Injury 50 (2019) 2167–2175

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Prehospital ultrasound in the management of trauma patients: Systematic review of the literature

Laura van der Weide[a,*], Zar Popal[a], Maartje Terra[a], Lothar A. Schwarte[b], Johannes C.F. Ket[c], Fabian O. Kooij[d], Aristomenis K. Exadaktylos[e], Wietse P. Zuidema[a], Georgios F. Giannakopoulos[a]

[a] Department of Trauma Surgery, Amsterdam University Medical Centres, location VUmc, De Boelelaan 1117, 1081 HV, the Netherlands
[b] Department of Anesthesiology, Amsterdam University Medical Centres, location VUmc, the Netherlands
[c] Medical Library, Vrije Universiteit, Amsterdam, the Netherlands
[d] Department of Anesthesiology, Amsterdam University Medical Centres, location AMC, the Netherlands
[e] Department of Emergency Medicine, Inselspital, University Hospital of Bern, Switzerland

ARTICLE INFO

Article history:
Accepted 26 September 2019

Keywords:
Prehospital
Ultrasound
Focused assessment with sonography in trauma (FAST)
Trauma patients

ABSTRACT

Introduction: Emergency ultrasound methods such as Focused Assessment with Sonography in Trauma (FAST) are a widely used imaging method. This examination can be performed to examine the presence of several life-threatening injuries. Early diagnosis may lead to better outcome, but the effect of timely diagnosis in the prehospital setting is not yet clear. Therefore, the aim is to determine the diagnostic accuracy and the effect of prehospital ultrasound performed in (poly)trauma patients.
Methods: A literature search was performed in PubMed, Embase and Cochrane's Library. Articles were included if prehospital ultrasound was performed as a diagnostic intervention in patients with trauma. The main outcome measures included diagnostic accuracy, changes in prehospital diagnosis/treatment, changes in destination hospital and in-hospital response. Case reports and case series were excluded.
Results: After screening 3343 articles, nine studies met the inclusion criteria. These included three retrospective and six prospective observational studies, with a total number of 2,889 patients. Five studies report at least one change in polytrauma management, ranging from 6% to 48,9% of the cases. The diagnostic accuracy of prehospital ultrasound was adequate in eight (out of nine) articles. High sensitivity and high specificity were found on several endpoints (pneumothorax, free abdominal fluid, haemoperitoneum, both on site and during transport).
Conclusion: Prehospital ultrasound led to a change in polytrauma management in all studies that included this as an outcome measure. The diagnostic accuracy was described in eight studies, high sensitivity and specificity were found. Overall, the studies seem to suggest a positive influence of performing ultrasound. However, additional research with homogenous accuracy endpoints and uniformly trained prehospital care providers is recommended.

Introduction

Trauma is a leading cause of death and disability worldwide [1]. A considerable part (30–40%) of trauma related mortality is caused by haemorrhage and 33–56% of these deaths occur during the prehospital phase [2]. Early discovery of haemorrhage after trauma seems to improve patients' outcome [3]. CT scanning is a sensitive imaging method used to detect internal damage or haemorrhage in trauma patients. However, hemodynamically unstable patients are unable to undergo such advanced and time-consuming imaging techniques on scene [4–6]. A safe, relatively cheap and widely used alternative is ultrasound, which can be used as an initial screening method in both adult and paediatric trauma patients [4,5,7,8].

Portable ultrasound devices are developing rapidly and are easily accessible for both the hospital and emergency medical services. The devices can be used to perform a systematic emergency ultrasound to detect free intraperitoneal fluid after traumatic injury, indicating internal damage and haemorrhage. Different parts of the torso are imaged, including the standard views (upper quadrants, pelvic view, etc.) [9]. Multiple ultrasound methods are described in this article, the key elements of each method are summarised in Appendix 1.

Depending on the regional medical system, the Emergency Medical Services (EMS) and Helicopter Emergency Medical Services

* Corresponding author.
E-mail address: l.vanderweide1@amsterdamumc.nl (L. van der Weide).

https://doi.org/10.1016/j.injury.2019.09.034
0020-1383/

(HEMS) are staffed by either physicians, nurses or paramedics. They can be trained to perform prehospital ultrasound to determine the severity of the injuries for appropriate trauma patient management. In multiple countries extended Focused Assessment with Sonography in Trauma (EFAST) or similar ultrasound methods are used in the prehospital setting. However, there is currently no sound evidence to support the beneficial effects of prehospital ultrasound [10,11]. The quality of the evidence used in 2010 and 2017 was deemed insufficient due to the great heterogeneity and the relatively small size of the population studied. As time elapsed since publication of the most recent systematic reviews on this topic, technology improved and more studies were performed and published. The aim of this review is to evaluate the current evidence regarding both the accuracy and the effect of prehospital ultrasound on trauma patient management, considering a change in prehospital treatment and/or diagnosis, transfer to most appropriate hospital and optimised hospital response.

Methods

Protocol and registration

The literature search was performed regarding the requirements of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)-statement (www.prisma-statement.org). The systematic review was recorded at the International Prospective Register of Systematic Reviews (PROSPERO) with number CRD42018090299 (https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=90299).

