Diagnostic accuracy of eFAST in the trauma patient: a systematic review and meta-analysis

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CLINICIAN'S CAPSULE

What is known about the topic?
Published studies demonstrate a wide range of sensitivities and specificities for the various components of the eFAST scan in trauma.

What did this study ask?
Through a systematic review process, we examined the pooled sensitivities and specificities for the components of an eFAST exam.

What did this study find?
The eFAST exam in trauma is helpful to rule in, but not to rule out, pneumothorax, pericardial effusion, and intra-abdominal free fluid.

Why does this study matter to clinicians?
An eFAST scan is an accepted part of the trauma assessment, and users should know the strengths and limitations of the test.

ABSTRACT

Objectives: Performing an extended Focused Assessment with Sonography in Trauma (eFAST) exam is common practice in the initial assessment of trauma patients. The objective of this study was to systematically review the published literature on diagnostic accuracy of all components of the eFAST exam.
Methods: We searched Medline and Embase from inception through October 2018, for diagnostic studies examining the sensitivity and specificity of the eFAST exam. After removal of duplicates, 767 records remained for screening, of which 119 underwent full text review. Meta-DiSc™ software was used to create pooled sensitivities and specificities for included studies. Study quality was assessed using the Quality in Prognostic Studies (QUADAS-2) tool.
Results: Seventy-five studies representing 24,350 patients satisfied our selection criteria. Studies were published between 1989 and 2017. Pooled sensitivities and specificities were calculated for the detection of pneumothorax (69% and 99% respectively), pericardial effusion (91% and 94% respectively), and intra-abdominal free fluid (74% and 98% respectively). Sub-group analysis was completed for detection of intra-abdominal free fluid in hypotensive (sensitivity 74% and specificity 95%), adult normotensive (sensitivity 76% and specificity 98%) and pediatric patients (sensitivity 71% and specificity 95%).
Conclusions: Our systematic review and meta-analysis suggests that e-FAST is a useful bedside tool for ruling in pneumothorax, pericardial effusion, and intra-abdominal free fluid in the trauma setting. Its usefulness as a rule-out tool is not supported by these results.

RÉSUMÉ

Objectif: Le recours à l'évaluation ciblée par échographie étendue en traumatologie (eFAST : sigle anglais) est pratique courante dans l'évaluation initiale des patients ayant subi un trauma. L'étude avait donc pour but une revue systématique de la documentation publiée sur l'exactitude du diagnostic reposant sur tous les éléments constitutifs de l'eFAST.
Méthode: Les chercheurs ont effectué une recherche d'études sur les examens de diagnostic ayant pour objets la sensibilité et la spécificité de l'eFAST, dans les bases de données Medline et Embase, depuis leur début respectif jusqu'à octobre 2018. Après le retrait des doubles, il restait 767 documents aux fins de sélection, dont 119 ont été soumis à un examen en texte intégral. Le logiciel Meta-DiSc^MC a servi à établir la sensibilité et la spécificité globales des études retenues. Quant à la qualité des études, elle a été évaluée à l'aide de l'instrument Quality in Prognostic Studies (QUADAS-2).
Résultats: Au total, 75 études totalisant 24 350 patients et publiées entre 1989 et 2017 répondaient aux critères de sélection. La sensibilité et la spécificité globales ont été calculées pour la détection des pneumothorax (69% et 99% respectivement), des épanchements péricardiques (91% et 94% respectivement) et de liquide libre intra-abdominal (74% et 98% respectivement). Il y a eu également analyse de sous-groupes en vue de la détection de liquide libre intra-abdominal chez les patients hypotendus (sensibilité : 74%; spécificité : 95%), les

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adultes normotendus (sensibilité : 76%; spécificité : 98%) et les enfants (sensibilité : 71%; spécificité : 95%).
Conclusion: D'après les résultats de la revue systématique et de la méta-analyse, l'eFAST au chevet se montre utile pour confirmer la présence de pneumothorax, d'épanchement péricardique ou de liquide libre intra-abdominal en traumatologie, mais pas pour en écarter la présence.

Keywords: Emergency medicine, trauma, ultrasound

BACKGROUND

Traumatic injuries are the most common cause of morbidity and premature mortality in young adults, and the incidence of trauma presentations with a high injury severity is increasing over time.[1–3]

The extended Focused Assessment with Sonography in Trauma (eFAST) exam is an accepted part of the trauma assessment[4,5] and can be used to identify pneumothorax (PTX), pericardial effusions (PCE), and intra-abdominal free fluid (FF).[6] Early detection of these findings can help clinicians prioritize the performance of further diagnostic and therapeutic interventions.[6,7]

Multiple studies have examined the use of ultrasound in the trauma setting, with variable reported sensitivities and specificities.[8,9] Prior reviews have used dated gold standards,[10] limited ultrasound use to surgeons,[11] or studied components of the eFAST in the pre-hospital setting.[12,13] Two recent reviews[14,15] examined the accuracy of an ultrasound for a patient with trauma, but no comprehensive systematic review has been performed examining the accuracy of all components of the eFAST exam. As such, we sought to determine the diagnostic accuracy of the eFAST exam for the detection of PTX, PCE, and FF in the undifferentiated trauma patient.

