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A review on using ultrasound for evaluation of pediatric blunt abdominal trauma

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Abstract: This study reviewed the former studies conducted on the usefulness of accuracy of focused assessment with sonography for trauma (FAST) or any plain ultrasonography (US) scan in pediatric blunt abdominal trauma (BAT), to assess its accuracy, sensitivity, specificity, and positive and negative predictive values (PPV and NPV).
Searches were conducted using the predefined keywords and Medical Subject Headings (MeSH) terms across MEDLINE (PubMed), Scopus, Web of Science, Cochrane Collaboration Library, Embase, ClinicalTrials.gov, Magiran and SID.ir databases. Duplicate publications were excluded; then the titles and abstracts of eligible studies were reviewed for how they report blunt trauma, pediatric patients, and ultrasound modality in their text. Cochrane RevMan version 5.3 was used for the results analysis and assessing the risk of bias in the studies.
Out of 923 studies, 902 were excluded, and only 19 articles were included in this review, out of which one was a randomized clinical trial (RCT), three were cohort studies, two were contrast-enhanced US (CEUS) studies, and 13 were prospective or retrospective descriptive studies. The total population studied in the articles was 3454 patients. The results showed that the specificity of US in pediatric BAT was 93%, the sensitivity was 54%, and the PPV in comparison to clinical examination was 73% versus 37%. CEUS protocol achieved 100% in both sensitivity and specificity analysis. The only RCT study which included about 28% of the studies population also reached a sensitivity and specificity of 97% and 98%, respectively using a combinational protocol of clinical examination, laboratory investigation, and US assessment.
Ultrasonography does not provide more results than clinical examination, though better PPV results. A combination of follow-up, US examination, and laboratory requests may also have more accurate results. Moreover, a CEUS protocol may reach that goal with an acceptable time-saving outcome, but it needs more studies to be confirmed.

Keywords: Abdomen; Focused Assessment with Sonography for Trauma; Nonpenetrating Wounds; Pediatrics; Ultrasonography

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1. Introduction

Trauma is one of the public health concerns worldwide, and pediatric trauma considers the studies and practices of this age range specialized due to various effects of their anatomy and physiology, in comparison to adult people (1-3). Blunt abdominal trauma (BAT) is one of these concerns. The introduction of ultrasound (US) in the late 1980s and its positive outcomes changed the guidelines for the use of US for abdominal traumas in adult patients. The primary studies have shown high sensitivity and specificity of US and focused abdominal assessment with sonography for trauma (FAST) modalities in pediatric patients; however, the ongoing practices and studies have questioned those results and kept the use of FAST or the US controversial in pediatric BAT (4-8).
Practitioners are inclined to clinically re-evaluate laboratory investigations or abdominopelvic computed tomography (CT) scans in suspected patients to clinically judge on pediatric BAT that causes longer hospital stay and higher care costs, as well as making better decisions on whether to admit or discharge the patient, or surgically intervene (5,9,10). The primary aim for using US in BAT was to reduce these intervenes as well as decision-making time to improve patient safety through accurate and smooth management. Despite the widespread use of US for adult patients, deciding on whether to use the plain US or FAST results for pediatric patients who are suspected to have BAT is controversial and practitioners prefer yet other tests for pediatric BAT management (2).
This study aimed to evaluate the accuracy of FAST or any plain US scan as a screening modality in pediatric patients with BAT due to its advantages in comparison to other imaging modalities like CT scan. These advantages are: low-cost,

wide usage, availability in emergency departments (EDs), familiarity of emergency medicine specialists or surgeons with the modality for their quick decision-making, and time-saving for pediatric practices.

2. Methods

2.1. Criteria for considering studies in this review

In this review, we planned to include any FAST study in the literature conducted on pediatric patients with BAT without any time limitation up to the end of 2018. The search results extended the FAST concept into other US studies, and prior researches on the field when the FAST exam was not introduced to the community, as well as late studies which involved point of care ultrasonography (POCUS) or other detailed USs for patient examination.

2.2. Types of studies

Researchers intended to include only randomized clinical trials (RCTs) in this review to achieve higher evidence in the final analysis; however, our search resulted in only one RCT in this area. To this end, other conclusive descriptive studies (i.e., cohort, prospective, and retrospective) were included for the primary goal of assessing sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the FAST examination in the pediatric age range.

2.3. Participants

The eligibility of pediatric patients to participate in this study was their blunt abdominal trauma. The varying reports of pediatric patients' age in studies included patients up to 18 years old, however most studies reported from birth to adolescence (12-16 years old). In this review, no age-specific limitation was considered during database search, or gathering data and analysis. Age groups of studies are summarized in appendix 1.

2.4. Index tests

Studies including any form of abdominopelvic US exam on pediatric patients with BAT, especially FAST or e-FAST (extended FAST) were included in this review.

