Reliability of Physician Estimation of Pelvic Free Fluid Volume on the Pediatric Focused Assessment With Sonography for Trauma

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Abbreviations

BAT, blunt abdominal trauma; CT, computed tomography; FAST, Focused Assessment with Sonography for Trauma; IAI, intra-abdominal injury; PECARN, Pediatric Emergency Care Advanced Research Network; PEM, pediatric emergency medicine

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Objectives—To evaluate the reliability of physician gestalt estimation of pelvic free fluid volume on pediatric Focused Assessment with Sonography for Trauma (FAST). To determine a reliable cut-off volume and characteristics associated with small pelvic free fluid.

Methods—Our study assessed the ability of 2 ultrasound-trained pediatric emergency medicine (PEM) physicians and 2 pediatric radiologists to characterize pelvic free fluid in a retrospective convenience sample of archived FAST from a Level 1 pediatric trauma center, April 2018–June 2020. Inter- and intra-rater reliability were measured to determine the most reliable volume cut-off. Chi-squared and Fisher's exact tests determined characteristics associated with physiologic fluid and fluid volume.

Results—Eighty-one (10.2%) of 797 FAST had pelvic fluid and met inclusion criteria. Volume estimates using none/trace/small versus moderate/large classifications were moderately reliable by the PEM physicians ($\kappa = 0.65$ [95% CI, 0.63–0.66]; raw agreement = 92%) and radiologists ($\kappa = 0.48$ [95% CI, 0.47–0.49]; raw agreement = 91%). This volume cut-off demonstrated higher reliability for both groups and greater agreement for PEM physicians than none/trace versus small/moderate/large. Girls ($P = .005$), isoechoic ($P = .045$), and location posterior to bladder ($P < .001$) were associated with physiologic fluid and hyperechoic ($P = .019$) with non-physiologic fluid. Hyperechoic ($P < .001$), anterior ($P < .001$), lateral ($P = .04$), or "other" location ($P < .001$) relative to the bladder were associated with moderate/large volume.

Conclusions—Ultrasound-trained PEM physicians and pediatric radiologists can reliably use gestalt estimation to distinguish moderate or large fluid from smaller pelvic fluid volumes on pediatric FAST.

Key Words—FAST; pediatric trauma; pelvic free fluid; reliability

Unintentional injury is the leading cause of death in children and adolescents aged 1–19 years.[1] Blunt abdominal trauma (BAT) is the most common initially unrecognized fatal injury.[2] Computed tomography (CT) is the gold standard for detecting intra-abdominal injury (IAI); however, clinicians must consider the risks and benefits of CT use, particularly given that operative intervention occurs in less than 2% of children after BAT.[3] Over the past 2 decades, the Focused Assessment with Sonography for Trauma (FAST) has gained more widespread use

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in children after BAT.[4] However, how to integrate FAST into clinical care is still controversial.[5]

A barrier to integrating FAST is differentiating physiologic free fluid from IAI-related hemorrhage. As many as 16–30% of children have small volumes of pelvic free fluid on ultrasound, which may be physiologic and unrelated to IAI.[6,7] Thus, while free pelvic fluid on FAST is highly specific for IAI in injured adults, "trace" or "small" volumes of free fluid isolated to the pelvis on FAST in stable children after BAT have unclear clinical significance. Prior studies suggest that these children may be candidates for observation rather than immediate CT.[8–10] Experts have called for more comprehensive studies to confirm these findings before clinicians can confidently qualify trace or small pelvic free fluid as potentially physiologic in children after BAT.[11] However, a challenge to investigating and implementing this strategy is that there is no established definition for estimating pelvic free fluid on pediatric FAST.

In this study, we aim to: 1) assess the reliability of physician gestalt estimation of pelvic free fluid volume among ultrasound-trained pediatric emergency medicine (PEM) physicians and experienced, fellowship-trained pediatric radiologists, respectively; 2) determine the most reliable gestalt, dichotomous volume cut-off; 3) and to identify demographic and ultrasonographic characteristics that distinguish small, potentially physiologic, pelvic free fluid from larger fluid volumes.

