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The diagnostic accuracy of prehospital triage tools in identifying patients with traumatic brain injury: A systematic review

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ABSTRACT

Introduction: Prehospital care providers are usually the first responders for patients with traumatic brain injury (TBI). Early identification of patients with TBI enables them to receive trauma centre care, which improves outcomes. Two recent systematic reviews concluded that prehospital triage tools for undifferentiated major trauma have low accuracy. However, neither review focused specifically on patients with suspected TBI. Therefore, we aimed to systematically review the existing evidence on the diagnostic performance of prehospital triage tools for patients with suspected TBI.
Methods: A comprehensive search of the current literature was conducted using Medline, EMBASE, CINAHL Plus and the Cochrane library (inception to 1st June 2021). We also searched Google Scholar, OpenGrey, pre-prints (MedRxiv) and dissertation databases. We included all studies published in English language evaluating the accuracy of prehospital triage tools for TBI. We assessed methodological quality and risk of bias using a modified Quality Assessment of Diagnostic Studies (QUADAS-2) tool. Two reviewers independently performed searches, screened titles and abstracts and undertook methodological quality assessments. Due to the heterogeneity in the population of interest and prehospital triage tools used, a narrative synthesis was undertaken.
Results: The initial search identified 1787 articles, of which 8 unique eligible studies met the inclusion criteria (5 retrospective, 2 prospective, 1 mixed). Overall, sensitivity of triage tools studied ranged from 19.8% to 87.9% for TBI identification. Specificity ranged from 41.4% to 94.4%. Two decision tools have been validated more than once: HITS-NS (2 studies, sensitivity 28.3–32.6%, specificity 89.1–94.4%) and the Field Triage Decision Scheme (4 studies, sensitivity 19.8–64.5%, specificity 77.4%-93.1%). Existing tools appear to systematically under-triage older patients.
Conclusion: Further efforts are needed to improve and optimise prehospital triage tools. Consideration of additional predictors (e.g., biomarkers, clinical decision aids and paramedic judgement) may be required to improve diagnostic accuracy.

Introduction

Traumatic brain injury (TBI) refers to an insult to the brain arising from an external force leading to a disruption in brain functions [1]. It remains one of the most common causes of death and long-term disability worldwide, and it is estimated that 69 million people are expected to be affected by TBI each year [2]. In addition, TBI is responsible for 4000 deaths [3], 1.4 million emergency department visits and almost a healthcare cost of £4.1 billion annually in the UK [4]. TBI is a spectrum disorder with severity ranging from mild disorientation with rapid recovery to injuries incompatible with life. Most years of life lost due to TBI are thought to result from TBI with intracranial injury (primary to the brain or secondary from expanding extra-axial haematoma), visible on CT scan. In England, it has been reported that 80% of patients with TBI are

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transported by ambulance services [5], highlighting the critical role of prehospital clinicians in contributing to the patient outcomes. A fundamental principle of prehospital care is to ensure that patients are transported to the right destination at the right time with continuing intervention and care en route to the hospital.

Current evidence proves the beneficial effects of prehospital care on the survival of patients with major trauma [6]. Across the world, paramedics must work with limited information and limited resources to make clinical decisions, including determining of the destination hospitals for their patients. Evidence suggests that transporting severely injured patients to a major trauma centre (MTC), equivalent to US level one trauma centre, could improve patients' outcomes after TBI [7,8]. Current guidelines from National Institute for Health and Care Excellence (NICE) and Brain Trauma Foundation recommend that patients with suspected significant TBI should be treated at a specialized neurosurgical centre [9]. Making accurate field trauma triage decisions is, therefore, highly important to achieve this goal.

Prehospital trauma triage tools are designed to aid prehospital care providers in triaging patients to the most appropriate level of care and guiding decisions about which patients require transport to specialised major trauma centres. The accuracy of the current prehospital triage tools is examined by using sensitivity and specificity. A triage tool with high sensitivity will ensure that the majority of patients with major trauma are transported to an MTC. This will reduce the number of severely injured patients who are transported to a non-specialised trauma centre, which may result in a delay in receiving definitive care and worse outcomes [10]. Conversely, however, a low specificity triage tool might result in a high proportion of patients without significant injury being transported to the MTC, leading to unnecessary use of limited resources for patients with minor trauma [11]. The American College of Surgeons Committee on Trauma (ACS-COT) states that an under-triage rate of <5% and an over-triage rate of 25% to 50% should be considered acceptable target levels [12].

