (estimated by using the standard error = 0.099 of the reference technique, US). This value enabled us to be sure that the sample size was within the required confidence ranges.

### Discussion

US is a good modality in the trauma setting because examinations can be performed quickly at a patient’s bedside, the US scanner is portable, and US is highly sensitive to the presence of free peritoneal fluid (1,3,4,7). However, since US is not sensitive for the detection of parenchymal lesions and because hemoperitoneum is not always present in patients with solid organ injuries, US is not a reliable method for use in the exclusion of abdominal lesions (27–31). Taylor and Sivit (11) discussed this drawback and reported that screening US for blunt abdominal trauma should be approached with caution. In their large cohort study, they noted the absence of peritoneal fluid in 37% of children with intraabdominal injuries, and they emphasized the limited importance of peritoneal fluid as a predictor of the need for laparotomy. Emery et al (15) reached the same conclusions when they found that 34% of children with normal findings at screening US had an intraabdominal injury at CT. Benya et al (14) concluded their prospective study by suggesting that normal US findings failed to ensure the absence of intraabdominal injury, and, therefore, US was not adequately helpful to the pediatric trauma surgeon when treatment had to be planned. However, the accurate assessment of parenchymal findings in lesions (extension, presence of hematoma, vascular injuries, etc) is particularly important in children, as nonsurgical treatment has long been the accepted strategy for the care of hemodynamically stable pediatric patients (32–34).

The most used and sensitive imaging modality in trauma assessment is contrast-enhanced CT, which is accurate for depicting abdominal injuries. It is able to depict the extension of lesions and the presence of vascular injuries—including active bleeding, pseudoaneurysms, and arteriovenous fistulas—which

### Table 1

<table>
<thead>
<tr>
<th>Statistic</th>
<th>US</th>
<th>Contrast-enhanced US</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specificity</td>
<td>13/15 (86.7)</td>
<td>15/15 (100)</td>
<td>.500*</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>8/14 (57.1)</td>
<td>13/14 (92.9)</td>
<td>.125*</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>13/19 (68.4)</td>
<td>15/16 (93.8)</td>
<td>. . .</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>8/10 (80.0)</td>
<td>13/13 (100)</td>
<td>. . .</td>
</tr>
<tr>
<td>Lesions correctly identified</td>
<td>21/29 (72.4)</td>
<td>28/29 (96.6)</td>
<td>.039*</td>
</tr>
<tr>
<td>( \kappa ) Value</td>
<td>0.442 ± 0.161*</td>
<td>0.931 ± 0.442†</td>
<td>.005†</td>
</tr>
<tr>
<td>0.719 ± 0.099</td>
<td>0.964 ± 0.041</td>
<td>.022‡</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>(0.526, 0.912)*</td>
<td>(0.884, 1.045)†</td>
<td></td>
</tr>
</tbody>
</table>

Note.—Unless otherwise indicated, data are those used to calculate statistics and data in parentheses are percentages.

* \( P \) values were calculated with the McNemar test.
† Data are means ± standard errors.
‡ Data are means ± standard errors. Data in parentheses are 95% confidence intervals.

### Table 2

<table>
<thead>
<tr>
<th>Lesion Location and Contrast-enhanced CT Grade</th>
<th>No. of Patients</th>
<th>Size of Lesions at Contrast-enhanced US (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade I</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Grade II</td>
<td>2</td>
<td>28, 29</td>
</tr>
<tr>
<td>Grade III</td>
<td>1</td>
<td>66</td>
</tr>
<tr>
<td>Spleen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade I</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Grade II</td>
<td>4</td>
<td>20, 22, 27, 28</td>
</tr>
<tr>
<td>Grade III kidney</td>
<td>2</td>
<td>34, 55</td>
</tr>
<tr>
<td>Grade III pancreas</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Grade II adrenal gland</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Grade I</td>
<td>1</td>
<td>Not detected</td>
</tr>
</tbody>
</table>

\( P \) values were calculated with \( z \) distribution.
are the major predictors of failure of nonsurgical management (35,36).

The introduction of US contrast agents has led to an increase in the diagnostic accuracy of US in many organs, and the technique now has a wide range of applications (37). Contrast-enhanced US has been used to assess trauma in adults and demonstrates a capacity to reveal abdominal solid organ injuries that is almost the same as that of contrast-enhanced CT (17–20). Contrast-enhanced US permits the accurate definition of the size and limits of the lesions, the extension to the solid organ capsule, and, most importantly, the presence of vascular injuries. Its ability to reveal contrast medium pooling as seen at CT was highlighted by Poletti et al (38). In the same study, the authors expressed certain reservations about the abilities of contrast-enhanced US in the trauma setting, but these results were not confirmed in subsequent studies (19,20). Investigators in two studies reported the feasibility of using contrast-enhanced US in children to diagnose and monitor abdominal organ injuries after blunt abdominal trauma (21,22).

In our study, we were able to identify abdominal solid organ lesions with contrast-enhanced US in the absence of free peritoneal fluid, with great accuracy in defining the extension of the lesions compared with the accuracy of contrast-enhanced CT. The sensitivity, specificity, and positive and negative predictive values of contrast-enhanced US were significantly higher than those of US, with good agreement with contrast-enhanced CT findings. The major strength of contrast-enhanced US is that it can provide precise information about parenchymal injuries. US contrast agents are blood pool agents that are used to identify subtle vascular alterations. The ability of contrast-enhanced US to depict extravasation of US contrast agents within the hematoma or the abdominal cavity makes it possible to distinguish those lesions that require surgical or interventional treatment and those that can be managed nonsurgically.

Only one lesion that was detected with contrast-enhanced CT was missed with contrast-enhanced US. This was a right adrenal gland contusion in a child with a more severe splenic fracture that had been correctly identified with contrast-enhanced US. This small lesion went unnoticed because it was confused with a slight collection in the Morison pouch. However, the quick resolution of this minor lesion and the absence of clinical relevance did not affect the care of the patient.

No adverse effects were observed in our study. This was in agreement with the good safety profile of US contrast agents, which have a low reported rate of adverse events (39). The accuracy and safety of contrast-enhanced US are in fact the determinant factors of this technique, which can also be considered for the follow-up of patients with injuries that do not require surgery. This examination can be performed at the patient’s bedside, without moving the traumatized child to the radiology department. To our knowledge, the use of contrast-enhanced US as the ideal imaging modality in monitoring patients treated conservatively was first suggested by Catalano et al (17) in terms of reducing the number of follow-up CT scans, especially in young (<18 years) patients. This represents a further and important application of contrast-enhanced US.

Our study had some limitations. First, contrast-enhanced US, like standard US, cannot depict certain types of injuries, such as diaphragmatic ruptures and some bowel and mesenteric injuries (40). US contrast agents are purely intravascular and are unsuitable for demonstrating extravasation in the renal collecting system. Second, this study was an initial experience and the number of patients in the series was limited. For example, the series included only one pancreas lesion and one renal lesion. Finally, not all patients underwent CT; therefore, we cannot rule out the possibility that some minor lesions were missed.

In conclusion, this preliminary experience shows that contrast-enhanced US is more accurate than US in the detection of abdominal solid organ injuries in children. Our data suggest that contrast-enhanced US can be considered for the triage of hemodynamically stable children with abdominal trauma. Moreover, the technique may represent a useful alternative to CT in the follow-up of hospitalized children with a known abdominal injury who are cared for nonsurgically and thus prevent the need to move the patient to the CT suite and spare the child from radiation exposure. Further prospective series are required to confirm our findings.

References


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