Methods

Study Design

We conducted a study evaluating the ability of ultrasound-trained PEM physicians and pediatric radiologists to characterize pelvic free fluid in a retrospective convenience sample of archived FAST from children after BAT. The UCSF Benioff Children's Hospital Oakland Institutional Review Board approved the study.

Study Setting and Sample Selection

We performed this study at a free-standing urban, Level 1 pediatric trauma center with an annual emergency department visit volume of over 45,000 patients. We queried and reviewed archived FAST obtained between April 2018 and June 2020 as part of routine care from our point-of-care ultrasound image storage system (Qpath E; Telexy Healthcare Inc, Maple Ridge, Canada). All FAST were performed or supervised by 15 PEM physicians credentialed in point-of-care ultrasound. All FAST undergo quality assurance by a PEM physician who completed a 1-year fellowship in emergency ultrasound. FAST performed on children aged 18 years and younger that were positive on clinical read or quality assurance review for pelvic fluid were included. To enrich the dataset, 20 negative FAST were also selected and included by random sampling. All FAST were performed with either a phased-array or curvilinear transducer using a Sonosite Edge II or X-Porte (Fujifilm Sonosite, Inc., Bothell, WA) ultrasound system. FAST were excluded if the pelvic view did not include a video clip.

Study Protocol

Two fellowship-trained pediatric radiologists (RC, PK) and 2 ultrasound-trained PEM physicians (AS, AK) reviewed FAST pelvic clips. Clips were presented to each reviewer using a standardized survey using REDCap (Vanderbilt University, Nashville, TN) with a single sentence prompt that included the child's age, sex, and the clinical context of trauma. Each reviewer independently determined if free fluid 1) was present; 2) volume classification as a "trace," "small," "moderate," or "large" amount; 3) location relative to the bladder[10]; 4) echogenicity relative to bladder contents[12] (hyperechoic relative to bladder [eg, echogenic] versus isoechoic relative to bladder [eg, anechoic]); and 5) was likely physiologic based on the aforementioned clinical context and fluid characteristics. To classify volume, reviewers were prompted to provide their subjective (or "gestalt") volume estimation without objective measurement and were not provided with an a priori definition. For intra-rater reliability, each reviewer re-reviewed 25 FAST.

Statistical Analysis

Inter-rater reliability of free fluid volume categorization was measured within the pediatric radiologist and ultrasound-trained PEM physician reviewer groups, respectively, and intra-rater reliability was measured for each reviewer. Responses regarding

fluid volume were collapsed into the following dichotomized classes:

1. "None/trace" versus "small/moderate/large free fluid"
2. "None/trace/small" versus "moderate/large free fluid"

We included "none" within these classes to establish a reliable volume cutoff (ie, less than trace or less than small). This decision is based on our hypothesis and previous studies[8–10] suggesting that trace or small volumes of pelvic free fluid may have similar clinical significance to no fluid. The most reliable cut-off for free fluid volume between these 2 dichotomized classes was determined by comparing kappa values and raw percent agreement. Using the most reliable volume cutoff, FAST were dichotomized to the volume class by the majority of reviewers (at least 3 out of 4). FAST that did not have a majority class were then re-reviewed and dichotomized via adjudication by the ultrasound-trained PEM physicians (AS, AK). Chi-squared or Fisher's exact tests, as appropriate, were then used to determine demographic and ultrasonographic characteristics associated with pelvic free fluid that were classified likely physiologic by both pediatric radiologists (RC, PK), given their expertise in this type of assessment. Next, the same analyses were performed to determine characteristics associated with volumes less than or greater than the most reliable volume cut-off, respectively. For the analyses of association, we captured variability in interpretation of fluid echogenicity and location by assigning these variables for each FAST whenever a given descriptor was selected by any 1 of the 4 reviewing physicians. For all analyses, 2-sided *P*-values <.05 were considered significant.

Results

Eighty-one (10.2%) out of 797 FAST met criteria for inclusion, including 22 by quality assurance review alone. Nineteen FAST were excluded for the absence of a pelvic video clip. Twenty additional negative FAST were chosen by random sampling for a total of 101, see Table 1. Fifty-two percent of FAST were performed on girls and age was evenly distributed among the 3 categories. There were no statistically significant differences among the demographic characteristics of the children with positive and negative FAST for pelvic free fluid.