Early identification of TBI in the prehospital field is challenging, particularly among elderly patients. Recent evidence from the United States and Norway showed a higher under-triage rate in patients with TBI [13–15]. It is worth noting that the accuracy of prehospital triage tools in identifying patients with TBI is unknown. Recent research regarding the accuracy of prehospital trauma triage rules focuses on undifferentiated major trauma patients, rather than focusing on TBI [16,17]. Therefore, in this systematic review we aimed to identify and evaluate the diagnostic performance of the current prehospital triage tools in identifying patients with suspected TBI in the prehospital setting.

Methods

This systematic review was undertaken and reported in accordance to the Preferred Reporting in Systematic Reviews and Meta-Analyses (PRISMA) guidelines [18]. After several scoping searches, the review protocol was developed in cooperation with the review team and was prospectively registered at the International Prospective Register of Systematic Reviews (PROSPERO) on June 26, 2021 (CRD42021260805).

A comprehensive search to identify all relevant studies was performed using Medline, EMBASE, CINAHL Plus and the Cochrane library from inception to 1st of June 2021. Additionally, an electronic grey literature search was carried out using Google Scholar search engine, OpenGrey, pre-prints (MedRxiv) and dissertation databases. Furthermore, the reference lists of the included publications were hand-searched to retrieve further potentially relevant studies that might have been missed. Finally, we attempted to contact corresponding authors of the included studies to identify additional published or unpublished data. Neither language nor date restrictions were applied to the databases search process. Endnote X9 and Rayyan QCRI web-tool (Qatar Computing Research Institute) were used to remove duplicates, exploring and filtering the search results [19]. Table 1 shows details of the search terms used in CINAHL Plus database.

Table1
Search strategy.

Database searched: CINAHL plus
Date of covering: From inception to June 2021
1- TI (Traumatic brain injury or Head trauma or Head injury or Brain injury) OR AB (Traumatic brain injury or Head trauma or Head injury or Brain injury)
2- TI (Emergency Medical Services OR Emergency Medical Technicians OR paramedic* OR pre-hospital OR prehospital OR ambulance* OR out of hospital OR out-of-hospital) OR AB (Emergency Medical Services OR Emergency Medical Technicians OR paramedic* OR pre-hospital OR prehospital OR ambulance* OR out of hospital OR out-of-hospital)
3- TI (triage or undertriage or overtriage or under-triage or over-triage or sensitivity or specificity) OR AB (triage or undertriage or overtriage or under-triage or over-triage or sensitivity or specificity)
4- S1 and S2 and S3

Eligibility criteria and data collection

Studies were eligible for inclusion if they aimed to examine the accuracy of existing prehospital triage tools in identifying adult patients (≥16 years old) with suspected severe TBI transported by ground ambulance services. Our outcome of interest was neurosurgically significant TBI, which we defined as any TBI requiring neurosurgical intervention or with an abbreviated injury scale (AIS) score of at least 3 points. However, recognising that heterogeneous outcomes may have been studied, we also collected data for alternative definitions of neurosurgically significant TBI used in individual studies. Regardless of the year of publication, retrospective, prospective and Randomised Control Trial (RCT) studies written in the English language were considered eligible. Studies were excluded if they included predominantly paediatric patients due to differences in anatomical, physiological, and trauma triage tools [20]. Studies that evaluated prehospital helicopter transportation were also excluded. The underlying reason for this is that most prehospital helicopter triage scores are usually used to identify patients who benefit from direct helicopter transport from the scene rather than specific clinical intervention [21,22].