Eligibility criteria

Peer-reviewed (non-)randomised controlled trials, case-control studies and cohort studies on the subject of prehospital ultrasound in trauma were included. Only articles written in Dutch or English were included. No limitations were placed on country of origin or publication date.

All patients undergoing prehospital ultrasound due to trauma were included. There were no restrictions in age or severity of injury.

Any form of diagnostic prehospital ultrasound was included. No restrictions were placed on the level of education and occupation of the ultrasound performer. Studies using ultrasound for telemedicine, simulation or in-hospital were excluded, as well as non-human studies. Also, studies using ultrasound to confirm the success of an intervention were excluded.

Endpoints included both the accuracy of prehospital ultrasound and the effect of prehospital ultrasound on trauma patient management, more specifically the treatment, diagnosis, transfer to most appropriate hospital and optimised hospital response. The inclusion and exclusion criteria are displayed in Table 1.

Data sources and search strategy

A review protocol was developed based on the PRISMA-statement. PubMed, Embase and Wiley/Cochrane Library were searched from inception up to 27 June 2019 (by LvdW and JCFK). The following terms were used (including synonyms and closely related words) as index terms, MeSH terms or free-text words: 'prehospital' or 'ambulance' or 'remote setting' and 'ultrasonography' or 'electrocardiography'. The full search strategies for all databases can be found in the Supplementary Information (Appendix 2). Duplicate articles were excluded.

Table 1
Inclusion and exclusion criteria.

Inclusion	Exclusion
Peer reviewed	Non-original data
Full-text available	Full-text not available
Dutch or English language	Non-eligible research question
All original data = (non) randomized controlled trials, case-control studies, cohort studies, case series or case reports	Non-human, in hospital, simulation or non-traumatic ultrasound
Prehospital ultrasound, assessed by same physician who made ultrasound	Ultrasound made for objectives other than diagnosis
Ultrasound performed on trauma patients	Studies about training EMS staff how to use prehospital ultrasound
	Tele-ultrasound

Study selection

Potential titles and abstracts were simultaneously screened for eligibility, by two independent researchers (LvdW and ZP). Both researchers were blinded for the results of the inclusion/exclusion until the full-text articles were assessed. Conflicting answers were solved with the help of a third researcher (GFG) to reach consensus. Rayyan (https://rayyan.qcri.org/) was used as a reference manager, to keep track of the screened and unscreened articles.

Data collection process and data items

A data extraction sheet was developed in Microsoft Excel to create a clear overview of the included data. The following data were extracted if mentioned from all relevant articles if mentioned: (1) first author, year, study country; (2) population, type of trauma; (3) methods; (4) training of ultrasound operator; (5) type of ultrasound; (6) results of accuracy; (7) results of trauma patient management. Also, the quality of the included studies was assessed using the Newcastle-Ottawa Quality Assessment Scale.

Results

Study selection

Through PubMed 1499 articles were found, through Embase 1738 articles and through Cochrane/Wiley Library 106 articles. After removal of duplicates, 3343 records were identified. All records were screened as mentioned above. In total 3266 articles were excluded based on title and abstract. The remaining 77 articles were read in full text to assess eligibility. The authors of four articles were contacted and requested to supplement necessary data in order to include their articles. Two authors did not respond; their articles were therefore excluded [12,13]. One author provided the requested data of two included articles [14,15]. In total, 68 articles were excluded based on full text screening. Eventually nine papers were included and further analysed (Table 2). The flowchart is presented in Fig. 1.

Study characteristics

Of the nine studies were six prospective and three retrospective observational cohort studies. A total of 2889 patients were included, from studies performed in Europe, USA and China.

The type of ultrasound examination differed in the articles. Seven articles used Focused Assessment with Sonography in Trauma (FAST) or similar alternatives (EFAST, prehospital FAST and in-flight FAST) [11,16–19]. Two articles used Polytrauma Rapid

Table 2
Results of individual studies.