Table 1. Demographics Characteristics of Children among FAST Reviewed (n = 101)

FAST Pelvic Free Fluid	Positive (n = 81), n (%)	Negative (n = 20), n (%)
Age (years)		
0–5	26 (32)	8 (40)
6–11	29 (36)	9 (45)
12–18	26 (32)	3 (15)
Sex		
Girls	37 (46)	12 (60)
Boys	44 (54)	8 (40)

There are no statistically significant differences among the demographic characteristics of the children with positive and negative FAST pelvic free fluid ($P = .3$).
FAST, Focused Assessment with Sonography for Trauma.

Inter-rater reliability was measured between pediatric radiologists and between PEM physicians (Table 2, respectively). When using the none/trace and small/moderate/large dichotomized volume classes, agreement for radiologists was 82%, kappa = 0.55 (0.53–0.56) (Table 2a) and agreement for PEM physicians was 78%, kappa = 0.49 (0.48–0.50) (Table 2b). When collapsing volume classes to none/trace/small and moderate/large, agreement for radiologists was 91%, kappa 0.48 (0.47–0.49) (Table 2a) and agreement for PEM physicians was 92%, kappa 0.65 (0.63–0.66) (Table 2b). Given the improved raw agreement for both reviewer groups, and kappa for PEM physicians, the latter cut-off of small or less was determined to be the most reliable. On re-review of 25 FAST, intra-rater raw agreement was 88% for each of the 4 reviewers, with each reviewer re-classifying the volume of 3 FAST.

The majority classifications of fluid volumes using the small or less versus moderate/large dichotomized classes of FAST without unanimous agreement among the 4 reviewers are shown in Supplemental Table 1. Illustrative examples of different fluid volumes (none, trace, small, moderate, and large), both those with unanimous/near unanimous agreement and those with significant disagreement, are shown as still images in Figure 1.

Demographic and ultrasonographic characteristics associated with fluid that was deemed likely to be

Table 2. (a) Pediatric Radiologist and (b) PEM Physician Inter-Rater Reliability (n = 101)

(a) Pediatric Radiologist Inter-Rater Reliability

None/trace vs small/moderate/large		
Reviewer 1 / Reviewer 2	None/trace	Small/moderate/large
None/trace	65	15
Small/moderate/large	3	18
Raw agreement	82.2%	
Kappa	0.55 (0.53–0.56)	
P-value	<0.01	
None/trace/small vs moderate/large		
Reviewer 1 / Reviewer 2	None/trace/small	Moderate/large
None/trace/small	87	7
Moderate/large	2	5
Raw agreement	91.1%	
Kappa	0.48 (0.47–0.49)	
P-value	<0.01	

(b) PEM Physician Inter-Rater Reliability

None/trace vs small/moderate/large		
Reviewer 1 / Reviewer 2	None/trace	Small/moderate/large
None/trace	59	12
Small/moderate/large	10	20
Raw agreement	78.2%	
Kappa	0.49 (0.48–0.50)	
P-value	<0.01	
None/trace/small vs moderate/large		
Reviewer 1 / Reviewer 2	None/trace/small	Moderate/large
None/trace/small	84	5
Moderate/large	3	9
Raw agreement	92.1%	
Kappa	0.65 (0.63–0.66)	
P-value	<0.01	

Inter-rater reliability (including raw agreement and kappa) of dichotomized volume classes (none/trace versus small/moderate/large and none/trace/small versus moderate/large) among pediatric radiologists (a) and PEM physicians (b).
PEM, pediatric emergency medicine.

physiologic by both radiologists is shown in Table 3. Seventeen FAST were agreed by both radiologists as likely being consistent with physiologic free fluid. Fourteen out of 17 FAST classified as physiologic pelvic free fluid were girls ($P = .005$). All 17 FAST were classified as small or less in volume, although the association between volume and physiologic fluid was not statistically significant ($P = .2$). All were described as isoechoic ($P = .045$) and posterior in location relative to the bladder ($P < .001$). Hyperechoic ($P = .019$) was associated with fluid not considered to be physiologic. Child's age ($P = .87$) was not associated with physiologic free fluid.