Two independent authors (NA and AA) screened titles and abstracts of identified citations using pre-defined inclusion and exclusion criteria. Both reviewers then independently performed the full-text analysis of potentially relevant articles to determine their eligibility. Any study that did not fulfil the inclusion and exclusion criteria was excluded. Finally, the third reviewer (RB) was consulted to resolve any disagreement on study eligibility.

Two reviewers (NA and AA) independently carried out the data extraction process using a standardized piloted data extraction form developed by the first author (NA) and was double-checked by the review team to ensure its validity and reliability. We extracted data on study characteristics, patient characteristics, index test, reference standard and accuracy metrics from each included study (sensitivity, specificity, overtriage and undertriage rates). Corresponding authors were contacted in case of missing data or for further clarification.

Table 2
Characteristics of included studies.

Publication	Study design	Study period	Country	Demographic	Sample size (n)	Triage tool	General study focus
Fuller et al. [24]	Retrospective study	2005–2011	UK	> 16 years	6559	a- LAS triage rule b- HITS-NS	The accuracy of triage rules in identifying severe TBI
Fuller et al. [25]	Diagnostic cohort study	January 2012 to 31 April 2013	UK	> 16 years	3628	HITS-NS	To examine the HITS-NS triage tool for severe TBI and to further explore the true positive and false negative cases
Van Rein et al. [31]	Retrospective study	January 2015 to December 2016	Netherland	≥ 16 years	980	Emergency medical provider judgement	To examine the prehospital care providers' judgement in identifying a head injury
Nishijima et al. [26]	Retrospective cohort study	1 January 2012, to December 31, 2012.	US	> 55 years	2110	a- FTDS b- FTDS + anticoagulant or antiplatelet use	The accuracy of adding anticoagulant/antiplatelet criteria to the current field triage tool in the identification of older patients with intracranial haemorrhage
Nishijima et al. [28]	Prospective study	August 1, 2015 to September 30, 2016	US	> 55 years	1147	a- FTDS b- FTDS + anticoagulant or antiplatelet use	The accuracy of different triage tools in identifying older patients with intracranial haemorrhage
Newgard et al. [29]	Retrospective cohort study	January 1, 2006 to December 31, 2008	US	≥ 65 years	634	a- FTDS b- Alternative field trauma triage	Derived an alternative triage tool that was compared with the current field triage tool. Subgroup analysis of TBI patients was included in the review
S Hon et al. [27]	Prospective cohort study	August 1, 2015 to September 30, 2016	US	>55 years	673	a- EMS provider judgement b- FTDS	To compare the prehospital care providers' judgement with different triage criteria for predicting traumatic intracranial haemorrhage
Caterino et al. [30]	Retrospective study	2002 to 2007	US	≥ 16 years	52,412	a- SMS b- GCS ≤13	To examine the accuracy of prehospital care providers' ability to obtain Glasgow coma scale and simplified motor score for predicting neurosurgical interventions, mortality and TBI

Abbreviations: UK: United Kingdom; US: United States; TBI: Traumatic Brain Injury; LAS: London Ambulance Service major trauma triage tool; HITS-NS: The Head Injury Transportation Straight to Neurosurgery; FTDS: Field Triage Decision Scheme; SMS: Simplified Motor Score; GCS: Glasgow coma scale.

Quality assessment and risk of bias

The methodological quality of included studies was assessed by two independent reviewers (NA and AA) using the modified Quality Assessment of Diagnostic Studies (QUADAS-2) tool, a revised validated quality assessment tool designed to evaluate diagnostic accuracy studies [23]. This tool consists of four key domains: patient selection, index test (trauma triage tool scoring), reference standard and flow and timing. Each domain is assessed for the potential risk of bias, and the first three domains are also evaluated for applicability concerns. A pilot assessment of one study was performed to ensure the suitability of the revised QUADAS-2 tool. Each study was assessed for bias and for its applicability to our research question using five domains: selection of participants, interpretation of the trauma triage score outcomes, TBI diagnosis allocation, the reference standard and flow and timing. Studies were scored as having a 'high', 'low' or 'unclear' risk of bias. An 'unclear' answer was chosen when a study did not report sufficient information to assess the risk of bias. Discrepancies were reconciled through discussion or by involving a third reviewer (RB).

