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Performance of abdominal ultrasonography in pediatric blunt trauma patients: a meta-analysis

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Abstract

Objective: The objective of the study was to obtain the best estimates of the test performance of abdominal ultrasonography (US) for identifying children with intraabdominal injuries (IAIs).

Methods: We gathered studies on the use of abdominal US in injured children from the following sources: a MEDLINE and Embase search, hand searches of 5 specialty journals and 4 clinical textbooks, the bibliographies of all identified articles, and contact with experts. Both prospective and retrospective studies were included if they used abdominal US for the detection of intraperitoneal fluid or IAIs in blunt trauma patients less than 18 years of age. All authors independently abstracted data from the selected studies. Disagreements between abstractors were resolved by mutual agreement.

Results: Twenty-five articles met the inclusion criteria, and 3838 children evaluated with abdominal US were included. Abdominal US had the following test characteristics for identifying children with hemoperitoneum: sensitivity, 80% (95% confidence interval [CI] 76%-84%); specificity, 96% (95% CI 95%-97%); positive likelihood ratio, 22.9 (95% CI 17.2-30.5); and negative likelihood ratio, 0.2 (95% CI 0.16-0.25). Using the most methodologically rigorous studies, however, yielded the following test characteristics of abdominal US for identifying children with hemoperitoneum: sensitivity, 66% (95% CI 56%-75%); specificity, 95% (95% CI 93%-97%); positive likelihood ratio, 14.5 (95% CI 9.5-22.1); and negative likelihood ratio, 0.36 (95% CI 0.27-0.47).

Conclusions: Abdominal US has a modest sensitivity for the detection of children with hemoperitoneum; however, its test performance characteristics worsen when only the most methodologically rigorous articles are included. A negative US examination has questionable utility as the sole diagnostic test to rule out the presence of IAI. Because of the high risk of IAI, a hemodynamically stable child with a positive US examination should immediately undergo abdominal computed tomographic scanning.

Blunt traumatic injury is the most common cause of death and disability in childhood [1]. Historical and physical examination findings in injured children are limited; thus, identification of intraabdominal injuries (IAIs) may be difficult [2,3]. Although abdominal computed tomographic (CT) scanning is the reference standard for identifying IAIs, recent concerns regarding the risk of radiation-induced malignancy have questioned the widespread use of abdominal CT, especially in the pediatric population [4-6]. Abdominal ultrasonography has recently garnered favor in the diagnostic evaluation of adult patients with blunt abdominal trauma, and the Focused Assessment with Sonography for Trauma

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(FAST) examination is used at many centers to identify adult patients with hemoperitoneum [7-9].

Several investigators have studied the use of abdominal ultrasonography in the pediatric trauma population; however, its use in children is controversial, as some authors support it whereas others question its utility [10-32]. Variations in study methodology as well as ultrasound protocol have led to confusion on the usefulness of abdominal ultrasonography in children. This confusion has led to limited application of abdominal ultrasonography in injured children as suggested in a recent survey that few pediatric trauma centers evaluate injured children with ultrasonography [33].

The objective of this systematic review and meta-analysis was to obtain the best estimates of the test performance of abdominal ultrasonography for detecting children with blunt IAIs. We hypothesize that abdominal ultrasonography will have good test characteristics for the identification of children with hemoperitoneum and will have improved performance when ultrasound protocols include images of solid organs.

1. Methods

1.1. Study design

We performed a systematic review and meta-analysis of studies measuring the test performance of abdominal ultrasonography in injured children.

1.2. Search strategy

We queried the medical literature to identify all studies that measured the test performance of abdominal ultrasonography for identifying children with IAIs. We searched MEDLINE and Embase for articles published up to November 2005. Search terms included *abdominal*, *ultrasound*, *ultrasonography*, *FAST*, *hemoperitoneum*, and *trauma*. The search was limited to children aged 0 to 18 years. The search was supplemented with a manual search of the bibliographies of all selected articles, 4 clinical textbooks on the subject [34-37], a hand search of the following 5 journals: *The Journal of Trauma*: *Injury, Infection, and Critical Care*; *The Journal of Pediatric Surgery*; *Annals of Emergency Medicine*; *Academic Emergency Medicine,* and *Pediatric Emergency Care*; and finally, experts in the field were contacted. No limitations were placed with regard to the language of the articles.