First author, year, country	Population, type of trauma	Methods	Training	Type of scan	Results of accuracy	Results of trauma patient management
(1) Brun, 2013, France	$N=98$ patients (mean age group 1 34 years, group 2 39 years, group 3 37 years) 89 blunt trauma, 7 penetrating trauma	Prospective, observational study EMS = physician, randomly divided into 3 groups October 2011 - June 2012	20 physicians EFAST qualifications > 4 years (at least 5 exams per month) Remaining 10 physicians training unknown	EFAST	1. On site ($n=44$) = feasibility 95,4%, sen 95.2%, spec 95.2%, PPV 95.2% NPV 95.2%, diagnostic efficiency 95% 2. During transport ($n=33$) = feasibility 93,9% sen 94.7%, spec 100%, PPV 100%, NPV 92.3%, diagnostic efficiency 96,7% 3. Both ($n=21$) = feasibility 95,2% sen 100%, spec 100%, PPV 100%, NPV 100%, diagnostic efficiency 100% No significant difference in duration compared to on-site, during transport or both ($w=0{,}68$) = mean 3,5 min–3,9 min - 3,7/3,7 min	No alterations described
(2) Heegaard, 2010, United States of America	$N=84$ patients, 6 positive exams (7,1%) Penetrating and blunt trauma	Prospective, observational study EMS = paramedic January 2008 - January 2009	6-hour training, 1-hour refresher course after 3 months and 8 months	FAST	8 inadequate exams 70 negative exams = 100% agreement between paramedic and blinded physician overreader, 6 positive exams = 100% agreement between paramedic and blinded physician overreader and confirmed by positive operative or CT findings Mean time = 2,6 min (median 2,3 min)	No delay in treatment or transport, limited per protocol No alterations described
(3) Hu, 2014, China	$N=45$ patients (mean age 43,5 years) male:female ratio 2:1 Chest, abdominal and mixed trauma	Letter to editor Earthquake, 24 h period all red/yellow ISS scale victims National Medical Rescue Team = not specified April 2013	Not mentioned	Streamlined FAST (SFAST)	SFAST (against ISS scale) = accuracy 91,1%, sen 90,9%, spe 91,3%, PPV 90,3%, NPV 91,9% Requirement of emergency surgery SFAST = accuracy 62,2%, sen 59,3%, spe 66,7%, PPV 72,7%, NPV 52,2% SFAST performed better compared to START against ISS scale, also better in determining whether patient needed emergency surgery (higher accuracy, sensitivity, specificity, PPV and NPV) Median triage time = 2,9 min	SFAST positive in 22 patients (48,9%), not further specified
(4) Ketelaars, 2013, Netherlands	$N=250$ patients (mean age 40) male:female ratio 3,6:1 Total of 287 ultrasound examinations Unspecified chest trauma	Retrospective study HEMS = physician January 2007 - June 2010	Not mentioned	Polytrauma Rapid Echo-Evaluation Program (PREP)	Pneumothorax sensitivity 38%, specificity 97%, positive predictive value 90%, negative predictive value 69% Mean duration 2,77 min (not trauma specific)	48 patients (19,2%) change in decision Cardiac = 2 times (0,8%) initiate inotropic medication, 4 (1,6%) stop resuscitation, alteration of intravascular fluid administration 6 (2,4%) Pulmonary = 10 (4%) refrain from inserting chest tube, 3 (1,2%) insert chest tube Destination = 10 (4%) change in destination (to hospital, lower level hospital, trauma centre), 4 (1,6%) preparations (OR, blood transfusion, call to surgeon)

(*continued on next page*)

Table 2 (*continued*)

First author, year, country	Population, type of trauma	Methods	Training	Type of scan	Results of accuracy	Results of trauma patient management
(5) Ketelaars, 2018, Netherlands	*N* = 1451 patients (mean age 40), Male:female ratio 3,5:1 Total of 1493 ultrasound examinations	Retrospective study HEMS = physician January 2007 - December 2016 Mostly blunt abdominal trauma	2-day PREP course	Polytrauma Rapid Echo-Evaluation Program (PREP)	Free abdominal fluid = sensitivity 31,3%, specificity 96,7%, positive predictive value 72,9%, negative predictive value 83,0%, accuracy 82,1% Early group = sen 26,9%, spe 94,6%, PPV 58,3%, NPV 82,2% Late group = sen 31,8%, spe 97,9%, PPV 80,8%, NPV 83,8%	In 180 patients (12,4%) impact on treatment Alteration in prehospital fluid management 28 (1,9%) Destination = 111 (8%) notification to receiving hospital, change in destination hospital 32 (2,2%), mode of transportation 59 (4,1%)
(6) Melanson, 2001, United States of America	*N* = 71 (mean age 35 years) 83% blunt 4% penetrating 13% not specified	Prospective study HEMS = nurse, paramedic Study period not mentioned	3-hour training session (didactic + practice)	FAST (3 views: right and left upper quadrant, suprapubic view)	No FAST exam performed in 34 of 71 patients (48%) due to insufficient time, inadequate patient access or combativeness 7 of 37 patients (19%) technical difficulties 8 of 37 patients (22%) no view adequately visualized 22 of 71 patients (31%) had at least 1 view adequately visualized In 2 of 37 patients (5%) all 3 views adequately Confidence of interpretation (*n* = 22) = very 14%, some what 59%, not very 4%, not at all 23%	Results of ultrasound not used in patient management, limited by study protocol
(7) Press, 2014, United States of America	*N* = 293 patients (mean age 41), 74% male 88,4% blunt 11,6% penetrating	Prospective, observational study HEMS = nurse, paramedic 7 months	1-day didactic/hands-on, 6 weekly internet-based training, proctored scanning sessions in ED, pocket flashcards, review session, pre/post testing, remedial training if necessary	In-flight EFAST	*Hemoperitoneum* = sensitivity 46%, specificity 94,1%, PPV 54,5%, NPV 92% *Required intervention (hemoperitoneum)* = sen 64,7%, spe 94%, PPV 50%, NPV 96,6% *Pericardial fluid* = sen 0%, spec 99,6%, PPV 0%, NPV 98,7% *Required intervention (pericardial fluid)* = sen 0%, spe 99,6%, PPV 0%, NPV 100% *Pneumothorax* = sen 18,7%, spec 99,5%, PPV 80%, NPV 92,7% *Required intervention (pneumothorax)* = sen 50%, spe 99,8%, PPV 90%, NPV 98,1%	EFAST performed on stable patients, preventing management alterations (by protocol)