Data synthesis

Combining the results of the included studies in a meta-analysis was planned and considered by pooling sensitivity, specificity, positive and negative predictive values. Additionally, if possible, the level of heterogeneity was planned to be assessed using I^2 and χ^2 tests. However, after extracting and collecting the data, it becomes apparent that there was considerable heterogeneity between studies in terms of the population of interest, prehospital triage tools used and outcome measures. Therefore, after several discussions between the authors, a narratively synthesis of the evidence identified was chosen as the most appropriate method to answer the review question. The key characteristics and results of the included studies were tabulated to compare similarities and differences between the current evidence. The included studies were also grouped and reported based on the study population. Furthermore, data accuracy measures, including sensitivity, specificity, positive and negative predictive values, were extracted, calculated and presented in Table 2. We used a web-based program (MedCalc) to calculate unreported predictive values using the information provided in each study,

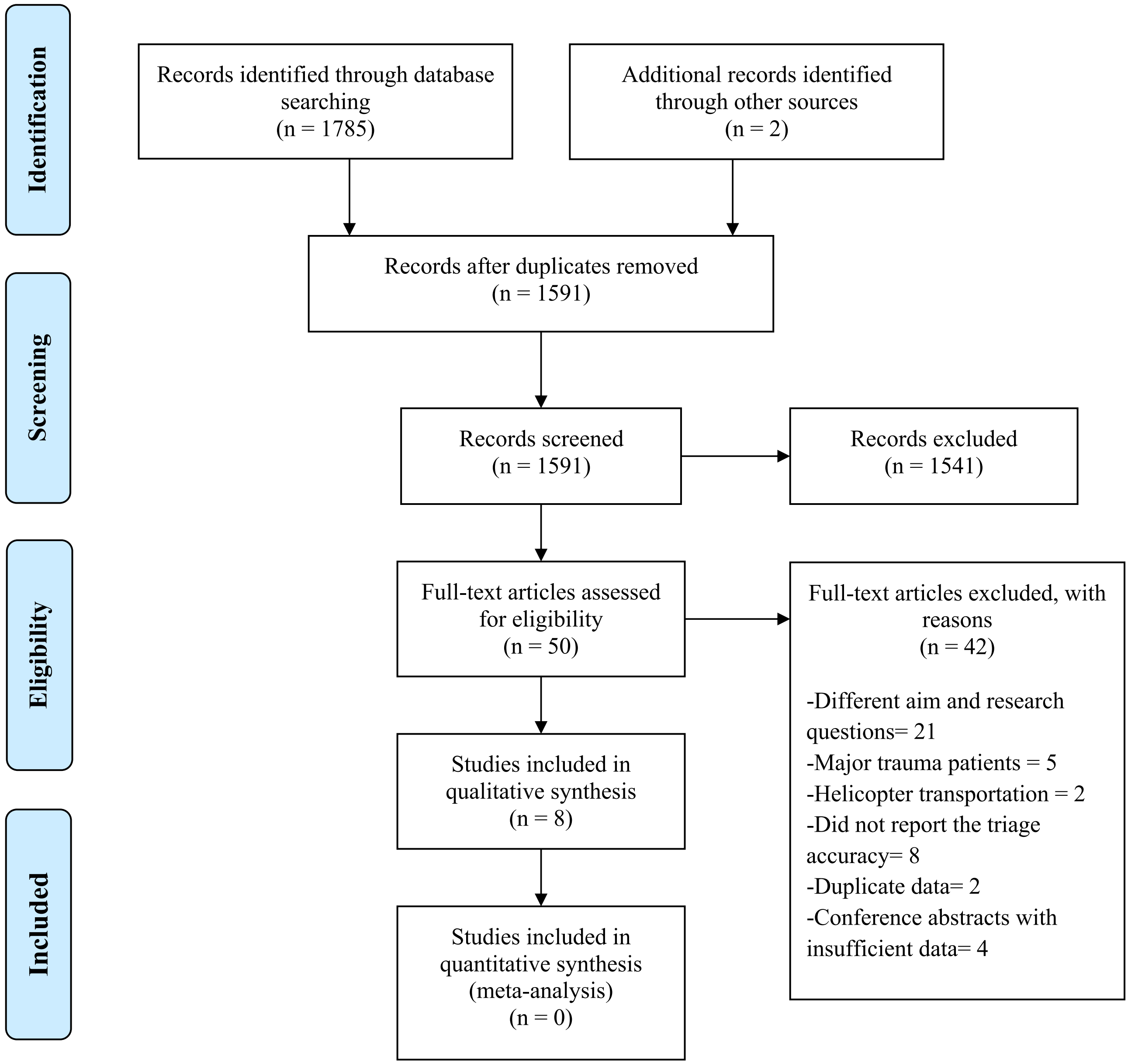

Fig. 1. PRISMA diagram.

including 95% confidence intervals using the Clopper-Pearson method.

Results

Study selection