METHODS

We adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) while undertaking this review.[16]

Search strategy

In collaboration with an expert librarian at the University of Saskatchewan, a search strategy was developed to search Embase and MEDLINE since inception (see Appendix One). Search terms (medical subject, Emtree headings, and free text words) related to trauma patients; bedside ultrasound; and the detection of PTX, PCE, and FF were combined using Boolean Logic. The search was initially performed on August 29, 2017, and was updated on October 19, 2018. No age or language restrictions were applied.

Study selection

Search results were combined using Covidence™ Software (www.covidence.org), and duplicates were removed. Titles and abstracts were initially screened for inclusion by two independent reviewers (SN and VM) prior to a full-text review. Bibliographies of all included studies were also reviewed.

Our population of interest was trauma patients (blunt, penetrating, or polytrauma), who were assessed in an emergency department (ED) or trauma centre, underwent an ultrasound examination during their initial assessment, and subsequently had a gold standard test performed. The ultrasound was considered positive for PTX if a lung point or lack of a lung slide was seen. Hypoechoic fluid in the appropriate anatomic location was considered a positive ultrasound scan for PCE or FF. These definitions of positive scans were consistent across the included studies. Pelvic assessments for FF were not included. The gold standard comparator for PTX was a computed tomography (CT) scan or gush of air with chest tube insertion. For FF, the gold standard was positive laparotomy findings, diagnostic peritoneal lavage/aspirate (DPL/DPA), or CT scan; for PCE, it was a CT scan or positive intra-operative findings. Disagreements regarding study inclusion were resolved by consensus, and, if consensus could not be achieved, a third independent reviewer (PD) adjudicated. For studies published in a foreign language, study authors were contacted for an English translation of their work, and, if not available, a translation attempt was made using an online translation program (Google Translate™).

Outcomes of interest

The primary outcome of interest was the sensitivity and specificity of eFAST. For inclusion, studies were required to have sensitivities and specificities expressed in a 2 × 2 table or to have provided enough information for the creation of a 2 × 2 table. Studies were excluded if they were performed in the wrong setting (pre-hospital), involved the wrong population (non-trauma), did not have an abovementioned gold standard comparator, or had incomplete data. All study designs were included except case reports and case series.

A subgroup analysis was planned for pregnant, geriatric, pediatric, and hypotensive trauma patients. Because of a paucity of available literature, the subgroup analysis was only possible for FF in pediatric and hypotensive patients. Because of high heterogeneity, a subgroup analysis of FF in adult normotensive patients was also performed.

Critical appraisal of included studies

Risk of bias (ROB) was evaluated by two independent reviewers (SN and VM) using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS 2) tool.[17] This tool examines the ROB in four domains: 1) patient selection; 2) the index test (ultrasound); 3) the reference standards (appropriate gold standard); and 4) timing and flow. Please see Appendix 2 for further information on the ROB domains and applicability concerns for all included studies, as well as the prompting questions used for this analysis.

Data extraction

Data were extracted using a piloted data extraction form by two independent reviewers (SN and VM). If discrepancies arose, an attempt at consensus was made, and, if consensus could not be reached, a third reviewer (PD) adjudicated. Extracted information included: gold standard test, study design, patient characteristics (age and gender), type of trauma, true positives, true negatives, false positives, and false negatives for an ultrasound while investigating for the presence of PTX, PCE, or FF.

Data synthesis

Data were compiled using Meta-DiSc™ software[18] and subsequently analyzed in collaboration with a statistician at the Clinical Research Support Unit (CRSU) at the University of Saskatchewan. A bivariate random effect model was used for generating pooled sensitivities, specificities, and positive and negative likelihood ratios.

RESULTS

After removing duplicates, our search strategy yielded 767 articles. After a title and abstract screen, 119 publications underwent a full-text review, of which 71 papers met the inclusion criteria. An additional four papers were added from the bibliographic review, representing a total of 75 included studies (Appendix 3). Seventeen of the included studies examined the eFAST detection of PTX (Appendix 4), nine studies considered the detection of PCE (Appendix 5), and 52 examined the detection of FF (Appendix 6).

PTX

Table 1 summarizes the patient characteristics and study outcomes of the 17 included studies examining the use of ultrasound for the identification of PTX. These studies included a total of 3653 patients. Five of the studies (as indicated in Table 1) considered each lung as a data point, meaning that each patient provided up to two data points. All studies combined provided 4816 data points. The average age was 39.8 years, 75% of the patients were male, and the predominating injury occurred through a blunt mechanism. Pooled sensitivity (Figure 1a) was 0.694 (95% confidence interval [CI] 0.660–0.727; $I^2 = 91\%$), and pooled specificity (Figure 1b) was 0.99 (95% CI 0.99–0.99; $I^2 = 66.9\%$), with high heterogeneity amongst included studies (see Figure 1a and b). The area under the curve (AUC) for the summary receiver operating characteristic (sROC) curve was 0.994 (Appendix 7), and the pooled accuracy was 0.943. Appendix 10 summarizes the ROB for the included studies. Overall, the ROB for the studies investigating PTX was low to moderate, with all bias largely coming from patient selection (Kappa values, as indicated in Appendix 3).