1.3. Selection of studies

All abstracts identified from the search strategy were reviewed independently by 2 authors (JH, AG), unmasked to journal of publication, to determine if the study met the inclusion criteria or any of the exclusion criteria. We included both prospective and retrospective studies if they used abdominal ultrasonography for the detection of intraperitoneal fluid or IAIs in blunt trauma patients younger than 18 years. Articles were excluded if they failed to include a minimum of the following 3 ultrasound views: Morisons pouch, splenorenal fossa, and the pelvis, or if the article failed to provide the necessary test characteristics (sensitivity and specificity) of the ultrasound examination. Finally, articles that included a mixture of both adult and pediatric patients were excluded.

1.4. Methods of measurement and data collection

All 3 authors independently abstracted data from the selected articles. Disagreements were resolved by mutual agreement. The methodological quality of the articles was assessed and graded independently by 2 of the authors (JH, AG). Disagreements between the 2 authors were resolved by the third author (CC). Level 1 studies included those studies with a sample size of more than 50 subjects, a representative sample of subjects (no selection bias), and an independent criterion standard diagnostic test (laparotomy, diagnostic peritoneal lavage, or abdominal CT scan). Level 2 studies consisted of those studies with a sample size of more than 50 subjects, minimal selection bias, and an independent criterion standard diagnostic test. Level 3 studies consisted of those studies with a sample size of more than 50 subjects, minimal selection bias, but no independent criterion standard diagnostic test (ie, after abdominal ultrasonography, all or a portion of the subjects in the study were assessed for IAI by observation and did not undergo a criterion standard diagnostic test). Level 4 studies consisted of those studies with a sample size not exceeding 50 subjects or with a moderate to severe selection bias.

Separate test performance measurements were calculated for the 3 variations in ultrasound protocol and outcome of interest as shown in Table 1.

When the necessary data could not be determined from the published study, the authors of that study were contacted

Table 1 Test performance measurements calculated for the 3 variations in ultrasound protocol and outcome of interest

Ultrasound protocol	Outcome of interest
1. Imaging solely for intraperitoneal fluid (FAST examination or FAST examination with paracolic gutter views)	Hemoperitoneum
2. Imaging solely for intraperitoneal fluid (FAST examination or FAST examination with paracolic gutter views)	IAIs with and without hemoperitoneum
3. Imaging for intraperitoneal fluid and solid organ injury	IAIs with and without hemoperitoneum

for clarification. Those studies in non-English languages were translated into English for data abstraction [16,38].

1.5. Data analysis

We used the published raw data from each selected study and used a random-effects model to generate conservative estimates of the sensitivity, specificity, likelihood ratio positive, and likelihood ratio negative, as well as 95% confidence intervals (CIs). The test for heterogeneity was conducted for each test characteristic, and heterogeneity between studies was considered present for a P value < .10.

1.6. Sensitivity analysis

A sensitivity analysis was planned for those instances where heterogeneity was identified. Two sensitivity analyses were designed to exclude the studies with significant methodological limitations. The first sensitivity analysis was performed by excluding all studies that failed to apply an adequate criterion standard to the study population. This methodological limitation has previously been demonstrated to falsely overestimate the performance of the diagnostic test [39]. The sensitivity analysis was thus performed by excluding studies judged as level 3 or level 4 methodology. The second sensitivity analysis was performed by excluding all retrospective studies, leaving only prospective studies for analysis.

2. Results

The search strategy yielded more than 1000 abstracts for review. Subsequently, 25 studies meeting all criteria were included for meta-analysis. All 25 studies were cohort studies and consisted of 3838 children undergoing abdominal ultrasonography. Study methodology was graded as follows: level 1 studies (2), level 2 studies (5), level 3 studies (13), and level 4 studies (5).

The sample size, abdominal ultrasound protocols, and outcomes of interest varied considerably among studies (Table 2). Of the 19 studies evaluating children for intraperitoneal fluid, 9 used solely a FAST protocol and 10 used a FAST protocol with the addition of views of the paracolic gutters.