We also measured the association between sex, age, echogenicity, location characterization, and consensus dichotomized volume classification (small or less versus moderate/large). Hyperechoic fluid echogenicity ($P < .001$) and fluid seen in anterior ($P < .001$), lateral ($P = .04$), or in "other" location (eg, retrouterine; $P < .001$) relative to the bladder were characteristics associated with fluid classified moderate/large in volume. Patient sex, age, isoechoic fluid echogenicity, and fluid location posterior to the bladder were not associated with either volume classification (Table 4).

Discussion

In this study, we have demonstrated that physician gestalt estimation of pelvic free fluid volume on pediatric FAST has good reliability among both ultrasound-trained PEM physicians and pediatric radiologists in classifying moderate/large pelvic free fluid from small fluid volumes. However, relying on physician gestalt to differentiate trace free fluid volumes is less reliable. While there is inherent variability in gestalt physician assessment of specific fluid volumes, our study suggests that gestalt estimation may be adequately reliable in distinguishing abnormal volumes of pelvic free fluid on FAST from smaller volumes that may not be clinically important in stable children after BAT.

Our study findings are similar to other studies, showing that ultrasound-trained PEM physicians have strong inter-rater agreement in classifying small volumes of pelvic free fluid. However, our study was unique in that we included expert pediatric radiologists and ultrasound-trained PEM physicians as well as a significant number of positive FAST with free fluid in the pelvis to determine a reliable volume cutoff. Specifically, we found strong inter-rater reliability among 2 ultrasound-trained PEM physicians for gestalt classification of moderate or large pelvic fluid from smaller volumes of 0.65 with 92% raw agreement. These findings were comparable to Riera et al.

Figure 1. Illustrative, still image examples of different pelvic free fluid volumes on FAST by reviewer agreement. The left column includes examples of no fluid as well as trace, small, moderate, and large fluid with unanimous or near unanimous agreement among the 4 physician reviewers. The right column includes representative examples of pelvic fluid with significant among the 4 physician reviewers (with respective volumes classification by each reviewer in parentheses), along with the features that complicated reliable interpretation.

