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Use of Abdominal Ultrasonography to Assess Pediatric Splenic Trauma

Potential Pitfalls in the Diagnosis

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Objective
The purpose of this study was to evaluate the accuracy of abdominal ultrasonography (US) for screening and grading pediatric splenic injury.

Summary Background Data
The use of abdominal US has increased rapidly as a method of evaluating organ damage after blunt abdominal trauma. Despite US's increasing use, little is known about its accuracy in children with splenic injury.

Methods
Children (N = 32) suffering blunt abdominal trauma who were diagnosed with splenic injury by computerized tomography (CT) scan prospectively were enlisted in this study. Degree of splenic injury was evaluated by both CT and US. The ultrasounds were evaluated by an initial reading as well as by a radiologist who was blinded as to the results of the CT.

Results
Twelve (38%) of the 32 splenic injuries found on CT were missed completely on the initial reading of the US. When the ultrasounds were graded in a blinded fashion, 10 (31%) of the splenic lacerations were missed and 17 (53%) were downgraded. Seven (22%) of the 32 splenic fractures were not associated with any free intraperitoneal fluid on the CT scan.

Conclusions
This study has shown that US has a low level of sensitivity (62% to 78%) in detecting splenic injury and downgrades the degree of injury in the majority of cases. Reliance on free intraperitoneal fluid may be inaccurate because not all patients with splenic injury have free intra-abdominal fluid. Based on these findings, US may be of limited use in the initial assessment, management, and follow-up of pediatric splenic trauma.

Splenic injury remains the most common visceral injury in children suffering blunt abdominal trauma. Because severe splenic injuries can be difficult to detect clinically, computerized tomography (CT) has become an accepted method for the detection of solid organ injuries after blunt abdominal trauma. Computerized tomography is thought to provide the most accurate information regarding splenic trauma.[1-5]

Despite the apparent diagnostic superiority of CT, the use of ultrasonography (US) to screen for splenic trauma is increasing. Trauma physicians relying on US cite ease of imaging at the bedside, the frequent need for sedation during CT examination, cost, and time constraints as the main advantages of US instead of CT.[6] The regular use of US as a screening method for pediatric splenic injury is unsupported by clinical data. Studies advocating the use of US in the detection of abdominal injury often rely on the visualization of intra-abdominal fluid rather than parenchymal damage for the detection of visceral injury.[7-13] Because the presence of free fluid is neither sensitive nor specific[14] for splenic injury, the validity of this approach is questionable. This is particularly the case in pediatric splenic trauma where blood in the peritoneal cavity is not an indication for surgical exploration.[15-17]

The purpose of this study was threefold. First, we wanted to evaluate the sensitivity of US in the initial diagnosis of parenchymal injury to the spleen and compare its accuracy to CT scanning. Second, we wanted to examine the accuracy of US in grading the degree of splenic injury. Third, we wanted to examine the association of splenic injury with the finding of free intra-abdominal fluid.

MATERIALS AND METHODS

The patient population consisted of 32 pediatric blunt abdominal trauma victims prospectively entered into this study between July 1992 and September 1995. All the patients had a CT-documented splenic laceration. The mode of splenic injury ranged from falls and bicycle accidents to automobile accidents. Thirty-one of the 32 patients had an abdominal CT as the first diagnostic study with the US examination after the CT by an average of 5.5 (±1.0) days.

The CT scans were done using a GE 9800 scanner (General Electric, Milwaukee, WI) using 5-mm and 10-mm slices at 10-mm intervals. All patients received intravenous contrast. Abdominal US was performed using either a portable or a permanent Acuson XP10 (Mountain View, CA) scanner at frequencies ranging between 3.5 and 7.0 MHz. The scans were done by an ultrasound technician under the direct supervision of an attending radiologist.