2.5. Target conditions

The goal of this study was to analyze sensitivity, specificity, PPV, and NPV of FAST exam in BAT pediatric patients for the detection of free fluid or solid organ injuries.

2.6. Reference standards

The reference standard for analysis was planned for CT scan as the modality of choice in trauma assessment. However, search results showed various modalities including diagnostic peritoneal lavage (DPL), contrast-enhanced US (CEUS), clinical follow-up, and laboratory investigations, as well as laparotomy results or autopsies. The reference standards of studies are summarized in appendix 1.

2.7. Search methods for identification of studies

The primary search keywords were retrieved from Medical Subject Headings (MeSH) including "Sonography", "Free Fluid", and "Blunt Abdominal Trauma". One Medical Sciences librarian assisted two authors of this study (MC and MM) in this regard, and the searches were performed (MM and HJ). While the search results were limited to pediatric age group, in cases that this option was not possible in the databases search, papers would be assessed for their eligibility via the primary screening of their titles and abstracts.

2.8. Selection of studies

Primary database search results (i.e., titles and abstracts) were independently reviewed by two authors (MC and MM) to assess their eligibility for inclusion in this review. The studies were assessed for their subjects including the use of US, pediatric patients, and BAT. Studies that seemed not to report these data exclusively or were out of the scope of the review were excluded by authors. The final studies selected by both authors were rechecked by a third author (MY) for any controversies.

2.9. Data extraction and management

The characteristic information including the size, age, male: female ratio, index modality, and its results, reference tests, and analyses of included studies are summarized and reported in a pre-defined and classified structural table (Appendix 1).

2.10. Assessment of methodological quality

Included studies (clinical trial or descriptive type studies) were assessed using CONSORT statement and STROBE checklist, respectively by two authors (MY and MM) independently. Bias in studies were also assessed considering Cochrane guidelines and using Cochrane RevMan version 5.3 (11). The detailed characteristics of studies are demonstrated in appendix 1.

2.11. Statistical analysis

True positive (TP), true negative (TN), false positive (FP), and false negative (FN) results were extracted from the studies, plain text information of which are provided in table 1. Cochrane RevMan version 5.3 was also applied for meta-analyses.

2.12. Ethical approval and consent to participate/publication

This project was found to be as per the ethical principles and the national norms and standards for conducting medical research in Iran – Approval ID: IR.IUMS.FMD.REC.1398.055-EN – Approval date: 2019-04-30.

Table 1 Summary of overall statistical findings

	TP	FP	FN	TN	Patient (total number)	Sensitivity	Specificity	PPV	NPV
Overall	469	169	347	2469	3454	0,5748	0,9359	0,7351	0,8768
Free fluid	282	128	234	1974	2618	0,5465	0,9391	0,6878	0,8940
Clinical vs. paraclinical	68	112	65	1192	1437	0,5113	0,9141	0,3778	0,9483
CEUS vs. CT scan	79	0	0	21	100	1	1	1	1

TP: True positive; FP: False positive; FN: False negative; TN: True negative; PPV: Positive predictive value; NPV: Negative predictive value; CEUS: Contrast-enhanced ultrasound