PCE

Table 2 summarizes patient characteristics and study outcomes from the nine studies examining the use of ultrasound for identification of PCE. These studies

Table 1. Patient characteristics and study outcomes of the 17 included studies examining the use of ultrasound for identification of PTX.

Author*†	Year	Location	N-value	No. patients	# TP	Type of trauma	Study design	Sensitivity	Specificity	+LR	-LR
Blaivas	2005	Augusta, USA	176	176	53	Blunt	Prospective	0.98	0.99	119.74	0.02
Kaya	2015	Eskisehir, Turkey	212	212	22	Blunt	Prospective	0.88	0.99	164.56	0.12
Abbasi	2013	Tehran, Iran	146	146	32	Blunt, penetrating, and polytrauma	Prospective	0.86	1.00	188.16	0.14
Soult	2015	Norfolk, USA	345	345	27	Blunt and penetrating	Retrospective	0.40	0.99	54.99	0.61
Ku	2013	Philadelphia, USA	549	549	27	Blunt and penetrating	Prospective	0.57	0.99	96.13	0.43
Helland	2016	Chicago, USA	260	260	33	Blunt	Prospective	0.67	1.00	284.08	0.33
Hyacinthe	2012	Grenoble, France	273	136	28	Blunt and penetrating	Prospective	0.53	0.95	10.57	0.48
Nandipati	2010	New York City, USA	205	205	20	Blunt and penetrating	Prospective	0.95	0.99	175.24	0.05
Brook	2009	Haifa, Israel	172	172	20	Not given	Prospective	0.47	0.98	20.00	0.55
Kirkpatrick	2004	Vancouver, Canada	467	233	33	Blunt and penetrating	Prospective	0.59	0.99	80.73	0.41
Soldati	2008	Multicenter, Italy	218	109	23	Blunt and penetrating	Prospective	0.92	0.99	177.56	0.08
Abdulrahman	2014	Doha, Qatar	610	305	32	Blunt	Prospective	0.43	0.98	22.83	0.58
Ianniello	2014	Rome, Italy	756	378	67	Not given	Retrospective	0.77	1.00	515.21	0.23
Nagarsheth	2011	Knoxville, TN	79	79	18	Blunt and penetrating	Prospective	0.82	1.00	93.30	0.18
Zhang	2006	Hangzhou, China	135	135	25	Blunt	Prospective	0.86	0.97	30.46	0.14
Soldati	2006	Multicenter, Italy	186	186	55	Blunt	Prospective	0.98	1.00	255.11	0.02
Rowan	2002	Vancouver, Canada	27	27	11	Blunt	Prospective	1.00	0.94	16.00	0.05
							Pooled:	0.69	0.99	62.58	0.26
							95% confidence interval:	0.66–0.73	0.98–0.99	32.7–119.7	0.18–0.36

-LR = negative likelihood ratio; +LR = positive likelihood ratio; TP = true positives.
*Studies by Hyacinthe, Kirkpatrick, Soldati, Abdulrahman, and Ianniello included each lung scanned as an n-value, but the other studies counted each patient scanned as an n-value.
†See Appendix 4 for a list of references.

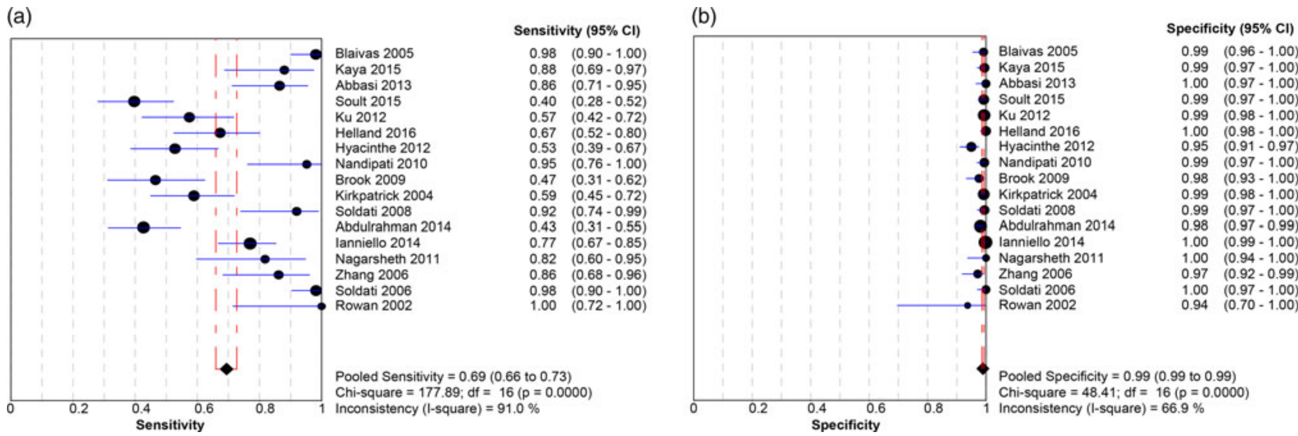

Figure 1. Forest plot displaying the sensitivity (a) and specificity (b) of the included studies for ultrasound identification of PTX in trauma patients.