Table 1. ANATOMIC GRADING OF SPLENIC INJURIES MODIFIED FOR EASE OF ULTRASOUND GRADING FROM THE MODEL ESTABLISHED BY THE AMERICAN ASSOCIATION FOR THE SURGERY OF TRAUMA[18]

Grade	Anatomic Basis
0	Normal spleen
I	Hematoma: <10% in or around the spleen; or Laceration: <1 cm parenchymal depth
II	Hematoma: 10–20% of spleen volume; or Laceration: 1–3 cm parenchymal depth
III	Hematoma: 20–50% of spleen volume; or Laceration: >3 cm or <50% devascularization
IV	Hematoma: >50% of spleen volume; or Laceration: >3 cm parenchymal depth or >50% devascularization
V	Laceration: Shattered spleen, only fragments remaining

All the patients in the study had CT-documented splenic injury. The 32 CT scans were read by a staff radiologist, and the degree of parenchymal injury was graded on a scale modified from that proposed by the American Association for the Surgery of Trauma[18] (Table 1). Accumulation of free intraperitoneal fluid was quantified by careful CT survey of Morison's pouch, perihepatic space, perisplenic space, paracolic gutters, pouch of Douglas, pelvis, and the perimesenteric area. The amount of fluid in each of the recesses was classified as either minimal (<50 mL), moderate (<150 mL), or marked (>150 mL). The total volume of abdominal fluid was estimated through summation of each of the areas using the method of Levine et al[19]: none (no identifiable fluid); small (minimal fluid in only one intraperitoneal location); intermediate (moderate amount of fluid in one location, or minimal fluid accumulation in more than one location); large (marked fluid accumulation in one location, or moderate fluid in more than one location, or minimal fluid in more than one location in combination with moderate fluid in another site).

Evaluation of the US was done three ways. This rigorous triple analysis of the US results provided objective and reproducible findings in our interpretation of splenic injuries. The initial evaluation of the US

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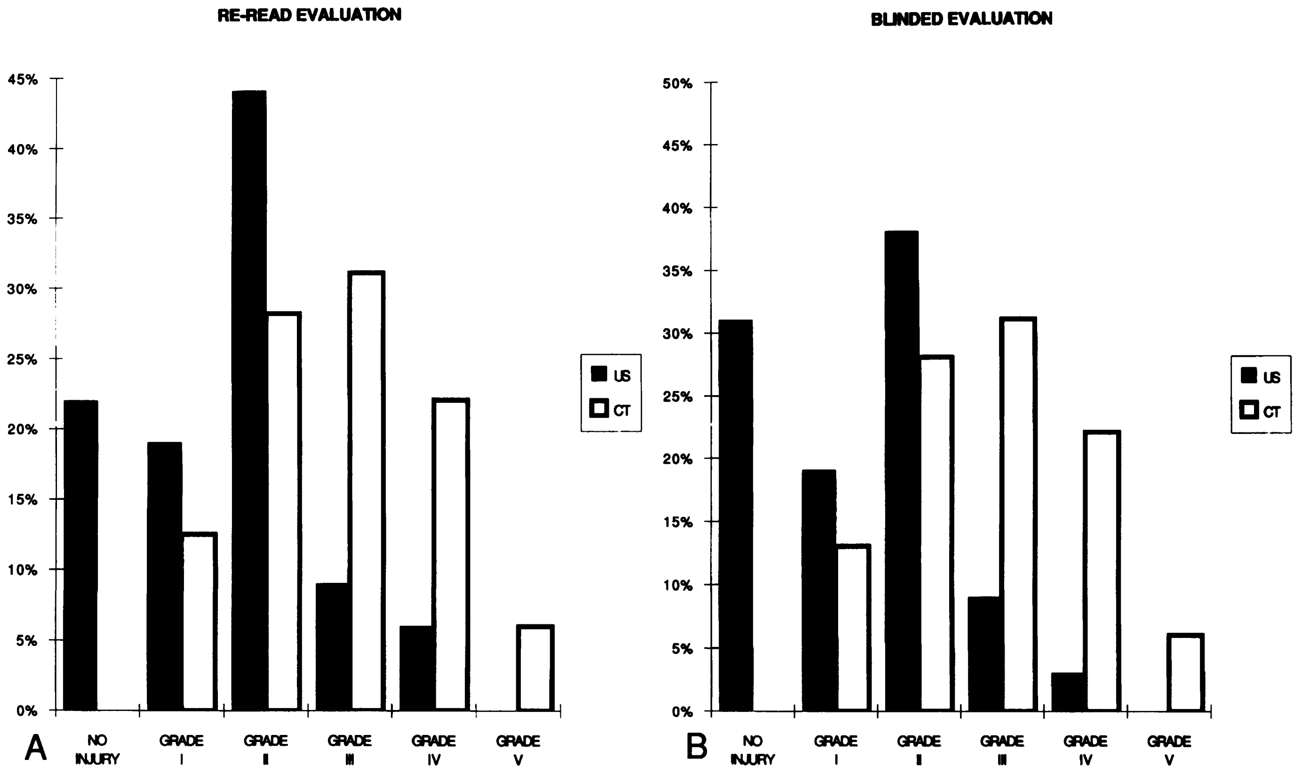