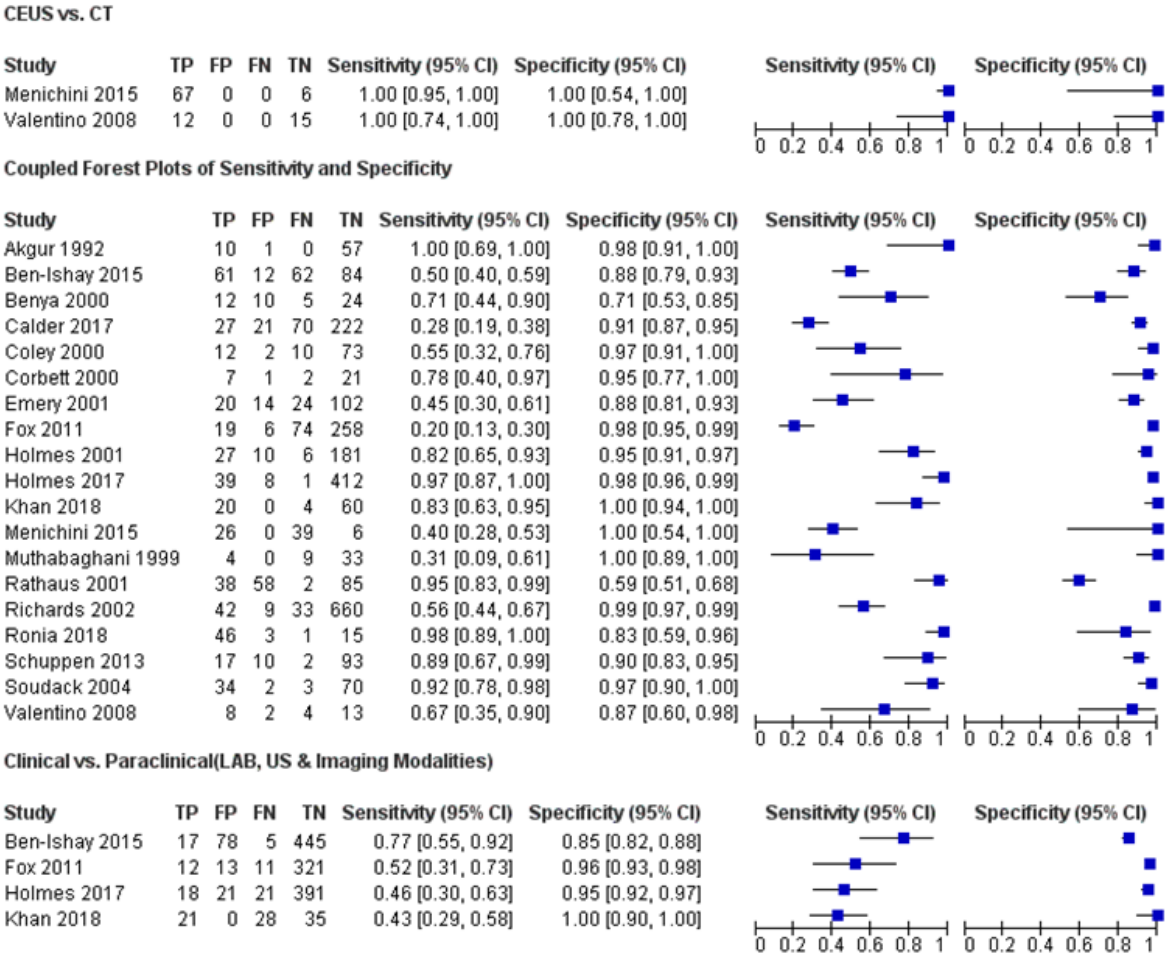

Figure 1 Forest plot of tests in summary (CEUS: Contrast-enhanced ultrasound; TP: True positive; FP: False positive; FN: False negative; TN: True negative)

3. Results

Databases search through defined keywords resulted in 1137 records. Using Zotero Reference Manager version 5.0.60, 216 duplicate records were merged and finally 921 records were analyzed by the review of their titles and abstracts to assess the eligibility for inclusion in the study.

The primary screening resulted in the exclusion of 888 records so that 31 studies remained for further full-text review. Of these records, full texts of 3 studies could not be retrieved, then the remaining 28 studies were assessed for their quality and entered into meta-analysis. In-mail messages were sent through the ResearchGate platform to the authors of those 3 studies without full texts. Till the time of this publication, no full texts were achieved. Eleven studies were excluded, mostly due to not reporting sufficient data for assessing the accuracy of US exams. Hence, the remaining 17 studies together with two other bibliographic reviews were considered for the final review and meta-analysis.

Out of these studies, one was RCT, three studies were prospective cohort studies, two were descriptive studies on using CEUS that one of them was prospective and the other was retrospective, 11 were prospective descriptive studies, and two were retrospective descriptive studies. The detailed characteristics of studies are summarized in appendix 1.

3.1. The methodological quality of the included studies

Retrieved studies were assessed for their quality of reporting using CONSORT statement and STROBE checklist. The included studies were also analyzed for their quality and possible bias by two authors considering Cochrane guidelines. It was planned to refer the controversy of authors to a third author, though not such kind of conflict was observed. Varying reports of using US exams in pediatric patients with BAT and assessing the sensitivity and specificity of this diagnostic modality differs from 20% to 100% in different studies. Most of the prior studies have reported higher sensitivity and specificity of the modality; however, later studies have confirmed its higher specificity but not sensitivity. The scoping review and meta-analysis of plain US yielded different sensitivity records (i.e., about 40% to 80%) however, the specificity analysis showed better results, that is mostly greater than 90% even up to 100%, which seems to be the same as the results of the meta-analysis for sensitivity and specificity of clinical examination in comparison to paraclinical assessment. Furthermore, the results of CEUS studies changed these concepts due to their 100% reports for sensitivity and specificity (Figures 1 and 2). In the study of Holmes et al., the combination of clinical examination and laboratory investigations with US examination in comparison to the sole use of US for patient management demonstrated very high and acceptable sensitivity and specificity. In the included RCT study, the sensitivity and specificity of 97% and 98%, respectively, could be nearly the same as the CEUS results (5,12,13). The final assessment of sensitivity, specificity, PPV, and NPV, respectively, from studies are summarized in detail in table 1. However, there is no significant difference between the US and clinical examination in the sensitivity and specificity analyses. It shows better PPV of the US in comparison to clinical examination, 73% versus 37%, respectively.