included a total of 1,031 patients and included only penetrating trauma. The average patient age was 30 years, with a male predominance (86%). Appendix 10 summarizes the ROB and concerns for applicability for all included studies. These studies averaged a low to moderate ROB, with all bias arising solely from factors involved with patient selection (Kappa values, as indicated in Appendix 3). The pooled sensitivity (Figure 2a) was 0.912 (95% CI 0.870–0.944; $I^2 = 65.6\%$), and pooled specificity (Figure 2b) was 0.941 (95% CI 0.922–0.957; $I^2 = 96.6\%$), with high heterogeneity amongst the included studies (see Figure 2a and b). The AUC of the sROC curve (Appendix 8) was 0.975, and the pooled accuracy was 0.934. There were two studies that presented significant outlying results.[19,20] Further, a sensitivity analysis with these two studies removed yielded a sensitivity of 0.982 (95% CI 0.937–0.998; $I^2 = 0\%$) and specificity of 0.985 (95% CI 0.973–0.992; $I^2 = 66.8\%$).

Intra-abdominal FF

Table 3 summarizes the patient characteristics and study outcomes of the 52 included studies examining the use of ultrasound for the identification of FF. These studies

Table 2. Patient characteristics and study outcomes from the nine studies examining the use of ultrasound for identification of a PCE.

Author*	Year	Location	No. of patients	# TP	Type of trauma	Study design	Sensitivity	Specificity	+LR	-LR
Carillo	2000	Louisville, USA	31	9	Penetrating	Prospective	1.00	1.00	43.70	0.05
Matsushima	2017	Los Angeles, USA	103	12	Penetrating	Retrospective	0.92	0.96	20.77	0.08
Rozycki	1999	multicenter, USA	261	29	Penetrating	Prospective	1.00	0.97	30.55	0.02
Tayal	2003	Charlotte, USA	32	8	Penetrating	Prospective	1.00	1.00	47.22	0.06
Nagy	1995	Chicago, USA	122	30	Penetrating	Retrospective	0.97	1.00	175.37	0.05
Nicol	2015	Cape Town, South Africa	172	117	Penetrating	Prospective	0.87	0.05	0.92	2.47
Rozycki	1996	Atlanta, USA	246	10	Penetrating	Prospective	1.00	1.00	452.45	0.05
Varin	2009	Rotterdam, Netherlands	30	12	Penetrating	Retrospective	1.00	1.00	36.54	0.04
Boulanger	2001	Lexington, USA	34	1	Penetrating	Prospective	0.33	1.00	24.00	0.67
						Pooled:	0.91	0.94	34.17	0.11
						95% confidence interval	0.87–0.94	0.92–0.96	0.9–1308	0.03–0.47

-LR = negative likelihood ratio; +LR = positive likelihood ratio; TP = true positives.
*See Appendix 5 for references.

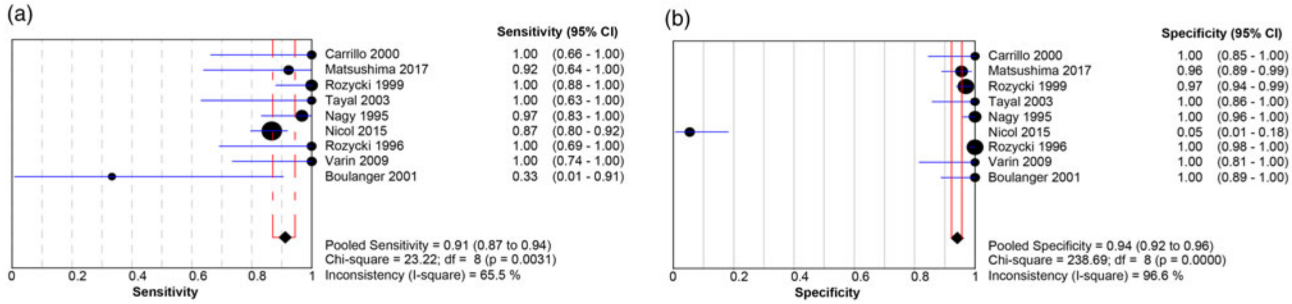

Figure 2. Forest plot displaying the sensitivity (a) and specificity (b) of the included studies for ultrasound identification of PCE in trauma patients.

included a total of 19,666 patients, with an average age of 33.3 years, of whom 68.4% were male. One study[21] examined only pregnant trauma patients, of whom 46%, were in their third trimester. Six studies included only pediatric patients.[22–27] Eight additional studies included patients of all ages (pediatric and adult) but did not stratify patients based on age.[28–35] Five papers included only hypotensive patients (systolic blood pressure [sBP] of <90 mm Hg).[28,36–39] One study[40] compared both a hand-held ultrasound machine and a regular ultrasound machine against the gold standard, providing two sets of data from one paper.