The electronic search strategy identified a total of 1787 citations. Searching the grey literature, and hand-searching bibliographies produced two additional studies, of which 196 were duplicates leaving 1591 potential articles for titles and abstracts screening. Of these, 1541 papers were excluded as they were irrelevant to the review question, leaving 50 papers for full-text review. After applying the inclusion and exclusion criteria, 42 articles were excluded. The reasons for exclusion were as follows: different aim and research questions ($n = 21$), included major trauma patients ($n = 5$), helicopter transportation ($n = 2$), did not report the triage accuracy ($n = 8$), duplicate data ($n = 2$) and conference abstracts with insufficient data ($n = 4$). Eventually, eight unique eligible papers were included in this systematic review. Fig. 1 visually presents the PRISMA flowchart.

Study characteristics

The characteristics of the eight included studies are provided in Table 2. Included studies were all conducted in high-income countries with regionalised trauma care: United Kingdom [24,25], the United States of America [26–30] and the Netherlands [31]. All included studies were published between 2011 and 2020. The data collection period varied between studies ranging from 12 months to 6 years. Three studies included only older adults (>55 years) [26–28], and one study only included adults aged ≥ 65 years [29]. The remaining studies included adults aged 16 years and older. In total, the relevant studies included 68,143 participants, ranging from 634 to 52.412 patients per study (median 1628.5 patients; interquartile Range (IQR) 903 to 4360.75). The median age was reported in the vast majority of the included studies and ranged