Figure 1. (A) Ultrasonography (US) evaluation of splenic parenchyma consistently downgraded the degree of injury from that established by computerized tomography (CT). When US scans were reread and compared side by side with CT scans, the degree of injury was underestimated in 17 (53%) of the scans ($p < 0.0005$). No grade V splenic lacerations were diagnosed by US and seven injuries were missed completely. (B) During the blinded evaluation of the US by a radiologist who had no knowledge of the CT findings, 18 (56%) of the 32 US scans were underestimated regarding the grade of injury ($p < 0.0002$), 10 lacerations were missed completely, and no grade V lacerations were identified.

(Initial Evaluation) consisted of the readings of the 32 US studies by the radiology department as part of the official radiology report. Most studies were performed under the direct supervision of an attending radiologist. Some studies were monitored by the resident radiologist on call and checked by an attending radiologist the next morning. The second evaluation of the US consisted of a rereading of the US scans (Reread Evaluation) by one of the authors (CEB) who had knowledge of the CT findings. This evaluation was done to confirm the presence of splenic injury and to assign a graded level of injury by a modified American Association for the Surgery of Trauma score (Table 1). The final evaluation of the US (Blinded Evaluation) consisted of a reading by another author (PJS) who was masked to the CT findings. The presence of splenic injury again was documented and the grade of injury re-established. To assess the specificity of this masked evaluation, 32 age-matched abdominal US studies randomly were mixed with the 32 splenic injuries to serve as negative control samples.

Results are expressed as the mean ± standard error of the mean. The data generated from the CT and US readings were analyzed using the Wilcoxon sign-rank test with a $p < 0.05$ being considered significant.

RESULTS

Mean age was 10 years (range, 1 to 17 years) and mean injury severity score (ISS) was 13 (range, 4 to 29). Thirty-

Table 2. SPLENIC INJURIES UNIDENTIFIED DURING THE INITIAL EVALUATION OF THE ULTRASOUND BY THE RADIOLOGY DEPARTMENT, REREAD EVALUATION BY ONE OF THE AUTHORS, AND BLINDED EVALUATION

Initial Evaluation	Reread Evaluation	Blinded Evaluation
12 (38%)	7 (22%)	10 (31%)