(*continued on next page*)

Table 2 (*continued*)

First author, year, country	Population, type of trauma	Methods	Training	Type of scan	Results of accuracy	Results of trauma patient management
(8) Walcher, 2005, Germany	*N* = 230 patients (202 complete protocol and follow-up; mean age 35,5) 66% male Blunt and penetrating abdominal trauma	Prospective, multicentre study 5x HEMS & 1x EMS = physician, paramedic December 2002 - December 2003	Those not familiar with ultrasound imaging = PFAST 1-day course	Prehospital FAST (PFAST)	Physical examination for intra-abdominal bleeding = sen 93%, spe 52%, accuracy 57% PFAST for free abdominal blood = sen 93%, spe 99%, accuracy 99%	On average, PFAST performed 35 min earlier than ultrasound or CT in receiving hospital Mean time 2–4 min *Prehospital care change* = 42 patients (21%) (modification of fluid resuscitation, exclusion of significant head injury) *Management change* = 61 patients (30%) (avoidance of any therapy beyond ALS in case of intra-abdominal bleeding) *Report supplemented* = 105 patients (52%) *Hospital change* = 44 patients (22%) *Receiving hospital response change* = 44 patients (22%) – including abdominal surgeon, preparing OR
(9) Yates, 2017, United States of America	*N* = 367 patients 190 (51,8%) complete EFAST examination 12 patients (6,3%) with positive EFAST Blunt and penetrating trauma	Prospective, observational study HEMS = nurse, paramedic June 2014–December 2015	8-h didactic education, 4-h supervised clinical practice, 1-h observed standard clinical examination, > 5 POCUS examinations per month with experienced provider	EFAST (point of care ultrasound, POCUS)	Flight crew of 178 EFAST examinations= PPV 100%, NPV 98,3% Trauma team of 188 EFAST examination = PPV 82,3%, NPV 99,4%	12 positive EFAST findings = 6x intra-peritoneal fluid, 5x haemothorax or pneumothorax, 1x cardiac arrest Not mentioned whether required treatment was influenced by EFAST findings

FAST focused assessment with sonography in trauma; EFAST extended focuses assessment with sonography in trauma; ISS injury severity score; US ultrasound; ED emergency department.
EMS emergency medical services; HEMS helicopter emergency medical services.
Sen sensitivity; spe specificity; PPV positive predictive value; NPV negative predictive value.