The pooled sensitivity, specificity, and positive and negative likelihood ratios of abdominal ultrasonography for

Table 2 Characteristics of the 25 studies included in the meta-analysis (in chronological order)

Reference	Age (y)	Type of study	Prevalence of IAI	Ultrasound interpreter	Criterion standard [a]
Hoelzer et al [17]	0.1-12	Retrospective	17/67 (25%)	Unknown	Clinical follow-up
Akgur et al [11]	1.5-16	Retrospective	26/109 (24%)	Radiologist	Clinical follow-up
Akgur et al [10]	0.1-17	Prospective	46/217 (21%)	Radiologist	Clinical follow-up
Luks et al [20]	1-18	Retrospective	81/259 (31%)	Radiologist	Clinical follow-up
Katz et al [19]	2-14	Retrospective	11/121 (9%)	Radiologist	Clinical follow-up
Richardson et al [27]	0.1-13	Retrospective	24/26 (92%)	Radiologist	Diagnostic test
Akgur et al [40]	0.75-15	Prospective	16/68 (24%)	Radiologist	Diagnostic test
Elabbassi-Skalli et al [38]	2-16	Retrospective	52/70 (74%)	Radiologist	Clinical follow-up
Partrick et al [23]	0-18	Retrospective	12/230 (5%)	Surgeon/ED physician	Clinical follow-up
Thourani et al [32]	0.2-14	Retrospective	10/192 (5%)	Surgeon	Diagnostic test
Mutabagani et al [21]	1.2-18	Prospective	13/46 (28%)	Radiologist	Diagnostic test
Patel and Tepas III [24]	2-14	Retrospective	15/94 (16%)	Radiologist	Clinical follow-up
Coley et al [13]	0.2-18	Prospective	32/107 (30%)	Radiologist	Diagnostic test
Benya et al [12]	0.04-16	Prospective	17/51 (33%)	Radiologist (sonographer)	Diagnostic test
Corbett et al [14]	0-18	Prospective	10/41 (24%)	ED physician	Diagnostic test
Emery et al [15]	0.1-18	Retrospective	44/160 (28%)	Radiologist	Diagnostic test
Holmes et al [18]	0.8-16	Prospective	42/224 (19%)	Radiologist	Clinical follow-up
Rathaus et al [25]	0.5-16	Retrospective	40/183 (22%)	Radiologist	Clinical follow-up
Fernandez et al [16]	0-8	Retrospective	17/22 (77%)	Unknown	Clinical follow-up
Richards et al [26]	0.1-16	Prospective	75/744 (10%)	Radiologist	Clinical follow-up
Ong et al [22]	0-15	Retrospective	38/193 (20%)	Radiologist	Clinical follow-up
Soudack et al [28]	0.2-17	Retrospective	40/313 (13%)	Radiologist	Clinical follow-up
Suthers et al [29]	0-17	Prospective	20/120 (17%)	Surgeon	Diagnostic test
Tas et al [31]	0-16	Prospective	96/96 (100%)	Radiologist	Diagnostic test
Soundappan et al [30]	0.25-16	Prospective	15/85 (18%)	Surgeon (fellow)	Clinical follow-up

Diagnostic test indicates that all patients underwent one of the following: laparotomy, diagnostic peritoneal lavage, or abdominal CT scan. *Clinical follow-up* implies that at least a portion of the patients in the study underwent nothing beyond observation and did undergo any of the following diagnostic tests: laparotomy, diagnostic peritoneal lavage, or abdominal CT scan.

ED indicates emergency department.

[a] Criterion standard refers to the minimum evaluation that each patient in the study received.

each of the 3 variations in ultrasound protocol and outcomes of interest are provided in Table 3. For identifying children with hemoperitoneum, abdominal ultrasonography had the following test characteristics: sensitivity, 80% (95% CI 76%-84%); specificity, 96% (95% CI 95%-97%); positive likelihood ratio, 22.9 (95% CI 17.2-30.5); and negative likelihood ratio, 0.2 (95% CI 0.16-0.25).