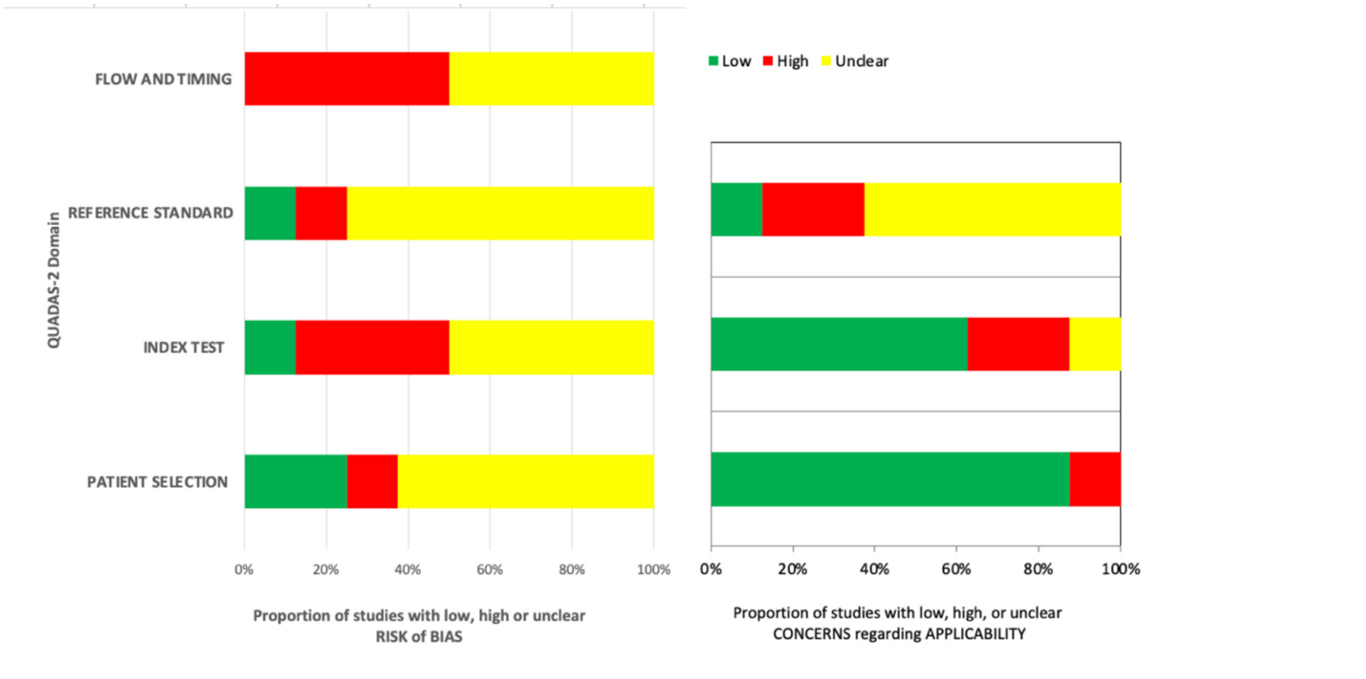

Fig. 2. Risk of bias and applicability assessment.

from 45 to 75 years. Furthermore, three studies were conducted only in a single emergency medical services (EMS) system [26–28].

In terms of the accuracy of triage, four studies reported data on the accuracy of the current field triage tools and two studies focused on the accuracy of adding pre-injury anticoagulant use to the triage protocols to identify older patients with intracranial haemorrhage requiring MTC care. Additionally, one study developed a new triage tool, which was compared with the field triage tool that was used in clinical practice at the time of the study [29], and one study compared a simplified motor score (SMS) with prehospital Glasgow coma scale (GCS) for prediction of TBI and neurosurgical interventions [30]. Ethical approval was presented and justified in all of the included studies.

Risk of bias assessment

As described above, risk of bias and applicability assessment was performed using a modified form of QUADAS-2 tool and is presented in Fig. 2.

Results of individual studies

The summary of the diagnostic accuracy results is presented in Table 3. Overall, the diagnostic accuracy of the current prehospital trauma triage scores in identifying patients with severe TBI fell below the ACS-COT sensitivity and specificity targets of ≥ 95% and ≥ 50%, respectively. The included studies reported sensitivities ranging from 19.8% to 87.9% and specificities ranging from 41.4% to 94.4%.

In the UK, two studies by Fuller et al.[24,25] examined two triage tools, the London Ambulance Service (LAS) major trauma triage tool and the Head Injury Transportation Straight to Neurosurgery (HITS-NS) triage rule, for identifying severe TBI patients. Both studies used a composite primary outcome of an AIS ≥3 or requirement for neurosurgical procedures. The authors reported that both tools had sensitivities <45% and specificities <90% for identifying severely injured patients. Interestingly, false-negative results occurred in older patients, highly likely to be female and those who have sustained ground-level falls.

Van Rein et al [31]. aimed to determine the accuracy of prehospital care providers' judgment in identifying TBI. The prehospital reports were retrospectively evaluated as an index test, whereas AIS (≥1) was used as the reference standard. The results demonstrated sensitivity and specificity of 67.9% and 87.7%, respectively. However, it should be stressed that 21% of severely injured (AIS ≥3) patients have not been identified in the prehospital setting. Another retrospective study was conducted to examine the predictive value of GCS score of ≤13 and SMS of 1 in predicting TBI and neurosurgical interventions, which showed similar sensitivity and specificity between GCS and Simplified Motor Score (SMS); sensitivity of GCS and SMS for TBI were 40.8% and 45.5%, respectively, while sensitivity for neurosurgical interventions were 52.9% and 60%, respectively [30].