The current review further aimed to find out whether the US (mostly FAST) is capable of diagnosing solid organ injuries or not; the results of this analysis seem to be the same as the current meta-analyses, and the capability of CEUS and the combination of clinical examination or laboratory investigations are both higher than that of the plain US for these diagnoses, patient management, and follow-up. Moreover, there is no significant difference between the analyses of free fluid and intra-abdominal injury (IAI). Appendix 1 and table 1 demonstrate these findings in detail.

4. Discussion

This review aimed to assess the accuracy of using the US especially FAST exam in pediatric trauma patients. Hence, a wide spectrum of primary databases search was conducted that directed finally into 28 articles plus other two bibliographic articles. Eleven articles were excluded due to not having raw data for meta-analyses or not providing accurate data about analysis and their study protocols.

This review statistically discussed the accuracy of using US (especially FAST exam) in pediatric BAT assessment. Accordingly, table 1 that summarizes these parameters showed an overall high specificity of US in pediatric BAT (~93%) which was not significantly different from the clinical assessment of patients (~91%) in comparison to the laboratory or other paraclinical investigations. However, the sensitivity of these approaches is low and may not be routinely recommended in

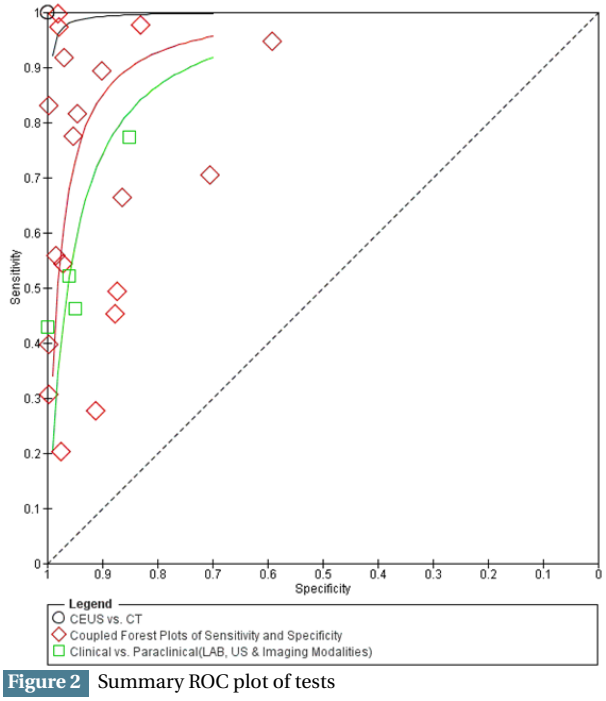

Figure 2 Summary ROC plot of tests

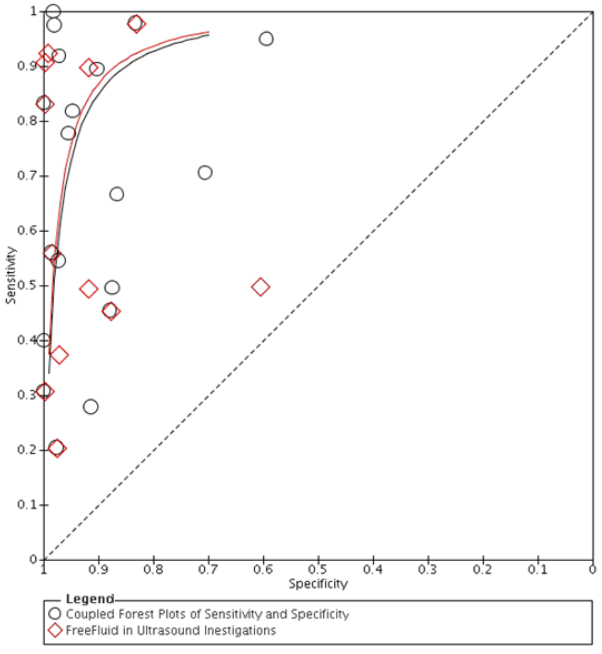

Figure 3 Summary ROC plot of free fluid vs. overall assessment in ultrasonography