Fig. 1 demonstrates the sensitivity of each selected study with 95% CIs for studies evaluating ultrasound's performance for hemoperitoneum. The sample size for each study was plotted against the sensitivity of the ultrasound examination (FAST examination) for patients with hemoperitoneum in a funnel plot (Fig. 2).

The presence of heterogeneity was assessed for all of the test performance calculations. There was no heterogeneity in the calculation of sensitivity or specificity for any of the 3 different types of study variation. However, heterogeneity was identified in the positive and negative likelihood ratios of all 3 types of study variation.

We performed 2 different sensitivity analyses to test the performance of abdominal ultrasonography. First, we performed an analysis after excluding the lower methodological quality studies from the analysis. Studies with either moderate to severe selection bias, a sample size of less than 50 subjects, or failure to apply a diagnostic test as the criterion standard (level 3 or 4 studies) were excluded. Eight studies remained for analysis. The test performance for ultrasonography after excluding the 17 level 3 or 4 studies is shown in Table 4. We additionally performed a second sensitivity analysis after excluding all the retrospective studies. Eleven prospective studies remained for analysis, and the test performance for ultrasonography in these 11 studies is shown in Table 5. These 2 tables both demonstrate that the test characteristics for abdominal ultrasonography worsen when only the most methodologically sound articles are included.

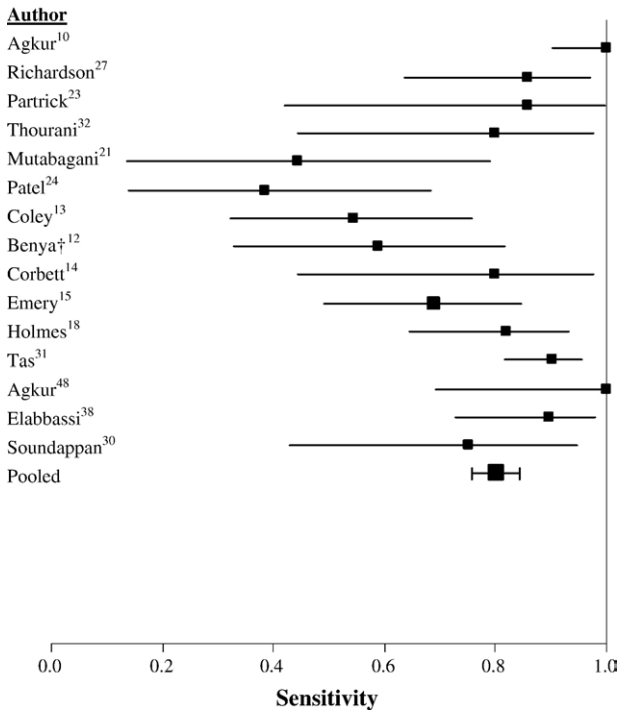

Fig. 1 Sensitivity of abdominal ultrasonography (FAST) for detecting children with hemoperitoneum. Abdominal ultrasound protocol: imaging solely for intraperitoneal fluid (FAST examination). Fifteen studies met the criteria. †The study reported the results of 2 radiologists, and each is presented in this figure.

3. Discussion

We identified and analyzed a substantial body of literature on the performance of abdominal ultrasonography in injured children. Unfortunately, substantial variability exists in the ultrasound protocols, the outcomes of interest, and the methodology for evaluating the outcomes of interest in these studies. This variability between studies prevented us from pooling all 25 studies into a single meta-analysis. Despite this, we determined that abdominal ultrasonography has a modest test performance for the detection of children with hemoperitoneum and/or IAIs. However, when methodologically less stringent articles were excluded from the analysis, the test performance of abdominal ultrasonography decreased substantially.

The pooled sensitivity for identifying children with hemoperitoneum using an abdominal ultrasonography

Table 3 Abdominal ultrasonography test characteristics

Ultrasound protocol	FAST (imaging solely for IP)	FAST (imaging solely for IP)	Imaging for both IP and solid organs
Outcome of Interest	Hemoperitoneum	Any IAI [a]	Any IAI [a]
	(n = 15)	(n = 11)	(n = 12)
Sensitivity	80% (76%-84%)	66% (60%-71%)	82% (78%-86%)
Specificity	96% (95%-97%)	93% (92%-95%)	97% (96%-97%)
Likelihood ratio positive	22.9 (17.2-30.5)	9.8 (7.9-12.1)	24.5 (19.0-31.6)
Likelihood ratio negative	0.2 (0.16-0.25)	0.37 (0.32-0.43)	0.18 (0.15-0.23)

95% CIs are provided in parenthesis.
IP indicates intraperitoneal fluid.
[a] Any IAI refers to those IAIs with and without hemoperitoneum.