Appendix 10 summarizes the ROB for all included studies. Overall, the ROB was low to moderate. Both patient selection and flow and timing factored into the overall bias assessment of these papers (Kappa values, as indicated in Appendix 3). The pooled sensitivity (Figure 3a) was 0.742 (95% CI 0.726–0.758; I^2 = 82.7%), and the pooled specificity (Figure 3b) was 0.976 (95% CI 0.973–0.978; I^2 = 83%), with high heterogeneity amongst the included studies (see Figure 3a and b). The AUC of the sROC curve (Appendix 9) was 0.931, and the overall pooled accuracy was 0.942.

If only pediatric patients were considered, the pooled sensitivity was 0.709 (95% CI 0.615–0.792; I^2 = 68.1%) and the pooled specificity was 0.951 (95% CI 0.933–0.965; I^2 = 72.1%).[22–27] The pooled positive likelihood ratio was 14.13 (95% CI 6.533–30.567; I^2 = 70.9%). The pooled negative likelihood ratio was 0.32 (95% CI 0.193–0.535; I^2 = 62.6%). The AUC of the sROC curve was 0.959, and the pooled accuracy from these studies was calculated to be 0.92.

Among studies examining only hypotensive patients (sBP < 90 mm Hg),[28,36–39] and the pooled sensitivity was 0.743 (95% CI 0.681–0.799; I^2 = 38.7%). The pooled specificity was 0.949 (95% CI 0.926–0.966; I^2 = 41.5%). The pooled positive likelihood ratio was 11.87 (95% CI 5.864–24.056; I^2 = 60.1%). The pooled negative likelihood ratio was 0.30 (95% CI 0.214–0.423; I^2 = 48.7%). The AUC of the sROC curve was 0.856, and the pooled accuracy from these studies was calculated to be 0.888.

Among studies examining only adult normotensive patients, the pooled sensitivity was 0.76 (95% CI 0.739–0.781; I^2 = 84.7). The pooled specificity was 0.98 (95% CI 0.975–0.981; I^2 = 85.4%). The pooled positive likelihood ratio was 33.5 (95% CI 23.354–48.121; I^2 = 80.1%), and the pooled negative likelihood ratio was 0.231 (95% CI 0.176–0.304; I^2 = 90.3%). The AUC of the sROC curve was 0.946, and the pooled accuracy from these studies was calculated to be 0.949.

DISCUSSION

The undifferentiated trauma patient can present several simultaneous diagnostic and disposition challenges. The eFAST exam provides trauma practitioners with a bedside tool that can provide adjunctive information to the primary survey and help prioritize care.

Two recent reviews evaluated components of the eFAST exam, and although methodologically different from this review, they reach similar conclusions.[14,15] Staub et al. investigated detection of both PTX and hemothorax (which was not a focus of this review) and reported a sensitivity of 81%, a specificity of 98%, and an AUC of 0.979 for ultrasound detection of PTX that is very similar to the one presented here (0.994, Appendix 7).

Stengel et al.[15] examined the use of ultrasound in blunt thoracoabdominal trauma patients. Their analysis had two subgroups: 1) all abdominal injury (FF, organ

Table 3. Patient characteristics and study outcomes of the 52 included studies examining the use of ultrasound for identification of intra-abdominal FF