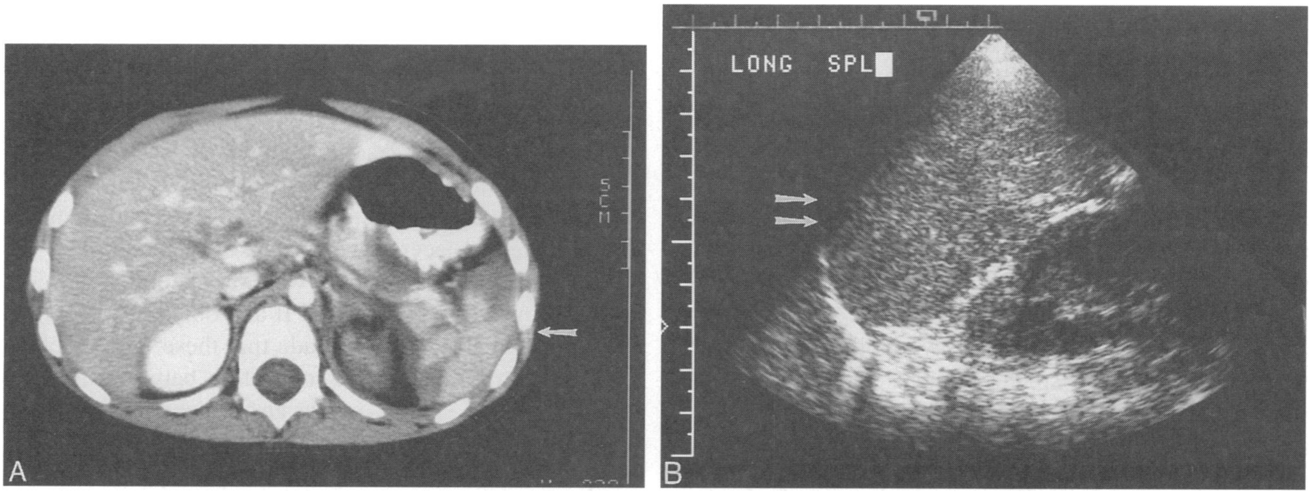

Figure 2. (A) Computerized tomography shows a grade III splenic injury with readily visible intraparenchymal hematomas (single arrow). (B) Ultrasonography of the same patient shows a normal-appearing spleen without visible defects (double arrows).

one of the 32 patients had an abdominal CT as the initial diagnostic study. Twenty-nine CT scans were done within 24 hours of the initial trauma, 2 were done 3 days after the injury, and 1 patient, transferred from an outside hospital, originally was evaluated by US and had the initial CT scan 12 days after the accident. All the patients underwent an US scan an average 6.5 ($\pm$0.9) days after the original trauma, 5.5 ($\pm$1.0) days after the CT scan.

Results from the Initial Evaluation of the US showed that of the 32 CT and US scans analyzed by the radiology department, 12 (38%) of the ultrasounds did not document splenic injury despite its presence by CT (Table 2).

During the Rereading Evaluation of the US, 7 of the 32 US scans did not show any evidence of splenic laceration (22%) (Table 2 and Fig. 1A). Grading of the splenic injury showed that 17 (53%) downgraded the degree of parenchymal injury (Fig. 1A). Overall, 24 (75%) of the 32 US scans either missed or significantly underestimated the degree of splenic injury despite the radiologist's knowledge that an injury actually existed ($p < 0.0005$).

The Blinded Evaluation of the US showed that a laceration could not be seen in 10 (31%) of the 32 ultrasounds (Table 2 and Fig. 1B) despite the diagnosis of injury by CT (Fig. 2). This gave a diagnostic sensitivity of 69%. None of the 32 negative control samples were read as having splenic injury, yielding a 100% specificity for US. Eighteen (56%) of the parenchymal injuries were downgraded compared to those of CT findings (Fig. 1B). Overall, 28 (88%) of the 32 splenic injuries were underdiagnosed when the radiologist was masked to the results of the CT ($p < 0.0002$).

No intra-abdominal fluid could be detected after a careful survey of the abdomen in 7 (23%) of the 32 CT scans (Fig. 3). One CT could not differentiate between intermediate or large amounts of fluid because of limited pelvic views. All the CT scans showing no intra-abdominal fluid were performed less than 24 hours from the time of injury.