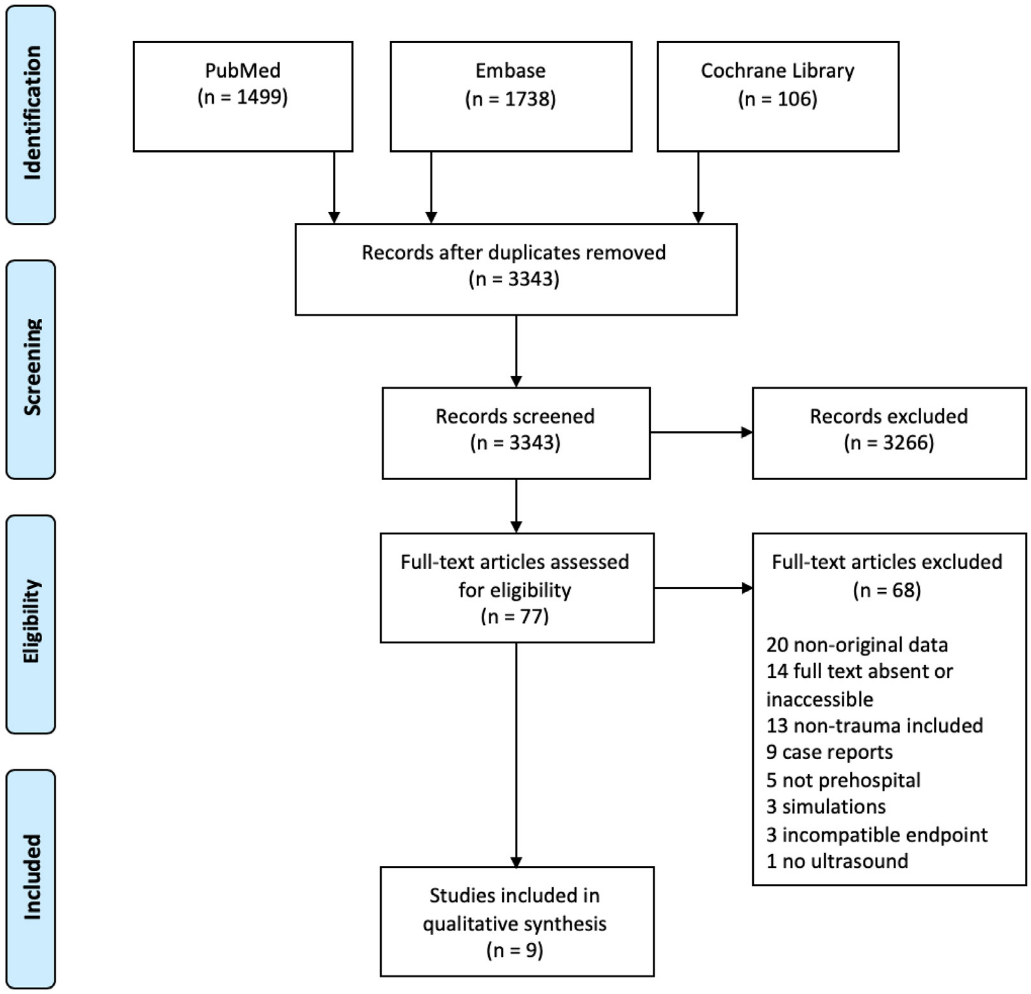

Fig. 1. Flowchart.

Echo-evaluation Program (PREP), which is an ultrasound method comparable to EFAST [14,15]. Appendix 1 describes the various ultrasounds methods.

Ultrasound was performed by either physicians, nurses and/or paramedics, or both. One article did not mention who performed the ultrasound, but only their affiliation with the National Medical Rescue Team [20].

Results of individual studies

Change in prehospital treatment

In three out of nine articles a change in prehospital treatment was described because of the ultrasounds performed. Alteration of prehospital trauma patient management was prohibited per protocol in three articles.

Ketelaars et al. [14] described a change in decision regarding therapy in 48 patients (19,2% of a total number of 250 patients). The prehospital ultrasound led to initiation of inotropic medication in two of these cases (0,8%), suspension of resuscitation in four cases (1,6%), alteration of intravascular fluid in six cases (2,4%), refraining from chest tube insertion in ten cases (4%) and the insertion of three chest tubes (1,2%).

Both Ketelaars et al. [15] and Walcher et al. [18] described an alteration of prehospital treatment, respectively in 180 patients (12,4%) and 42 patients (21%). In both articles, mainly the prehospital fluid management was changed based on the results of the ultrasound. In the article of Yates and Baylous [19] is it unclear whether the required treatment was influenced by the ultrasound findings.

Change in prehospital diagnosis

Only one article described a change in prehospital diagnosis. Walcher et al. [18] reported a change in management because of the ultrasound diagnosis in 61 patients (30%). It included the avoidance of any therapy beyond advanced life support (ALS) in case of the detection of intra-abdominal bleeding. The reports of the trauma patients were supplemented by the findings of the ultrasound in 105 patients (52%).

Change in destination hospital

In three out of nine articles a change in destination hospital was described. Alteration of prehospital trauma patient management was prohibited per protocol in three articles.

Ketelaars et al. [14] described a change in destination hospital in 10 patients (4% of entire population). These patients were transported to a hospital instead of not being transported, to a lower level hospital or to a trauma centre. Ketelaars et al. [15] reported a change in destination hospital in 32 patients (2%) and a change in mode of transportation in 59 patients (4%).

Walcher et al. [18] described a change in destination hospital in 44 patients (22%), but did not specify the type of change.

Change in hospital response

Three articles describe a change in receiving hospital response. Ketelaars et al. [14] reported preparations by the receiving hospital in four cases (1,6% of entire population). It included the preparation of the operation theatre, preparation of blood transfusions and a personal call to the surgeon. Ketelaars et al. [15] mentioned a notification to the receiving hospital in 111 cases (8%) as a result of the ultrasound findings. Walcher et al. [18] described a change in receiving hospital response in 44 patients (22%), including the preparation of the operation theatre and the notification of an abdominal surgeon.

Accuracy

All nine articles describe a form indicator of accuracy of prehospital ultrasound, however multiple endpoints are considered. Table 2 shows the extensive results of the articles included.

Brun et al. [16] compared the efficiency and accuracy of EFAST on site, during transport and in both situations. For hemodynamically stable patients (72%), the golden standard for determining the diagnostic accuracy of prehospital ultrasound included a CT-scan within 30 min after arrival and echography performed by a radiologist. If the patient was not stable enough to undergo a whole-body CT-scan (28%), a comparison was made with the result of the prehospital ultrasound and the combined result of the ultrasound performed by a radiologist and the operating report. There was no difference in the duration of the EFAST in the different settings. The diagnostic accuracy of EFAST examinations were similar to examinations carried out in intensive care units.

Heegaard et al. [21] described the ability of paramedics to perform and interpret FAST examinations after a one-day training and two refresher courses. Of the 84 FAST examinations performed, eight (7,7%) were deemed inadequate, seventy (83,3%) were negative and six (7,1%) positive for findings. Both the negative and positive examinations had 100% agreement between the paramedics and an independent physician. Positive FAST results were confirmed by positive operative or CT findings. The diagnostic accuracy of the negative FAST ultrasounds is not described in the article. The mean examination time during ambulance transport was 2,6 min.