Author	Year	Location	No. patients	# TP	Type of trauma	Study design	Sensitivity	Specificity	+LR	-LR
Holmes	2004	Sacremento, USA	447	92	Blunt	Retrospective	0.79	0.95	17.50	0.22
McGahan	1997	Sacramento, USA	121	24	Blunt	Prospective	0.63	0.95	13.11	0.39
Massarutti	2004	Udine, Italy	40	7	Blunt	Retrospective	0.64	0.83	3.69	0.44
Waydhas	1991	Munich, Germany	64	17	Blunt	Prospective	0.74	0.95	15.15	0.27
Niebuhr	1992	Heidberg, Germany	233	27	Blunt and polytrauma	Prospective	0.96	1.00	390.69	0.05
Gaarder	2009	Oslo, Norway	104	16	Blunt and penetrating	Prospective	0.62	0.96	16.00	0.40
Nural	2005	Samsun, Turkey	454	32	Blunt	Retrospective	0.86	0.95	18.98	0.14
Nunes	2001	Philadelphia, USA	147	9	Blunt, penetrating, and polytrauma	Prospective	0.69	1.00	183.21	0.32
Udobi	2001	Baltimore, USA	75	19	Penetrating	Prospective	0.59	0.95	12.77	0.43
Boulanger	2001	Lexington, USA	66	12	Penetrating	Prospective	0.67	0.98	32.00	0.34
Salera	2005	Ancona, Italy	621	68	Blunt	Retrospective	0.88	0.99	96.08	0.12
Wherrett	1996	Toronto, Canada	69	17	Blunt	Prospective	0.85	0.90	8.33	0.17
Varin	2009	Rotterdam, Netherlands	229	44	Penetrating	Retrospective	0.65	0.98	26.04	0.36
Miller	2003	Allentown, USA	359	16	Blunt	Prospective	0.42	0.98	16.89	0.59
Richards	2004	Sacramento, USA	4320	409	Blunt	Prospective	0.69	0.98	29.04	0.32
Ma	1995	Milwaukee, USA	245	32	Blunt and penetrating	Retrospective	0.86	1.00	179.89	0.14
Kimura	1991	Tokyo, Japan	72	13	Blunt	Prospective	0.87	1.00	97.88	0.13
Jehle	1993	Buffalo, USA	44	9	Blunt	Retrospective	0.82	0.94	13.50	0.19
Hoffman	2009	Omaha, USA	458	80	Blunt	Retrospective	0.58	0.92	6.94	0.45
Brown	2001	San Diego, USA	2693	145	Blunt	Prospective	0.84	0.96	23.10	0.16
Rozycki	1993	Washington, DC, USA	476	71	Blunt and penetrating	Prospective	0.79	0.96	17.91	0.22
Brooks	2004	Nottingham, UK	110	10	Blunt and penetrating	Prospective	0.77	0.99	75.38	0.23
Ruchholtz	2004	Essen, Germany	80	30	Blunt	Prospective	0.75	0.98	30.00	0.26
Lingawi	2000	Vancouver, Canada	1063	66	Blunt	Retrospective	0.94	0.98	49.28	0.06
Hsu	2007	Sydney, Australia	410	78	Blunt	Prospective	0.78	0.97	30.23	0.23
Rothlin	1993	Zurich, Switzerland	312	52	Blunt	Prospective	0.98	1.00	505.56	0.02
Goodwin	2001	Sacramento, USA	126	5	Blunt	Retrospective	0.83	0.98	33.33	0.17

(*Continued*)

Table 3. Continued.

Author	Year	Location	No. patients	# TP	Type of trauma	Study design	Sensitivity	Specificity	+LR	-LR
Matsushima	2017	Los Angeles, USA	103	37	Penetrating	Retrospective	0.69	0.94	11.19	0.34
Catan	2002	El Salvador, Chile	251	58	Blunt and penetrating	Retrospective	1.00	1.00	384.71	0.01
Kumar	2015	New Delhi, India	50	37	Blunt	Prospective	0.80	0.75	3.22	0.26
Bode	1993	Leiden, Netherlands	338	26	Blunt	Retrospective	0.93	1.00	568.38	0.09
Friese	2007	Dallas, USA	96	11	Blunt	Retrospective	0.26	0.96	7.07	0.77
Ingeman	1996	Toledo, USA	97	18	Blunt	Prospective	0.75	0.96	18.25	0.26
Gruessner	1989	Mainz, Germany	73	31	Blunt	Prospective	0.84	0.83	5.03	0.19
Boulanger	1995	Toronto, Canada	206	25	Blunt	Prospective	0.81	0.98	47.03	0.20
Brooks	2002	Nottingham, UK	50	5	Blunt and polytrauma	Prospective	1.00	1.00	78.83	0.08
Shek	2012	Hong Kong	153	20	Blunt	Retrospective	0.50	0.97	18.83	0.51
Dammers	2017	Leeuwarden, Netherlands	415	12	Blunt	Retrospective	0.67	1.00	134.33	0.34
Fleming	2012	London, England	71	24	Blunt	Retrospective	0.46	0.95	8.77	0.57
†Kirkpatrick a	2005	multisite (2)	328	51	Blunt	Prospective	0.77	0.99	95.43	0.23
‡Kirkpatrick	2005	multisite (2)	328	35	Blunt	Prospective	0.69	0.97	21.86	0.32
Kornezos	2010	Athens, Greece	1999	106	Blunt	Prospective	0.88	1.00	553.26	0.12
McKenney	1994	Miami, USA	200	29	Blunt	Prospective	0.83	0.99	136.71	0.17
Shackford	1999	Burlington, USA	234	35	Blunt	Prospective	0.69	0.98	41.86	0.32
Smith	2010	Ngwelezana, South Africa	72	15	Blunt and penetrating	Prospective	0.71	1.00	73.27	0.30
Soyuncu	2007	Antayla, Turkey	442	31	Blunt	Prospective	0.86	0.99	87.40	0.14
Lentz	1996	Miami, USA	54	13	Blunt	Prospective	0.87	0.97	33.80	0.14
Coley	2000	Columbus,USA	107	12	Blunt	Prospective	0.55	0.86	3.86	0.53
Thourani	1998	Atlanta, USA	192	8	Blunt	Prospective	0.80	1.00	78.81	0.23
Corbett	2000	Riverside, USA	47	9	Blunt and penetrating	Prospective	0.75	0.97	26.25	0.26
Holmes	2001	Sacramento, USA	224	27	Blunt	Prospective	0.82	0.95	15.63	0.19
Akgur	1993	Izmir, Turkey	69	10	Blunt	Prospective	1.00	0.98	59.00	0.05
Fox	2011	Orange, USA	357	12	Blunt	Prospective	0.52	0.96	13.40	0.50
						Pooled	**0.74**	**0.98**	**25.21**	**0.26**
						95% confidence interval	**0.73–0.76**	**0.97–0.98**	**19.42–32.71**	**0.21–0.31**