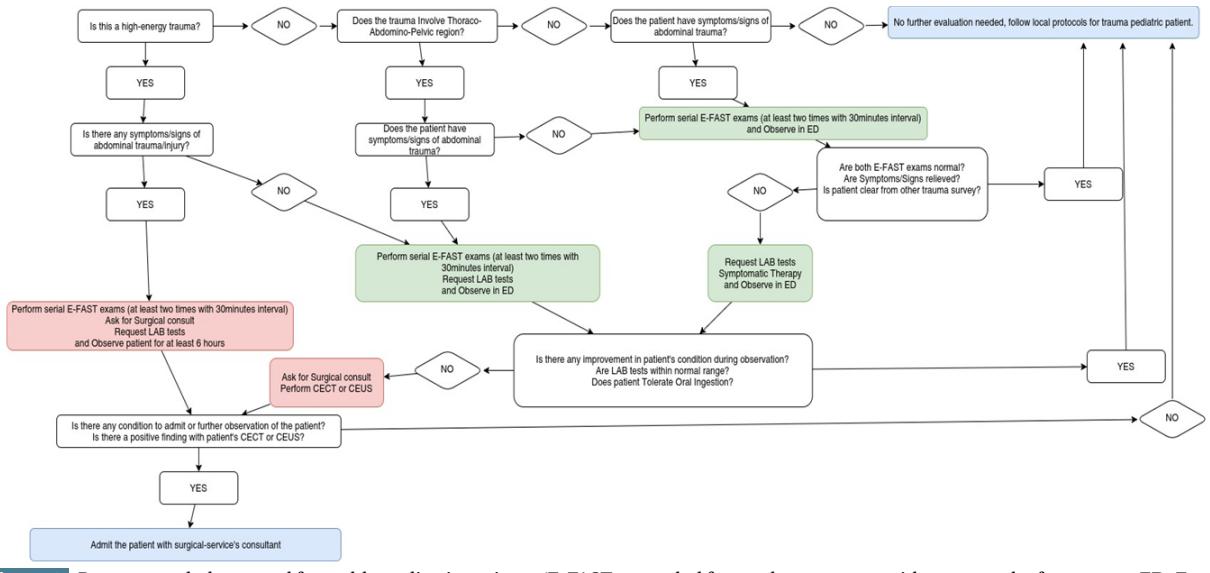

Figure 4 Recommended protocol for stable pediatric patients (E-FAST: extended focused assessment with sonography for trauma; ED: Emergency department)

all pediatric trauma assessments in clinical practice (~55%); but using the US in comparison to the sole clinical assessment showed better PPV and this power of the US could be useful in investigating suspicious patients. The very primary study of Akgür et al. in 1992 had findings different from this overall analysis, showing nearly 100% sensitivity and specificity of using US in pediatric BAT exam, as the two CEUS studies showed these accuracy levels as well. Although newer plain US studies did not support that accuracy, a combination of clinical examination, US, and laboratory investigation may reach this accuracy as the only RCT of Holmes et al. in 2017 declared it. Figures 1 and 2 demonstrate how these findings could be discussed in further details (5,8,12,13). The findings of the only RCT study which included about 28% of the studies population may show the use of US in pediatric BAT very useful; however, to recommend its use as a solo screening tool, another huge populated RCT may be needed. It is better to keep in mind that ALARA (as low as reasonably achievable) principle may be achieved better by CEUS than by intravenous contrast for a CT scan examination. It means the use of CEUS for pediatric BAT which showed 100% sensitivity and specificity may be an alternative for achieving the ALARA goal; however, the only two studies in this field were from Italy, with a total population of 100 patients that is less than 3% of all studies population and this method needs to be proved by other studies in other locations. Furthermore, the overall assessment in comparison to free fluid assessment by the plain US did not show a significant difference through the meta-analyses of data (Figure 3) and may show a great controversy of why the accuracy of plain US did not reach the high level, but CEUS did, and whether these study results in CEUS could be like the primary study of 1992 in the plain US? The main results of this study agree with those of previous studies and reviews, but the goal of this study in assessing the use of US in pediatric patients, could be the novelty of this study, which caused the gathering of more studies and populations for final analysis in this field (2–4,10,12–16).

The study design and reporting in this review were satisfying so that about 7 out of 19 had a very low risk of bias assessment. The overall risk of bias assessment and applicability concerns of studies showed good but not excellent results in this field; however, the newer studies had more concerns than previously reported ones. Authors recommend using CONSORT and STROBE tools for clinical trials and descriptive studies, respectively to the whole scientific community.

A new multi-centric, multi-national, double-blinded, huge-populated RCT may be needed to come to the final conclusion on the controversies of using different types of US in pediatric BAT. It is also recommended that patients are clustered as standard ED care, e-FAST patients, and CEUS patients in different age and gender groups. As a point of ethical issue, a minimum of 6-12 hours of stay in ED or observation ward or discharge with the point of access to ED facility in case of new or suspicious symptoms are recommended for a future research study.

5. Strengths and weaknesses of the review

This review included nearly all of the studies on the use of US exams in pediatric BAT with no time limitation up to the end of 2018; the variation of studies made the conclusion more complicated. However, it showed where to focus and clarify for future studies and may dispel doubts in decision-making, guidelines, and local protocols.

6. Conclusion

The use of US in assessing pediatric BAT may not rule out normal patients compared to clinical examination, but it has better PPV and this could be the power of this test for assessing suspicious patients. However, it does not seem to be sufficient and it is recommended that pediatric patients should be assessed by other investigation methods (i.e., laboratory requests, clinical follow-up, and re-evaluations both clinically and with US facility or contrast-enhanced CT scan (CECT)) as well. Sometimes it is better to consult with a senior or expert colleague or (pediatric) surgeon to make an appropriate decision on a patient's situation. E-FAST exam also gives results like those of detailed abdominopelvic US exams and could be recommended as a point of care US (POCUS) in the clinical setting with no doubt, which saves time and facilitates the decision-making on a patient health outcome. However, if it is needed to move the patient from ED for radiologic or US investigations, using CEUS may achieve the ALARA goal much better. With these findings, authors neither recommend nor forbid routine use of US in pediatric BAT; however, in case of high-energy trauma or suspicious abdominal injury, it is recommended that local guidelines on how to investigate patients with clinical serial examinations +/- US examinations, laboratory or CEUS/CECT requests should be followed.