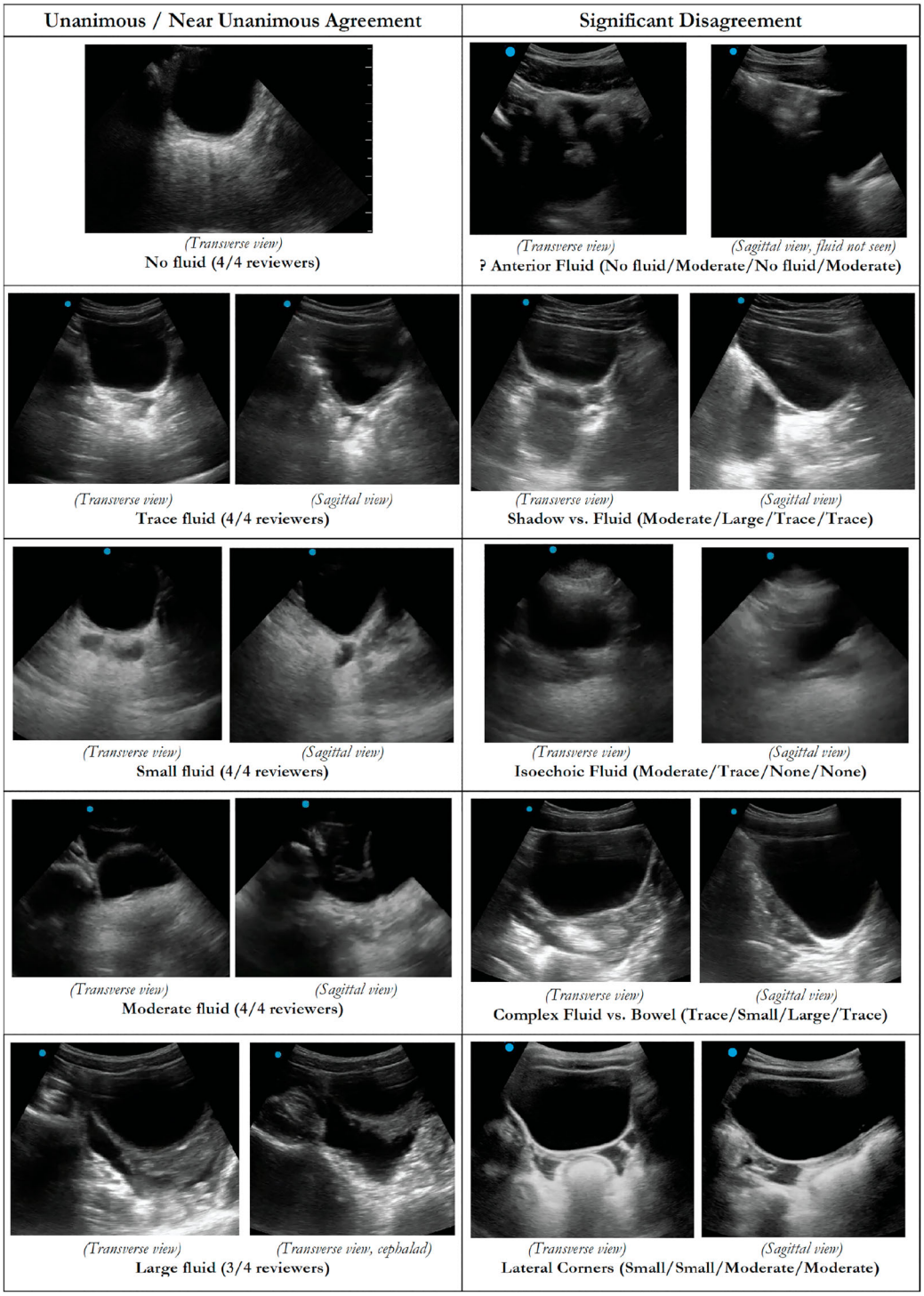


Table 3. Demographic and Ultrasonographic Characteristics Associated with Pelvic Free Fluid

		Classified as Physiologic Free Fluid		
	All FAST, n = 101	**Neither or 1 Radiologist, n = 84**	**Both Radiologists, n = 17**	***P*-value**
Sex, n (%)				
Girls	52 (51)	38 (45)	14 (82)	0.005
Boys	49 (49)	46 (55)	3 (18)	
Age (years), n (%)				
0–5	34 (34)	28 (33)	6 (35)	0.87
6–11	38 (38)	31 (37)	7 (41)	
12–18	29 (29)	25 (30)	4 (24)	
Volume class, n (%)				
Small or less	90 (89)	73 (87)	17 (100)	0.2
Moderate/large	11 (11)	11 (13)	0 (0)	
Echogenicity,[a] n (%)				
Hyperechoic	15 (18)	14 (17)	1 (6)	0.019
Isoechoic	78 (94)	61 (73)	17 (100)	0.045
Location[a], n (%)				
Anterior	10 (10)	9 (11)	1 (6)	>0.9
Posterior	63 (62)	46 (55)	17 (100)	<0.001
Lateral	8 (8)	6 (7)	2 (12)	0.6
Other	3 (3)	3 (4)	0 (0)	>0.9

Chi-squared and Fisher's exact results for demographic and ultrasonographic pelvic free fluid characteristics associated with physiologic free fluid classification.
[a]Free fluid echogenicity and location defined for each FAST based on characterization by any 1 or more of the 4 reviewers. Echogenicity is relative to bladder contents.