Hu et al. [20] examined the accuracy of streamlined FAST examination (Appendix 1) in blunt chest trauma patients, against the benchmark of an Injury Severity Score (ISS) of fifteen or higher. A higher diagnostic accuracy was found compared to Simple Triage and Rapid Treatment (START) protocol. Also, the ability to determine the need of emergency surgery was studied. Again, the diagnostic accuracy was higher than the accuracy found using the START protocol. Extensive accuracy results are described in Table 2.

Ketelaars et al. [14] examined the accuracy of PREP performed by physicians in patients with chest trauma. The accuracy was determined using the X-ray and CT results of those patients. A high sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of PREP were found, allowing for early and accurate diagnosis. The duration of the examination shortened over the four years of the study period.

Ketelaars et al. [15] examined the diagnostic performance of abdominal prehospital ultrasound performed by physicians. The accuracy of PREP was determined using the CT and laparotomy reports. A comparison was made between an early group (PREP upon arrival or during treatment) and late group (PREP during transport, upon arrival). A high specificity and accuracy for free abdominal fluid was found, but low sensitivity. The results found were similar to FAST examinations in the emergency room setting.

The feasibility of FAST examination was studied by Melanson et al. [17] performed by nurses and paramedics after a 3-hour training session. In 48% of the patients no FAST examination was performed, due to insufficient time, inadequate patient access or patient combativeness. More than 30% of patients had at least one view adequately visualised. The confidence of interpretation was also mentioned, mostly "somewhat confident" was noted.

Table 3
Quality assessment.

	S1	*S2*	S3	S4	*C1*	O1	O2	O3	Total
Brun, 2013	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Heegaard, 2010	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Hu, 2014	[a]	[a]	[a]	[a]	*NA*	[a]	[a]	[a]	6[c]
Ketelaars, 2013	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Ketelaars, 2018	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Melanson, 2001	[a]	*NA*	–[b]	[a]	*NA*	–[b]	[a]	[a]	4
Press, 2014	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Walcher, 2005	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6
Yates, 2017	[a]	*NA*	[a]	[a]	*NA*	[a]	[a]	[a]	6

[a] Star allocated.
[b] No star allocated.
[c] The star allocated at the S2 section is not included, as explained beforeNA Not applicable.

Press et al. [22] evaluated the accuracy of EFAST examinations during aeromedical transport performed by nurses and paramedics. The accuracy benchmark varied for determining haemoperitoneum, pericardial fluid and pneumothorax. The accuracy of the diagnosis of haemoperitoneum was studied, as well as the accuracy of haemoperitoneum requiring surgery. The sensitivity for determining haemoperitoneum requiring operation was higher than of the diagnosis of haemoperitoneum alone, but the specificity did not differ. The sensitivity for detecting a pneumothorax was poor, although higher for pneumothorax requiring thoracostomy than this injury alone. The specificity on the other hand was very high. A higher sensitivity was found for ultrasound examination of the right lung compared to the left lung, for the diagnosis pneumothorax and pneumothorax requiring intervention.

Walcher et al. [18] examined the ability of prehospital FAST (PFAST) to adequately detect haemoperitoneum. PFAST was performed by physicians and paramedics in abdominal trauma patients. Ultrasound and CT in the emergency department were used for reference. The PFAST accuracy found was higher compared to physical examination alone.

Yates et al. [19] studied the accuracy of EFAST examinations during aeromedical transport performed by nurses and paramedics. The results were compared with FAST performed in the emergency department, CT and operative reports. The PPV of the flight crew was higher than that of the trauma team in the emergency department. The NPV op the flight crew was slightly lower.

Risk of bias within studies

The Newcastle-Ottawa Scale (NOS) was used to assess the quality of the included studies. As can be seen in Table 3, most of the studies got six stars allocated. The S2 section and the C1 section of the NOS were not included in the assessment for this review, since this factor was not applicable for most of the included studies.

Discussion

In this study an overview of the current evidence was created regarding the use of prehospital ultrasound in trauma patients. In summary, prehospital ultrasound led to a change in trauma management in five out of nine included studies. Additionally, the accuracy rate was considered to be adequate in eight studies and the rate of adequate visualisation was moderate only in one.

Some factors influence the use of ultrasound and should therefore be taken into consideration. First of all, the performance of ultrasound in the prehospital setting is more challenging compared to a hospital environment. Problems included insufficient time, difficult visualisation of the screen in daylight, battery failure and motion of aircraft or ambulance. Furthermore, the assessment of the ultrasound performed was complicated in patients with e.g. obesity, subcutaneous emphysema, patient packaging such as haemostatic dressings, making one or more views inaccessible.

Secondly, the different endpoints made it very difficult to conduct a meta-analysis. The diversity consisted of both the patients and type of trauma undergoing ultrasound, and the ultrasound operator. The included patients had either chest trauma, abdominal trauma or both; penetrating injuries, blunt injuries or both. A more homogeneous result could be presented when all patients included had sustained comparable injuries.