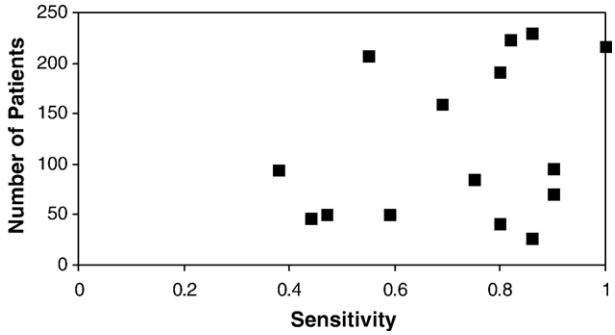

Fig. 2 Funnel plot of each study's sample size vs the sensitivity of ultrasonography for detecting patients with hemoperitoneum.

protocol searching solely for intraperitoneal fluid (FAST examination) suggests that 80% of children with hemoperitoneum will be identified with ultrasonography. This number is somewhat lower than findings in adult studies and may reflect increased difficulty in identifying small amounts of fluid frequently present in children with IAIs.

One of the known limitations of the FAST examination is its inability to identify patients with IAIs without hemoperitoneum. The FAST examination solely attempts to identify intraperitoneal fluid; and therefore, those patients with IAIs but without hemoperitoneum will not be identified. Approximately 26% to 34% of patients with IAIs do not have hemoperitoneum [41-43]. The expected decrease in sensitivity of the FAST examination when measured against an outcome of interest of all children with IAIs, regardless of the presence of hemoperitoneum, was indeed identified in this meta-analysis, as the sensitivity decreased from 80% to 66%.

Investigators, acknowledging the limitations of the FAST examination for identifying patients with IAIs without hemoperitoneum, have attempted to improve the sensitivity of ultrasound by adding images of the patients' solid organs [44-46]. In this meta-analysis, protocols involving images of the solid organs had the best sensitivity (82%); but this represents only a modest increase from the overall sensitivity of the FAST examination and is likely inflated by evaluation bias. Further study is necessary to determine if adding images of the patients' solid organs adds to the overall usefulness of the ultrasound examination in children. In addition, although multiple studies report the ease at which physicians of several different specialties (emergency medicine, radiology, and surgery) may successfully perform and interpret the FAST examination [9,47], little data exist on the ability of these nonradiology specialists to successfully image solid organs. In this systematic review, all studies that included imaging of solid organs had these images interpreted by radiologists.

The results of the sensitivity analysis suggest that the test performance of abdominal ultrasonography in injured children may be inflated by evaluation bias. The first sensitivity analysis that we performed (Table 4) was limited to those studies using a definitive criterion standard test (in most instances abdominal CT scanning) for the diagnosis of the outcome of interest. When only the most methodologically sound studies were incorporated, the sensitivity of the FAST examination for detecting children with hemoperitoneum decreased from 80% to 66% and the sensitivity decreased from 66% to 50% when attempting to detect all children with IAIs (regardless of the presence of hemoperitoneum). This sensitivity analysis highlights the limitations of the studies that use observation or clinical follow-up as the

Table 5 Results of the sensitivity analysis (including only prospective studies)

Ultrasound protocol	FAST (imaging solely for IP)	FAST (imaging solely for IP)	Imaging for both IP and solid organs
Outcome of interest	Hemoperitoneum	Any IAI [a]	Any IAI [a]
	(n = 9)	(n = 5)	(n = 5)
Sensitivity	81% (76%-86%)	55% (46%-64%)	75% (67%-81%)
Specificity	95% (93%-97%)	97% (95%-98%)	97% (96%-98%)
Likelihood ratio positive	17.0 (11.9-24.1)	19.3 (11.0-33.7)	25.6 (17.4-37.7)
Likelihood ratio negative	0.19 (0.15-0.26)	0.46 (0.38-0.56)	0.26 (0.20-0.34)

95% CIs are provided in parenthesis.
[a] Any IAI refers to those IAIs with and without hemoperitoneum.