Four studies aimed to evaluate the accuracy of field triage tools in identifying older adults with TBI. Of these, two studies evaluated the utility of anticoagulant or antiplatelet use in a triage rule in identifying older patients (>55 years) with traumatic intracranial haemorrhage (tICH). The two studies compared field triage decision scheme (steps 1 to 3) with and without the addition of anticoagulant or antiplatelet use (steps 1 to 3 plus anticoagulant or antiplatelet use). Nishijima et al [26]. showed that the addition of anticoagulant use to the current triage rule improved sensitivity from 19.8% to 59.5%; specificity decreased from 93.1% to 67.2% in identifying tICH and sensitivity increased from 34.1% to 70.7%; specificity decreased from 92.8% to 66.2% for death and neurosurgery. Similarly, a prospective study by Nishijima et al [28]. measured an improvement in sensitivity from 26.8% to 63.4% for tICH identification and from 59.1% to 72.7% for death and neurosurgery. However, a significant decrease in specificity was reported (90.3% to 55.7%) for tICH. However, the ability of prehospital care providers to ascertain the use of medications were not reported in both studies.

A recent prospective study was conducted to evaluate prehospital care provider discretion for tICH in older adults (>55 years). The paramedics' judgement was compared with the current filed triage rule and showed a sensitivity of (77.6% vs 26.3%) and speci-

Table 3
Diagnostic accuracy characteristics of included studies in identifying TBI.

Author (Year)	Triage tool		Reference standard	Predictive values						Sensitivity	Specificity
				TP	**FN**	**FP**	**TN**	**PPV%**	**NPV%**		
Gordon Fuller et al. [24]	a-	LAS triage rule	(AIS) ≥3 or Neurosurgical interventions.	2461	3046	321	713	88.46% (87.45-89.40%)	18.97% (18.25–19.71)	44.5% (43.37–46)	69.0% (66–71.77)
	b-	HITS-NS		1801	3724	113	921	94.10% (93.03–95.01)	19.83 (19.38–20.28)	32.6% (31.36–33.85)	89.1% (87.01–90.91)
Gordon Fuller et al. [25]	HITS-NS		(AIS) ≥3 or Neurosurgical interventions.	52	132	192	3252	21.31% (17.16–26.15	96.10% (95.74–96.43	28.3% (21.88–35.35)	94.4% (93.61–95.17)
Van Rein et al. [31]	Emergency medical provider judgement		(AIS) ≥1	NR	NR	NR	NR	NR	NR	67.9% (64.9–70.7)	87.7% (86.1–89.2)
Nishijima et al. [26]	a-	FTDS	tICH	26	105	136	1843	16.05% (11.56–21.86)	94.61% (94.15–95.03)	19.8% (5.5–51.2)	93.1% (91.2–94.7)
	b-	FTDS + antico-agulant or antiplatelet use		78	53	650	1329	10.71% (9.32–12.29)	96.16 (95.31–96.87)	59.5% (42.9–74.2)	67.2% (61.1–72.7)
Nishijima et al. [28]	a-	FTDS	tICH	30	82	100	935	23.08% (17.33–30.04)	91.94% (91.05–92.74)	26.8% (18.9–36.0)	90.3% (88.4–92)
	b-	FTDS + anticoagulant or antiplatelet use		71	41	458	577	13.42% (11.71–15.35)	93.37% (91.64–94.75)	63.4% (53.8–72.3)	55.7% (52.7–58.8)
Newgard et al. [29]	a-	FTDS	(AIS) ≥3	409	225	NR	NR	NR	NR	64.5% (60–68.2)	77.4% (76.6–78.1)
	b-	Alternative field trauma triage		557	77					87.9% (85.2–90.5)	41.4% (40.5–42.2)
S Hon et al. [27]	a-	EMS provider judgement	tICH	59	17	349	248	14.46% (12.83–16.26)	93.58% (90.47–95.73)	77.6% (66.62–86.40)	41.5% (37.55–45.61)
	b-	FTDS		20	56	70	527	22.22% (15.60–30.93)	90.39% (89.13–91.52)	26.3% (16.87–37.68)	88.3% (85.42–90.74)
Caterino et al. [30]	a-	SMS	TBI (skull fractures, intracranial haemorrhage and cerebral contusion)	NR	NR	NR	NR	NR	NR	40.8% (39.7–41.8)	90.5% (90.2–90.8)
	b-	GCS ≤13								45.4% (44.3–46.5)	89.3% (89–89.6)