Thirdly, the accuracy of ultrasound differs strongly with the level of practice and experience of the operator. In this review the ultrasound operators have been educated in different but comparable types of prehospital ultrasound, received different amounts of training (both theoretic and hands-on) and had different experience levels at the beginning of the study. Solely the article of Melanson et al. [17] reports an ultrasound training protocol of three hours with no previous experience; all other articles outline a training protocol of at least eight hours and two articles did not mention the training protocol at all. This might explain the lower level of adequately visualised ultrasound views reported by Melanson et al. [17], compared to the other articles. No obvious relation has been found in the medical background of the operator. Nurses, paramedics and physicians all can perform prehospital ultrasound with high accuracy, as is shown in the included studies.

Furthermore, differences in outcome between the articles might be explained by the fact that there is a great range in publication date between the studies, varying from 2001 to 2018. In that period of time, technological improvements have been made to the portable ultrasound and more experience is gained worldwide, resulting in an increased efficiency of the scanning process.

In this systematic review most articles used some form of FAST or a similar method. This is a commonly used method, but it is currently unknown what the influence is of changing the sequence of the various windows, based on the position of the patient. Some articles suggest that certain views are more sensitive than others in determining the presence of free abdominal fluid. Especially the right upper quadrant (hepato-renal view) is a common and sensitive view. It is currently unknown what the influence is of the sequence of the various windows and whether it is possible to reduce the amount of views based on their individual diagnostic accuracy [23,24]. Prehospital ultrasound methods are not able to detect specific injuries, only the subsequent bleeding visible as free fluid. Therefore, we suggest performing additional research in order to determine the accuracy of solely investigating the most likely view based on the patient's position. If an acceptable accuracy is found, this could potentially lead to a more widespread use since the time necessary would drastically decrease.

Time is an important factor in prehospital ultrasound. It allows for earlier diagnoses, but time is also a potentially limiting factor. Potentially, performing a prehospital ultrasound can hinder optimal care in the prehospital setting since it takes one person's focus and hands away from different tasks, leading to a potential delay in transportation or patient care. This general concept is known as the "time-thoroughness trade off" and applies to all prehospital interventions and procedures [25]. A local protocol should be developed to prevent this type of delay in trauma patient care, facilitating both early diagnosis and rapid patient care. Moreover, some abnormalities are diagnosed more easily once progressed further. For example, a small pneumothorax might be missed on prehospital ultrasound because of the small size of the abnormality. Over time, the diagnosis becomes easier as the abnormality grows, for instance when performing the same ultrasound examination upon arrival in the hospital (after transportation). This might partly explain false-negative test results of the prehospital ultrasounds performed.

Some limiting factors were identified. This systematic review contains nine articles with differing patient populations from different countries as can be seen in Table 2. Besides the different countries of origin, the type of injury and the group size varied. Due to this, the results presented are of a heterogeneous origin, making it impossible to perform a meta-analysis of the results found. Therefore, we suggest performing a meta-analysis on this subject with a more homogeneous population and study endpoints, in order to increase the power of the results found.

Overall, a high accuracy is described in the included articles. This suggests that ultrasound is especially accurate in confirming and to a lesser extend in excluding the presence of free abdominal fluid in the prehospital setting. This is also supported by the results found for the alteration of prehospital trauma patient management. Therefore, more trauma systems should consider adding ultrasound equipment to the inventory of their ambulances and helicopters, in order to be able to detect free abdominal fluid in trauma patients earlier and to optimize the trauma patient management with minimal time lost due to preparation of the operation room and additional imaging methods. Also, the article of Hu et al. [20] describes the use of FAST in case of natural disaster. This is a promising finding for a broader use of prehospital ultrasound in the setting of a natural disaster, but in general further investigation, with for instance uniformly trained prehospital care providers and homogenous endpoints, is suggested and encouraged.

Funding

None.

Declaration of Competing Interest

I, Laura van der Weide, hereby state that there are no conflicts of interest.

Acknowledgement

Rein Ketelaars, the author of two articles, provided us with the necessary data, making it possible to include his two articles and the large number of patients described. For this, we thank him greatly.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2019.09.034.

References

[1] Krug, Etienne G, World Health Organization. Violence and Injury Prevention Team. (1999). Injury: A leading cause of the global burden of disease. https://apps.who.int/iris/handle/10665/66160.

[2] Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. J Trauma 2006;60:S3–11. doi:10.1097/01.ta.0000199961.02677.19.

[3] Clarke J, Trooskin S, Doshi P, Greenwald L, Mode C. Time to laparotomy for intra-abdominal bleeding from trauma does affect survival for delays up to 90 min. J Trauma 2002;52:420–5. doi:10.1097/00005373-200203000-00002.

[4] Pariyadath M, Snead G. Emergency ultrasound in adults with abdominal and thoracic trauma. UpToDate 2019. https://www.uptodate.com/contents/emergency-ultrasound-in-adults-with-abdominal-and-thoracic-trauma?search=Emergency ultrasound in adults with abdominal and thoracictrauma&source=search_result&selectedTitle=1~150&usage_type=default&display_rank=1.

[5] Saladino R, Conti K. Pediatric blunt abdominal trauma: initial evaluation and stabilization. UpToDate 2018. https://www.uptodate.com/contents/pediatric-blunt-abdominal-trauma-initial-evaluation-and-stabilization accessed March 16, 2019.