DISCUSSION

The recognition of the spleen's importance in immunologic surveillance and the dangers of postsplenectomy sepsis have decreased drastically the use of routine splenectomy after pediatric splenic injury. Splenic conservation after blunt abdominal trauma has now become the

Figure 3. A grade V splenic laceration is associated with no free perisplenic fluid. No free fluid could be detected in the rest of the abdominal cavity or in the dependent areas of the pelvis as well.

standard of care. In the early 1980s, Zucker et al.[20] achieved a high rate of splenic salvage by conservative treatment of scintigraphy-proved but stable splenic injuries. Subsequent studies support these positive results with an 80% to 90% splenic salvage rate after conservative therapy and a 0% rate of rebleeding.[21-23] Seven days of strict in-hospital bed rest and monitoring after documented splenic trauma is now the standard of care in our institution and across the country.[24] Failure to recognize splenic injury after blunt abdominal trauma can have catastrophic consequences. Before the availability of sensitive imaging methods for splenic injury, the majority of splenic lacerations would remain undetected with the potential for rebleeding and an associated mortality rate as high as 10%.[25] Early recognition of splenic injury can allow the clinician to triage and treat victims of blunt abdominal trauma properly.

Although CT scanning currently is viewed as the ''gold standard'' to screen patients with abdominal–splenic trauma,[1-5] US recently has been advocated as a reliable alternative. Ultrasonography has been used routinely as the primary method of screening for splenic injury after blunt abdominal trauma in European emergency departments.[9] Within the past several years, some North American hospitals also have begun to rely on US as the primary method of screening for splenic injury. Advantages cited include rapidity of diagnosis, availability of US at the bedside, and lower cost of US compared to CT.[6] Despite these advantages, the role of US in the screening of blunt abdominal trauma still is unclear. In particular, the use of this method for the evaluation of the pediatric patient has not been defined clearly.[26]

Many of the studies advocating the use of US as an adequate and sensitive method have substantial pitfalls in their analysis. A number of studies do not follow-up a negative US scan with any other diagnostic method, assuming that patients without clinical sequelae are without significant injury. This allows splenic injuries not diagnosed by the initial US to remain undetected, falsely inflating the sensitivity of US and skewing the results of the study.[12,27-29] Other studies define a positive US examination result as one detecting either free fluid or a splenic laceration.[7-11] Further analysis of these studies shows that they rely predominately on abdominal fluid as an indicator of splenic injury. Because free fluid is neither sensitive nor specific for splenic injury, this method clearly is inaccurate. This is particularly important in the pediatric-aged patient, because the finding of blood in the peritoneal cavity is not necessarily an indication for operative intervention.[15-17] Our study is unique because every US is correlated with a CT scan, allowing us to determine the sensitivity of US in these children properly. In addition, parenchymal injury and the finding of abdominal fluid are analyzed separately.

Our data show that US has a low level of sensitivity (69%) for the detection of splenic injury despite the CT documentation that a fracture actually exists. The use of a method with a low level of sensitivity could lead to improper management and premature release of patients with undetected lacerations. Because the majority of the splenic injuries missed by US were of anatomically lower grades (nine were grades I and II and only one was grade III), an argument could be made that these injuries clinically are insignificant. The correlation between the anatomic extent of splenic injury and its clinical outcome, however, still is unclear, because even minor lacerations can present with rebleeding and delayed splenic rupture, whereas major injuries can be treated successfully in a nonoperative manner.[30]

Recognizing the limitations of US in the initial diagnosis of splenic injury, some authors have proposed that the use of US be limited to future follow-up and surveillance of CT-diagnosed splenic laceration.[31] Because the majority (53% to 56%) of US-imaged splenic lacerations were downgraded by one to three points from their respected CT grade, the use of US for follow-up of splenic lacerations must, at best, be considered questionable. Regression of a lesion on US could not be correlated properly with its CT-documented extent, and residual laceration can remain undetected by US.