Table 4. Demographic and Ultrasonographic Characteristics Associated with Free Fluid Volume Classification

		Small or Less	**Moderate or Large**	***P*-value**
All FAST	101	90 (89)	11 (11)	
Sex, n (%)				
Girls	52	48 (53)	4 (36)	0.3
Boys	49	42 (47)	7 (64)	
Age, n (%)				
0–5	34	32 (36)	2 (18)	0.5
6–11	38	33 (37)	5 (45)	
12–17	29	25 (28)	4 (36)	
Echogenicity[a], n (%)				
Hyperechoic	15	8 (11)	7 (64)	<0.001
Isoechoic	78	67 (93)	11 (100)	0.2
Location[a], n (%)				
Anterior	10	4 (4.4)	6 (55)	<0.001
Posterior	63	54 (60)	9 (82)	0.2
Lateral	8	5 (5.6)	3 (27)	0.04
Other	3	0 (0)	3 (27)	<0.001

Chi-squared and Fisher's exact results for demographic and ultrasonographic fluid characteristics associated with dichotomous free fluid volume classifications (small or less versus moderate/large).
[a]Free fluid echogenicity and location defined for each FAST based on characterization by any 1 or more of the 4 reviewers. Echogenicity is relative to bladder contents.

who demonstrated an inter-rater reliability among 2 ultrasound-trained PEM physicians for a predefined "concerning FAST" (any fluid outside of the pelvis or moderate to large pelvic free fluid) of 0.72 with 86% raw agreement.[10] This study, which included review of 448 FAST (31 positive, 18 "concerning," 28 with any pelvic fluid, and 3 with isolated moderate or large pelvic fluid), defined moderate and large amounts of pelvic fluid according to anatomic landmarks.[10] Using this definition, their expert reviewers disagreed regarding the categorization of pelvic fluid volume on 6 of 28 (19%)[10] compared to disagreement in our study for 8 of 81 (10%) FAST between ultrasound-trained PEM physician. Of note, this was similar to disagreement between that of the pediatric radiologist reviewers in this study, 7 of 81 (9%).

Our study demonstrates that the inter-rater reliability of FAST is comparable to other commonly used predictor variables used in evidence-based diagnostic strategies for evaluating children after BAT. For example, the Pediatric Emergency Care Advanced Research Network (PECARN) clinical decision rule for clinically important IAI in children after BAT

includes signs and symptoms with reliability greater than 0.6 and lower confidence interval greater than 0.4.[3,13] Additionally, raw agreement may even be a more accurate reflection of reliability given that Cohen's kappa measurement may be falsely lowered due to the low prevalence conditions, such as the moderate/large pelvic free fluid class in our study.[14,15] In our study, FAST pelvic free fluid agreement was >90% between ultrasound-trained PEM physicians and pediatric radiologists in the classification of moderate or large fluid from smaller fluid volumes.

Unlike prior studies, our study evaluated the reliability of pediatric radiologists. The regularity with which pediatric radiologists visually estimate free fluid volume and their dedicated training in ultrasound interpretation makes their characterization of free fluid likely to be physiologic (provided the appropriate clinical context) a suitable clinical reference standard. Pediatric radiologists encounter physiologic and pathologic free fluid on abdominal ultrasound and CT frequently. Similarly, it is common practice of pediatric radiologists to quantify volume using the terms "small" and "trace" based on gestalt estimation without formalized criteria. Pelvic free fluid considered physiologic by both pediatric radiologist reviewers were most often girls (14 of 17), anechoic (isoechoic relative to the bladder, without heterogeneous echoes or septa), and classified as trace or small. Conversely, hyperechoic fluid was most often not considered physiologic, corresponding to the known higher density and echogenicity of clotted blood or enteric contents.[12,16,17] Only 1 FAST with fluid described as hyperechoic was considered physiologic, although 3 of the 4 reviewers had actually described the fluid as isoechoic. Similarly, only 1 FAST with moderate free fluid was considered physiologic, by 1 of the 2 radiologist reviewers. Although fluid considered physiologic was most likely to be located posterior to the bladder, the highest proportion of fluid in this location coincided with disagreement between the radiologists regarding the potentially physiologic nature of the fluid. This finding suggests that this characteristic is less helpful in differentiating physiologic from pathologic pelvic free fluid given that both commonly collect in this location.