[6] Jang T, Geffen D. Focused assessment with sonography in trauma (FAST). Medscape 2017. https://emedicine.medscape.com/article/104363-overview.

[7] Torloni MR, Vedmedovska N, Merialdi M, Betrán AP, Allen T, González R, et al. Safety of ultrasonography in pregnancy: who systematic review of the literature and meta-analysis. Ultrasound Obstet Gynecol 2009;33:599–608. doi:10.1002/uog.6328.
[8] Heijerman L, De Jong I. Diagnostiek algemeen: afbeeldingstechnieken. Compend Geneeskd Deel 2016;4:246–9.
[9] Gross A, Stolz LA, Stolz U, Amini R, Adhikari S, O'Brien KM. Focused assessment with sonography for trauma examination. J. Med. Ultrasound 2015;34:1429–34. doi:10.7863/ultra.34.8.1429.
[10] Jørgensen H, Jensen CH, Dirks J. Does prehospital ultrasound improve treatment of the trauma patient? a systematic review. Eur J Emerg Med 2010;17:249–53. doi:10.1097/MEJ.0b013e328336adce.
[11] O'Dochartaigh D, Douma M, Alexiu C, Ryan S, MacKenzie M. Utilization criteria for prehospital ultrasound in a canadian critical care helicopter emergency medical service: determining who might benefit. Prehosp Disaster Med 2017;32:536–40. doi:10.1017/S1049023X1700646X.
[12] Busch M. Portable ultrasound in pre-hospital emergencies: a feasibility study. Acta Anaesthesiol Scand 2006;50:754–8. doi:10.1111/j.1399-6576.2006.01030.x.
[13] Quick J, Uhlich R, Ahmad S, Barnes S, Coughenou JP C. In-flight ultrasound identification of pneumothorax. Emerg Radiol TA - TT 2016;23:3–7. doi:10.1007/s10140-015-1348-zLK.
[14] Ketelaars R, Hoogerwerf N, Scheffer GJ. Prehospital chest ultrasound by a dutch helicopter emergency medical service. J Emerg Med 2013;44:811–17. doi:10.1016/j.jemermed.2012.07.085.
[15] Ketelaars R, Holtslag JJM, Hoogerwerf N. Abdominal prehospital ultrasound impacts treatment decisions in a Dutch helicopter emergency medical service. Eur J Emerg Med 2019;26:277–82. doi:10.1097/MEJ.0000000000000540.
[16] Brun PM, Bessereau J, Chenaitia H, Pradel AL, Deniel C, Garbaye G, et al. Stay and play eFAST or scoop and run eFAST? that is the question!. Am J Emerg Med 2014;32:166–70. doi:10.1016/j.ajem.2013.11.008.
[17] Melanson SW, Heller M, Kostenbader J, Stromski CJ, McCarthy J. Aeromedical trauma sonography by flight crews with a miniature ultrasound unit. Prehospital Emerg Care 2007;5:399–402. doi:10.1080/10903120190939607.
[18] Walcher F, Weinlich M, Conrad G, Schweigkofler U, Breitkreutz R, Kirschning T, et al. Prehospital ultrasound imaging improves management of abdominal trauma. Br J Surg 2006;93:238–42. doi:10.1002/bjs.5213.
[19] Yates JG, Baylous D. Aeromedical ultrasound: the evaluation of point-of-care ultrasound during helicopter transport. Air Med J 2017;36:110–15. doi:10.1016/j.amj.2017.02.001.
[20] Hu H, He Y, Zhang S, Cao Y. Streamlined focused assessment with sonography for mass casualty prehospital triage of blunt torso trauma patients. Am J Emerg Med 2014;32:803–6. doi:10.1016/j.ajem.2014.03.014.
[21] Heegaard W, Nelson B, Hildebrandt D, Chason K, Spear D, Ho J. Prehospital ultrasound by paramedics: results of field trial. Acad Emerg Med 2010;17:624–30. doi:10.1111/j.1553-2712.2010.00755.x.
[22] Press GM, Miller SK, Hassan IA, Alade KH, Camp E, Del Junco D, et al. Prospective evaluation of prehospital trauma ultrasound during aeromedical transport. J Emerg Med 2014;47:638–45. doi:10.1016/j.jemermed.2014.07.056.
[23] Rozycki GS, Ochsner MG, Feliciano DV, Thomas B, Boulanger BR, Davis FE, et al. Early detection for hemoperitoneum by ultrasound examination of the right upper quadrant: a multicenter study. J Trauma 1998;45:878–83. doi:10.1097/00005373-199811000-00006.
[24] Lobo V, Hunter-Behrend M, Cullnan E, Higbee R, Phillips C, Williams S, et al. Caudal edge of the liver in the right upper quadrant (RUQ) view is the most sensitive area for free fluid on the fast exam. West J Emerg Med 2017;18:270–80. doi:10.5811/westjem.2016.11.30435.
[25] Hollnagel E. The etto principle: efficiency-Thoroughness trade-off; why things that go right sometimes go wrong. 2009.