Ultrasonography has been reported to have a high sensitivity in the detection of free intra-abdominal fluid.[9,11,32,33] However, in our study, a significant proportion of splenic lacerations was associated with only a small amount (16%) or no (23%) free fluid (Fig. 3). Based on our study, even the absence of abdominal fluid still would mandate a CT scan to rule out a splenic parenchymal injury. In addition, because the presence of free intraperitoneal fluid is not an indication for a laparotomy in the pediatric patient,[15-17] a definitive therapeutic decision could not have been made despite the presence of free fluid by US. A CT scan still would be needed to find the source of the fluid and the potential visceral lesion. The detection of such an injury could both explain the source of the hemoperitoneum and justify the hospitalization of the victim for bed rest and monitoring. Because neither the presence nor the absence of hemoperitoneum as shown by US scans allows any therapeutic decisions to be made without further testing, US becomes unnecessary as a nondiagnostic study in the evaluation of this patient population. Based on the number of patients lacking free abdominal fluid, a trauma workup would necessitate a CT scan to be performed for further evaluation of the splenic parenchyma. Computerized tomography also would allow concurrent evaluation of other abdominal organs not accessible to US.[3]

One potential pitfall of our analysis is the average delay of 6.5 days between the US and the trauma. One could suspect that during this time, some healing of the splenic laceration could have contributed to the lower US grade. It is unlikely, however, that 6.5 days is enough time for any healing to occur. One group monitoring experimentally produced canine splenic hematomas detected absolutely no decrease in the size of the lesion during a month-long follow-up by CT.[34] Serial monitoring of known splenic lacerations in humans also has shown only a gradual rate of healing with the earliest detected resolution of intrasplenic hematomas and contusions occurring 7 weeks after the injury.[35] There also is evidence that false-negative US results actually can be higher immediately after trauma because of the smaller size and the isoechoic nature of a fresh splenic injury. It is common for the volume of the spleen and splenic hematoma to enlarge for 1 to 2 weeks after trauma or infarction because of the necrosis, edema, and breakdown of the blood and blood products.[36] The same blood breakdown products and hematoma organization can change the appearance of fresh blood, isoechoic with the splenic parenchyma, to a hypoechoic fluid collection, distinct and easily discernible from the surrounding splenic tissue.[35] For these two reasons, repeat US not uncommonly shows a splenic lesion that was missed on the initial US.[33,35] Based on these data, waiting an average of 6.5 days after the original trauma (5.5 days after the initial CT), our false-negative rate for US actually may have been reduced compared to the initial rate at presentation. Because the resorption of intra-abdominal fluid is much quicker than the resolution of parenchymal injury,[35] free abdominal fluid was evaluated by CT because of its temporal proximity to the time of injury.

By pointing out the inadequacies of US for the detection of splenic parenchymal injuries, we do not imply that US has no role in the evaluation of abdominal trauma. In the hemodynamically unstable patient, with the potential for multiorgan trauma, simply the presence of a large hemoperitoneum on US may be an indication for laparotomy. In this situation, a quick, portable ultrasound in the emergency department might be advantageous instead of the CT. Simply the presence of intra-abdominal fluid in a stable pediatric patient is not an accepted indication for an operation.[15–17] However, if the trauma surgeon's decision to operate is based solely on the presence of fluid in the abdomen, US also might be the study of choice.[7] A trauma center following the Swiss model of admitting every child for a period of observation after blunt trauma might use US successfully as the only imaging method of the spleen.[37] The danger of missing a splenic laceration would be offset by the period of observation, and any hemodynamic compromise or occult bleeding from delayed splenic rupture could be dealt with in-house immediately. Such an approach would not address future activity restrictions of patients with a splenic fracture nor be compatible with current economic constraints of medical practice in the United States.

In conclusion, we found that US, by itself, is an inadequate study to screen for splenic trauma in the pediatric population. Physicians relying exclusively on US possibly would misdiagnose a significant number of splenic lacerations, underestimate the level of injury, and potentially compromise the level of patient care.

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