Characteristics of pelvic fluid that were associated with gestalt fluid volume classification coincided with existing literature, reflecting the expertise of the reviewers in our study. For instance, locations anterior or lateral to the bladder were associated with moderate or large volumes of fluid, similar to the predetermined definitions used by Riera et al.[10] Similarly, fluid located in "other" location (eg, retrouterine) was associated with moderate or large collections, emphasizing the importance of adequate depth and fanning fully through adjacent organs on FAST. Fluid that was moderate or large in volume was also more likely to be described as hyperechoic (64% versus 11% of fluid small or less in volume). However, it is important to highlight that non-anechoic fluid (eg, complex fluid that is echogenic or heterogeneous) is always abnormal, regardless of volume.

Our observations from cases that required adjudication highlight several important considerations for improving the reliability of pelvic free fluid interpretation on pediatric FAST. First, it is essential to fan slowly and thoroughly through both pelvic views, ensuring complete visualization in both sagittal and transverse planes, which helps confirm fluid presence and volume. Second, fluid located anterior or superior (which may appear anteriorly on transverse view when the transducer is fanned cephalad) to the bladder poses a specific challenge. Confirming or ruling out fluid in these locations requires using both views (transverse and sagittal) and meticulous fanning. Third, shadows created by pelvic structures can complicate interpretation, and distinguishing between fluid and shadow artifacts requires careful attention. Fourth, isoechoic or hyperechoic areas of fluid are often difficult to detect, particularly when posterior acoustic enhancement is present; adjusting the far gain can help reduce this effect and improve fluid visibility. Fifth, in 2 cases, fluid concurrently at both lateral corners of the bladder was classified differently by PEM physicians and radiologists, with PEM physicians rating it as moderate and radiologists as small. For consistency with our study findings, we propose considering such findings as moderate.

We determined that multiple physician experts can use gestalt to reliably distinguish moderate or large pelvic fluid from smaller fluid collections in a sample of positive pediatric FAST. Based on our study findings and investigator review, we developed the following working definition for gestalt estimation of fluid volumes: trace fluid is a barely perceptible

stripe; small fluid appears as a thin layer in the pelvic recesses; moderate fluid is a more conspicuous collection beginning to cause visible displacement of structures, extending superior to, anterior to, lateral to, or concurrently at both lateral corners of the bladder; large fluid is extensive fluid causing significant displacement of pelvic organs and extending between bowel loops above the bladder. Future studies should evaluate whether PEM physicians without ultrasound fellowship training may be able to make similarly reliable assessments to a blinded ultrasound expert. Prior retrospective investigation at our institution has found that negative FAST in conjunction with physical examination may have greater negative predictive value than either alone, suggesting its utility in children with low pre-test probability of IAI.[18] In light of the present findings, as well as prior studies examining small volumes of isolated pelvic free fluid in children after BAT,[6,7,9,10] prospective studies are needed to evaluate the clinical relevance of isolated pelvic fluid estimated by gestalt to be small or less in volume, particularly in patients with low risk of clinically significant IAI.[3,19]

Our study has several limitations. First, the retrospective nature of the FAST limited the ability to evaluate image interpretation with the patient's clinical presentation, as would be done in real-time at bedside. However, given our primary aim of assessing reliability, this allowed blinded review of a larger sample of FAST positive for fluid in the pelvis and limited reviewer bias. We did include a short prompt describing the patient age and sex, given potential relevance of these factors to pelvic fluid volume assessment and physiologic classification. Second, our study was not powered to detect more complex multivariate relationships among patient age, sex, and fluid characteristics. Given the relevance of menarchal status to the presence of physiologic pelvic free fluid, we might have expected to find an association between age and physiologic fluid. Given that 14 of 17 FAST deemed physiologic were in girls (median age 9.5 years), capturing menarchal status may have be elucidating. Third, image acquisition quality was variable and, apart from excluding FAST with still images only, was not among the inclusion criteria for this study. Variability in image quality (such as missing the sagittal view of the pelvis[20]) occurs clinically, so this may strengthen the generalizability of our findings. Our findings also underscore the importance of including both sagittal and transverse views of the pelvis to more reliably identify and characterize free fluid on FAST. Fourth, our findings among ultrasound experts may not be generalizable to all PEM physicians. However, establishing the reliability of a gestalt assessment of pelvic fluid volume among experts, without complex measurement or formalized definition, is an important first step in evaluating its utility for future studies and implementation.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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