Authors recommend (as of a local protocol in a trauma center) at least 6 hours of observation is required for suspicious patients along with serial clinical examinations, e-FAST, hemoglobin level check and urine analysis before discharge and notifying red flags of thoracoabdominal injuries with patients and their caregivers while discharging. A recommended algorithm is demonstrated in figure 4.

7. Declarations

7.1. Acknowledgment

Authors used a bunch of Libre/Open Source Softwares to surf the web, collect information, analyze data & publish the paper; our kind pleasures belong to alumni of "Mozilla Firefox", "LibreOffice", "Zotero", "uGet", "Grammarly" & "Cochrane RevMan" (hope the last one someday would be published under software freedoms Two and Three too); and at last "Richard Stallman" founder of "Free Software Foundation (www.fsf.org)", for bringing these useful elaborate softwares and the philosophy of software freedom for human beings. Also Mrs. Ilghami for her kind and supportive language editing.

7.2. Authors' contribution

MC conceptualized the primary idea of the study & review. The primary study proposal was a work of MC & HBG. MM & MC defined the primary searching keywords using MeSH keywords. MM & HJ searched the databases with keywords independently. MM & MC reviewed retrieved records' titles and abstracts for their ineligibility of the study; it was planned to refer any conflicts to HBG. MM & MY extracted the selected articles' characteristics information independently; it was planned to refer any conflicts to HBG that did not happen. MM & HJ extracted patient data from articles for statistical analysis independently; it was planned to refer any conflicts to HSB which didn't happen. The final statistical analysis is a proof work of all three authors. MM, MY, HBG, MC & SMM wrote the primary draft of the article with predefined sections' editing. The final proof of the paper is the result of all of seven authors' collaboration.

7.3. Conflict of interest

There are no interests to report.

7.4. Funding

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References

1. ATLS subcommittee; American College of Surgeons' Committee on Trauma; international ATLS working group. Advanced trauma life support (ATLS®): the ninth edition. J Trauma Acute Care Surg. 2013;74(5):1363–6.
2. Stengel D, Leisterer J, Ferrada P, Ekkernkamp A, Mutze S, Hoenning A. Point-of-care ultrasonography for diagnosing thoracoabdominal injuries in patients with blunt trauma. Cochrane Database Syst Rev. 2018;2018(12):CD012669
3. Stengel D, Rademacher G, Ekkernkamp A, Güthoff C, Mutze S. Emergency ultrasound-based algorithms for diagnosing blunt abdominal trauma. Cochrane Database Syst Rev. 2015; 2015(9):CD004446.
4. Taş F, Ceran C, Atalar MH, Bulut S, Selbeş B, Işık AO. The efficacy of ultrasonography in hemodynamically stable children with blunt abdominal trauma: a prospective comparison with computed tomography. Eur J Radiol. 2004;51(1):91–6.
5. Holmes JF, Kelley KM, Wootton-Gorges SL, Utter GH, Abramson LP, Rose JS, et al. Effect of abdominal ultrasound on clinical care, outcomes, and resource use among children with blunt torso trauma: a randomized clinical trial. JAMA. 2017;317(22):2290-6.
6. Benya EC, Lim-Dunham JE, Landrum O, Statter M. Abdominal sonography in examination of children with blunt abdominal trauma. Am J Roentgenol. 2000;174(6):1613-6.
7. Emery KH, McAneney CM, Racadio JM, Johnson ND, Evora DK, Garcia VF. Absent peritoneal fluid on screening trauma ultrasonography in children: a prospective comparison with computed tomography. J Pediatr Surg. 2001;36(4):565–9.
8. Akgür FM, Aktuğ T, Kovanhkaya A, Erdağ G, Olguner M,