-LR = negative likelihood ratio; +LR = positive likelihood ratio; TP = true positives.
*See appendix 6 for references.
†Kirkpatrick = handheld ultrasound.
‡Kirkpatrick = regular ultrasound.

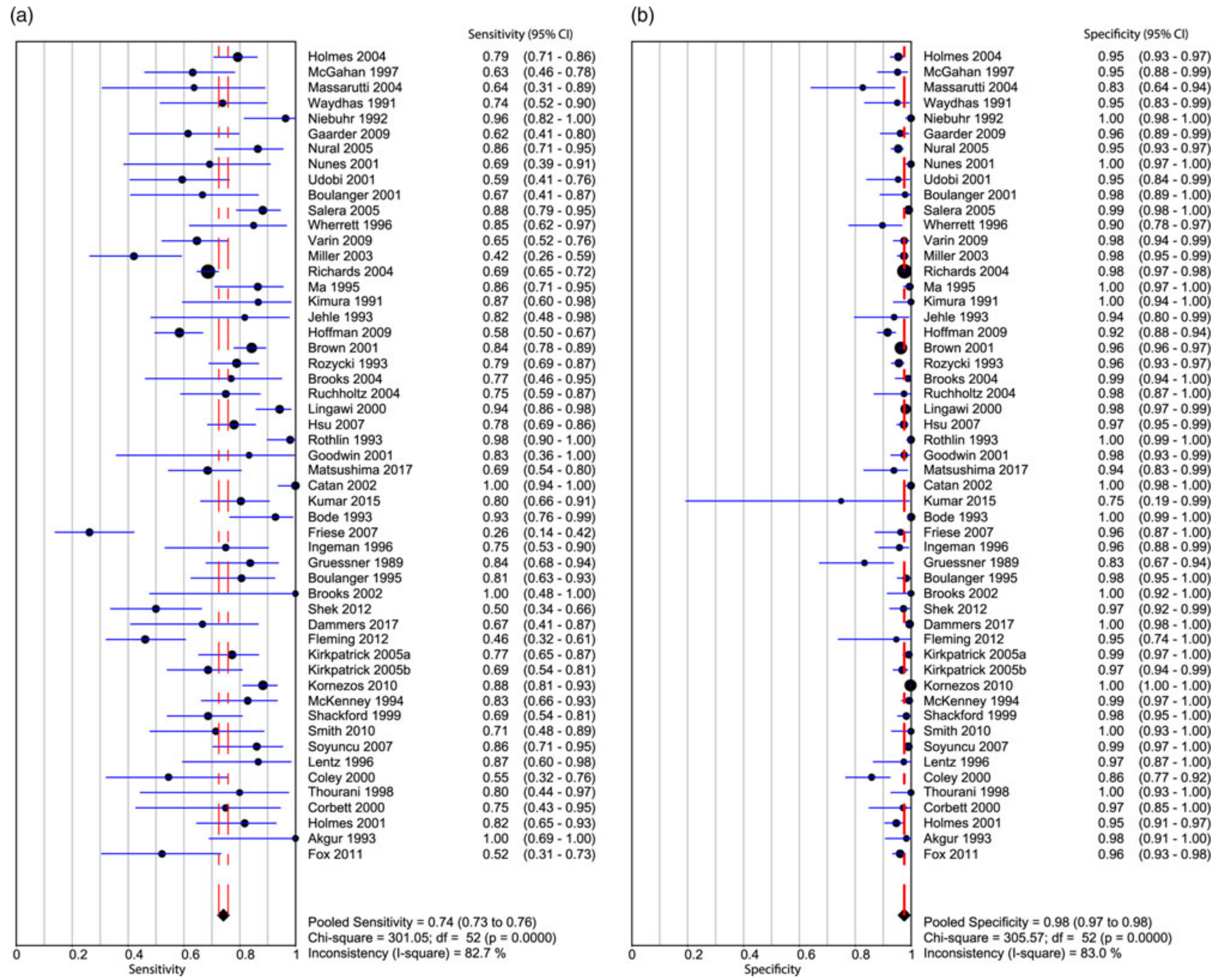

Figure 3. Forest plot displaying the sensitivity (a) and specificity (b) of the included studies for ultrasound identification of intra-abdominal FF in trauma patients.

injury, vascular injury; sensitivity 68% and specificity 95%); or 2) abdominal FF and/or intra-abdominal free air (sensitivity 78% and specificity 97%). Direct comparison to our review is difficult as we did not look at ultrasound use for the detection of free intra-abdominal air, organ injury, or vascular injury. In their thoracic group analysis, only four papers investigating the use of ultrasound in the detection of PTX's were included, making direct comparison difficult. Regardless of these differences, the reported sensitivities and specificities are very similar to our findings.