Table 4 Results of the sensitivity analysis (including only level 1 and 2 studies)

Ultrasound protocol	FAST (imaging solely for IP)	FAST (imaging solely for IP)
Outcome of interest	Hemoperitoneum	Any IAI [a]
	(n = 6)	(n = 5)
Sensitivity	66% (56%-75%)	50% (41%-59%)
Specificity	95% (93%-97%)	97% (95%-98%)
Likelihood ratio positive	14.5 (9.5-22.0)	14.8 (8.9-24.4)
Likelihood ratio negative	0.36 (0.27-0.47)	0.51 (0.43-0.61)

Sensitivity analysis included only those articles graded as level 1 or level 2 methodology. 95% CIs are provided in parenthesis.
[a] Any IAI refers to those IAIs with and without hemoperitoneum.

tool for assessing the presence or absence of IAI. If a criterion standard test is not applied uniformly across the population studied, then the outcome of interest may be misclassified. Those patients with the disease but not undergoing the criterion standard test will not be identified and thus misclassified as being free of the outcome of interest. The results of this meta-analysis suggest that many of these abdominal ultrasonography studies overestimate the sensitivity of abdominal ultrasonography by failing to correctly classify patients who do not undergo a criterion standard test.

There are limitations to this meta-analysis. Only 25 studies met all eligibility criteria, and we may have excluded potentially useful data. We did not include unpublished data, but believe that publication bias does not affect the results of this study. Publication bias occurs when studies with "negative" results are not published but "positive" studies are. Abdominal ultrasonography is a relatively new diagnostic test in injured children, and the medical literature contains both positive and negative studies. Fig. 2 demonstrates that the reported sensitivity and sample size of the study had little effect on the publication of that study. Finally, the data may reflect the performance of specialized trauma centers with clinicians trained in the performance and interpretation of abdominal ultrasound examinations in children. Clinicians with less experience may not reach these same results.

We included both prospective and retrospective studies in the analysis. We believe that certain limitations inherent to retrospective studies (difficulty in abstracting data points from the medical record) have limited impact on the current study where the points measured include a dictated radiology test and the presence or absence of IAI. We, however, performed a second sensitivity analysis after excluding all retrospective studies. The results in Table 5 demonstrate slightly worse test performance characteristics for ultrasonography when only prospective studies are included; but in many instances, the results are quite similar to the analysis with both the retrospective and prospective studies.

Because of the high positive likelihood ratio, an abdominal ultrasound examination demonstrating intraperitoneal fluid should prompt an immediate abdominal CT scan in the hemodynamically stable patient to confirm the presence of and grade the IAI [48]. A negative abdominal ultrasound examination, however, has a modest negative likelihood ratio; and thus, a negative abdominal ultrasound is not sufficient to rule out the presence of IAI in all instances. Furthermore, the negative likelihood ratio worsened when only the most methodologically sound studies were included. Because of this modest negative likelihood ratio, children with a moderate pretest probability of IAI should undergo abdominal CT scanning regardless of the findings on abdominal ultrasonography. Clinicians may consider ultrasonography as the sole diagnostic test only in a select cohort of children at an extremely low risk of having an IAI. In those children with a very low pretest probability of IAI, a negative ultrasound examination lowers the posttest probability of disease to a level that may not warrant screening with abdominal CT scanning. Several studies exist that may assist the clinician in risk stratifying children for IAI [2,3]. Because of the risks of abdominal CT scanning (radiation exposure, contrast administration, and need for sedation in very young children), abdominal CT scanning is to be avoided in children when the test is not clinically indicated.

In conclusion, abdominal ultrasonography has a modest sensitivity for detection of children with hemoperitoneum. A negative US examination has questionable utility as the sole diagnostic test to rule out the presence of IAI. Because of the high risk of IAI, the hemodynamically stable child with a positive ultrasound examination should immediately undergo abdominal CT scanning.

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