Hoşgör M, et al. Initial evaluation of children sustaining blunt abdominal trauma: ultrasonography vs. diagnostic peritoneal lavage. Eur J Pediatr Surg. 1993;3(5):278-80.
9. Ben-Ishay O, Daoud M, Peled Z, Brauner E, Bahouth H, Kluger Y. Focused abdominal sonography for trauma in the clinical evaluation of children with blunt abdominal trauma. World J Emerg Surg. 2015;10:27.
10. Khan RA, Hazique M, Wahab S. Analytical revisit to basics helps reduce unnecessary CT scan in children with abdominal trauma: a single institution experience. Pediatr Traumatol Orthop Reconstr Surg. 2018;6(2):54–62.
11. Cochrane handbook for systematic reviews of interventions version 5.1.0. 2011.
12. Menichini G, Sessa B, Trinci M, Galluzzo M, Miele V. Accuracy of contrast-enhanced ultrasound (CEUS) in the identification and characterization of traumatic solid organ lesions in children: a retrospective comparison with baseline US and CE-MDCT. Radiol Med (Torino). 2015;120(11):989–1001.
13. Valentino M, Serra C, Pavlica P, Morselli Labate AM, Lima M, Baroncini S, et al. Blunt abdominal trauma: diagnostic performance of contrast-enhanced US in children—initial experience. Radiology. 2008;246(3):903–9.
14. Katz S, Lazar L, Rathaus V, Erez I. Can ultrasonography replace computed tomography in the initial assessment of children with blunt abdominal trauma? J Pediatr Surg. 1996;31(5):649–51.
15. Suthers SE, Albrecht R, Foley D, Mantor PC, Puffinbarger NK, Jones SK, et al. Surgeon-directed ultrasound for trauma is a predictor of intra-abdominal injury in children. Am Surg. 2004;70(2):164-7.
16. Netherton S, Milenkovic V, Taylor M, Davis PJ. Diagnostic accuracy of eFAST in the trauma patient: a systematic review and meta-analysis. CJEM. 2019;21(6):727–38.
17. Calder BW, Vogel AM, Zhang J, Mauldin PD, Huang EY, Savoie KB, et al. Focused assessment with sonography for trauma in children after blunt abdominal trauma: a multi-institutional analysis. J Trauma Acute Care Surg. 2017;83(2):218–24.
18. van Schuppen J, Olthof DC, Wilde JCH, Beenen LFM, van Rijn RR, Goslings JC. Diagnostic accuracy of a step-up imaging strategy in pediatric patients with blunt abdominal trauma. Eur J Radiol. 2014;83(1):206–11.
19. Coley BD, Mutabagani KH, Martin LC, Zumberge N, Cooney DR, Caniano DA, et al. Focused abdominal sonography for trauma (FAST) in children with blunt abdominal trauma. J Trauma. 2000;48(5):902-6.
20. Corbett SW, Andrews HG, Baker EM, Jones WG. ED evaluation of the pediatric trauma patient by ultrasonography. Am J Emerg Med. 2000;18(3):244–9.
21. Fox JC, Boysen M, Gharahbaghian L, Cusick S, Ahmed SS, Anderson CL, et al. Test characteristics of focused assessment of sonography for trauma for clinically significant abdominal free fluid in pediatric blunt abdominal trauma: sensitivity and specificity of pediatric FAST. Acad Emerg Med. 2011;18(5):477–82.
22. Holmes JF, Brant WE, Bond WF, Sokolove PE, Kuppermann N. Emergency department ultrasonography in the evaluation of hypotensive and normotensive children with blunt abdominal trauma. J Pediatr Surg. 2001;36(7):968–73.
23. Mutabagani KH, Coley BD, Zumberge N, McCarthy DW, Besner GE, Caniano DA, et al. Preliminary experience with focused abdominal sonography for trauma (FAST) in children: is it useful? J Pediatr Surg. 1999;34(1):48–54.
24. Richards JR, Knopf NA, Wang L, McGahan JP. Blunt abdominal trauma in children: evaluation with emergency US. Radiology. 2002;222(3):749–54.
25. Ronya R, Baruah RR, Bhattacharyya N, Goswami JK, Saha M, Goswami R, et al. Role of focused abdominal sonography for trauma in solid organ injury in paediatric blunt abdominal trauma. J Evol Med Dent Sci. 2018;7(17):2074–7.
26. Rathaus V, Zissin R, Werner M, Erez I, Shapiro M, Grunebaum M, et al. Minimal pelvic fluid in blunt abdominal trauma in children: the significance of this sonographic finding. J Pediatr Surg. 2001;36(9):1387–9.
27. Soudack M, Epelman M, Maor R, Hayari L, Shoshani G, Heyman-Reiss A, et al. Experience with focused abdominal sonography for trauma (FAST) in 313 pediatric patients. J Clin Ultrasound. 2004;32(2):53–61.