Identification of pneumothorax

Our results suggest a moderate sensitivity and good specificity in detecting PTX in the trauma setting, corresponding to a positive likelihood ratio of 62.57 and a negative likelihood ratio of 0.256 (Table 1). While our results suggest that the eFAST scan can be used as a rule-in test for the detection of PT, it lacks adequate sensitivity to be used as a rule-out test. Further, it should be noted, that depending on the patient's age and comorbidities, several false positives (e.g., prior pleurodesis and interstitial lung disease) and negatives (e.g., small PTX, and subcutaneous air) can occur.[41]

A previous review from 2012 included eight studies examining ultrasound detection of PTX in traumatic and non-traumatic patients and suggested a similar specificity (98.2%), with a much higher sensitivity of 90.9%, however with significant heterogeneity.[8] This discrepancy could be explained by technological improvements in the gold standard test and the increased frequency in the detection of occult pneumothoraces because of the increased use of CT.

A more recent 2018 systematic found a sensitivity of 81% and specificity of 98% in ultrasound detection of traumatic PTX.[14] For various reasons, our review included different studies than Staub et al. Three papers included in our review, but not theirs, had sensitivities of 40%,[42] 43%,[5] and 77%.[43] The two papers not included herein but cited by the aforementioned review had sensitivities of 83%[44] and 95%.[45] These likely explain the sensitivity differences. However, whether having a sensitivity of 69% or 81%, ultrasound still does not perform well enough to be used as a rule-out test.

Identification of a PCE

Our pooled results suggest excellent sensitivity and specificity of eFAST in the detection of a PCE in the trauma setting with a positive likelihood ratio of 34.169 and negative likelihood ratio of 0.110 (Table 2). Two papers[19,20] presented outlying results, with one paper[19] having a specificity of 5%. While not directly commented upon in the original publication, this appears to be because of including only penetrating injuries to the cardiac box, which would have a high pretest probability of injury, resulting in few true negative scans and an overall low specificity. In the other study, only one true positive result was returned,[20] limiting this study. Removal of these outlying papers from the analysis resulted in a sensitivity of 98.2% and specificity of 98.5%. These adjusted results better reflect the summary of available literature. A false positive PCE scan can result from epicardial fat or pleural fluid, but false negatives can be because of small volumes of PCE or pericardial lacerations.

Identification of free intra-abdominal fluid

Our pooled results suggest a moderate sensitivity and excellent specificity of eFAST in the detection of FF corresponding to a positive likelihood ratio of 20.3 and negative likelihood ratio of 0.25 (Table 3). These test characteristics did not change significantly if pediatric, hypotensive, and adult normotensive subgroups were considered. If considering use, it should be noted again that there is the potential for false positives (e.g., perinephric fat and abdominal ascites) and false negatives (e.g., a small volume of fluid). Lastly, as there were high degrees of heterogeneity amongst included studies, clinician judgment should predominate while considering disposition based on ultrasound imaging.

Limitations

Our study had several potential limitations. First and foremost, our study was potentially limited by our search strategy. To minimize selection bias, we employed an expert librarian to develop our search strategy and used a bibliographic review of all included studies to minimize the chances of missing important literature. Given the moderate to high heterogeneity of included studies, it is unlikely that any missed studies would have dramatically changed our final results or conclusions. Further, our results are similar to two recent reviews.[14,15]

We recognize the potential for publication bias, as only positive results are generally published. However, some included papers report low sensitivities and specificities, and during the history of ultrasound literature, many groups investigated whether the technology would be of benefit that is reflected by the large heterogeneity of study results. Funnel plot analysis was performed for lung and abdominal exam aspects of the eFAST and did not show evidence of publication bias (data are not shown).

Thirdly, the quality of the included studies is always a concern in systematic reviews and meta-analyses. As with study quality, we are also unable to control the statistical heterogeneity of the presented studies, by which this study is limited. If compared to the entire group of studies examining FF, the subgroup analyses had similar results, yet improved heterogeneity. While the large group was heterogeneous, these similar results in the less heterogeneous subgroups provide some reassurance to our findings.

CONCLUSIONS

Our findings suggest that eFAST can be used as a rule-in test for PTX, FF, or PCE in a trauma setting. This is supported by the high specificities and high positive likelihood ratios for each scan. Its usefulness as a rule-out tool in the trauma setting is not supported by our findings.

SUPPLEMENTARY MATERIAL

The supplementary material for this article can be found at https://doi.org/10.1017/cem.2019.381.

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