Appendix 1 Characteristics of included studies (studies which included free intra-abdominal fluid results separately)

Study	Type	Sample size	Patients age distribution (years)	Male: female ratio (percent)	Ultrasound test(s)	Ultrasound positive findings summary	Reference test(s)	Timeline
Randomized clinical trial								
Holmes 2017(5)	RCT	925	9.7 ± 5.3	62:38	FAST	10% sensitivity of positive FAST	1- CT scan 2- Clinical evaluations & suspicious	April 2012 – May 2015
Cohort								
Ben-Ishay 2015(9)	Descriptive (cohort)	543	8.2 ± 5	?	FAST	Overall 50% sensitivity of FAST for FIF 77% sensitivity of FAST for IAI	1- CT scan 2- Clinical follow up 3- Laparotomy	January 2010 – December 2012
Calder 2017(17)	Descriptive (multi-center prospective cohort)	2188 (829 FAST performed – 340 included in final report)	7.8 ± 4.6	?	FAST	27.8% sensitivity for IAI 44.4% sensitivity for IAI-I	CT scan	July 2014 – July 2015
van Schuppen 2013(18)	Descriptive (cohort)	122	8-15 (median: 11)	61:39	FAST	22% positive FAST	1- CT scan 2- Clinical evaluations 3- Laboratory investigations	January 2008 – December 2012
Contrast enhanced ultrasonography								
Menichini 2015(12)	Descriptive (retrospective)	73	8.7 ± 2.8	69:31	1- Complete abdominal ultrasonography 2- CEUS	US / CEUS Negative: 64.4% / 8.2% Left kidney injury: 2.7% / 17.8% Right kidney injury: 2.7% / 9.6% Spleen injury: 9.6% / 35.6% Liver injury: 20.6% / 23.8%	CECT	October 2013 – October 2013
Valentino 2008(13)	Descriptive (prospective)	27	8.9 ± 2.8	67:33	1- Complete abdominal ultrasonography 2- CEUS	57.1% sensitivity in US 92.9% sensitivity in CEUS	CECT	September 2003 – August 2006
Prospective descriptive								
Akgür 1992(8)	Descriptive (prospective)	68	9 months to 15 years	66:34	Seems to be as FAST	98.5% accuracy of FAST exam for FIF	DPL	January 1991 – June 1992
Benya 2000(6)	Descriptive (prospective)	51	2 weeks – 16 years (mean: 6 years & 7 months)	68:32	Abdominopelvic US	64.7-70.6% sensitivity in US exam results	Abdominopelvic CT scan	October 1996 – October 1997
Coley 2000(19)	Descriptive (prospective)	97	95 months ± 51 months	64:36	FAST	55% sensitivity of FAST	CECT	July 1997 – August 1998
Corbett 2000(20)	Descriptive (prospective)	47	2-17 (mean: 9)	?	Ultrasound curriculum for ED physicians	75% sensitivity of FAST for air or free fluid	CT scan	February 1995 – February 1996
Emery 2001(7)	Descriptive (prospective)	160	1 month to 18 years (Mean: 9 years and 5 months)	59:41	FAST	45% sensitivity of FAST	CT scan	February 1997 – June 1998
Fox 2011(21)	Descriptive (prospective)	357	0-17 (13-17: 44%; 2-6: 25%; 7-12: 22%; 0-2: 9%)	64:36	FAST	70% sensitivity of positive FAST	1- CT scan 2- Clinical evaluations or laparotomy	2004-2007
Holmes 2001(22)	Descriptive (prospective)	224	?	?	FAST	82% sensitivity in US	1- CT scan 2- Clinical evaluations 3- DPL 4- Laparotomy	April 1996 – September 1999
Khan 2018(10)	Descriptive (prospective)	84	?	?	Detailed abdominal sonography	90.9% sensitivity of positive US findings	1- IV & oral contrasted CT scan 2- Clinical evaluations 3- Laboratory investigations	Period of two years
Mutabagani 1999(23)	Descriptive (prospective)	46	15months to 18 years (mean: 8 years)	63:37	FAST	95% sensitivity	CT-Scan	?
Richards 2002(24)	Descriptive (prospective)	744	10.1 ± 4.9	47:53	FAST	73% sensitivity of positive FAST	1- IV & oral contrasted CT scan 2- Clinical evaluations 3-Laboratory investigations	January 1995 – October 1998
Ronya 2018(25)	Descriptive (prospective)	65	<12 years old	72:28	FAST	93.7% sensitivity 94% specificity 90.6% accuracy	Not exactly defined but seems to be a protocol of 1- CT scan 2- Clinical follow- up 3- Laparotomy	January 2012 – December 2013
Retrospective descriptive								
Rathaus 2001(26)	Descriptive (retrospective)	178	6 months to 16 years (mean: 8.6 years)	69:31	Ultrasound	89.5% sensitivity 96.6% specificity	1- CT scan 2- Clinical Follow-up 3- Ultrasonography	1996-1999
Soudack 2004(27)	Descriptive (retrospective)	313	2 months- 17 years (mean: 7.1)	65:35	FAST	33% sensitivity of positive FAST	1- CECT 2- ELAP	May 1998 – January 2000

FAST: Focused assessment with sonography for trauma; IV: Intravenous; DPL: Diagnostic peritoneal lavage; CECT: Contrast-enhanced CT scan; CEUS: Contrast-enhanced ultrasound; IAI: Intra-abdominal injury; IAI-I: Intra-abdominal injury needed intervention; RCT: Randomized clinical trial; ED: Emergency department; FIF: Free intra-abdominal fluid; ELAP: Explorative laparotomy