Abbreviations: LAS: London Ambulance Service major trauma triage tool; HITS-NS: The Head Injury Transportation Straight to Neurosurgery; AIS: Abbreviated Injury Scale; FTDS; Field Triage Decision Scheme; tICH: Traumatic Intracranial Haemorrhage; SMS: Simplified Motor Score; GCS: Glasgow coma scale; TP: True Positive; FP: False Positive; FN: False Negative; TN: True Negative; NR: Not reported or cannot be calculated; PPV: Positive Predictive Value; NPV: Negative Predictive Value.
Confidence intervals calculated using the data presented.

ficity (41.5% vs 88.3%)(27). Additionally, Newgard et al [29]. derived an alternative triage tool for older adults (≥ 65 years) with a serious TBI (AIS ≥ 3 or any intracranial interventions) that was compared with the current field triage tool. The modified triage tool consists of any positive triage criterion from the current field triage tool, GCS ≤ 14 and abnormal vital signs. The alternative tool showed a higher sensitivity in identifying severe TBI (87.9% vs 64.5%) but decreased specificity (41.4% vs 77.4%). It has also been found that using the current field triage tool resulted in an under-triage rate of 35.4% (225 out of 634) of patients with serious TBI.

Discussion

To the best of our knowledge, this systematic review is the first to examine the current prehospital triage tools in identifying patients with potentially life threatening or life changing TBI. Previously, two systematic reviews have been conducted with a focus on major trauma patients, and one review focused on the elderly trauma population. The findings indicated that the discriminative value of the current prehospital triage rules is poorly accurate [32,33]. This systematic review identified eight studies that evaluated various prehospital triage tools for TBI with intracranial injury identification. The findings showed a lack of sensitivity to accurately identify patients with an intracranial injury raising concerns about undertriage severely injured patients. Included studies failed to provide results that meet ACS-COT recommendations of undertriage rate (<5%) and overtriage rate (up to 50%) [12]. This implies that patients with significant TBI might be at risk of receiving suboptimal care at non-MTCs, exposing them to secondary transfer risks, which can adversely affect the patients' outcomes [34].

Prehospital triage protocols have been introduced to enable prehospital personnel to accurately discriminate between patients with and without major trauma and determine the most appropriate hospital destination. However, over-triage and under-triage of trauma patients result from incorrect triage decisions. Previous research has demonstrated that patients with TBI is considered at high risk of under-triage [35]. Commonly, current field triage tools assess several variables (e.g., vital signs, GCS, mechanism of injury, anatomy of injury and special considerations), but this approach did not provide high accuracy findings. In two studies, prehospital personnel judgment was examined as a triaging criterion in determining the need for major trauma centre care [27,31]. However, the role of prehospital care providers judgment in the field triage process needs further evaluation as it has not been validated as an accurate method [36]. A recent systematic review showed that it could reduce the undertriage of major trauma patients even in case of meeting none of the triage criteria [37].

Additionally, recent attempts to develop new criteria have improved triage sensitivity, but with a substantial decrease in specificity, which might increase the over-triage rate with many patients with minor injuries could be triaged to MTCs. This inverse relationship has been previously discussed [38]. This is exemplified in the work undertaken by Newgard et al [29]. who developed an elderly-specific triage rule to improve the identification of high-risk patients. Using the new instrument has improved the sensitivity (87.9% vs 64.5%) but with low specificity (41.4% vs 77.4%). Furthermore, a multivariate logistic regression analysis of risk factors was used in two studies that included multiple variables (abnormal prehospital GCS, loss of consciousness, a history of vomiting, anticoagulant or antiplatelet use and injury above the clavicle). Similarly, the findings showed a high sensitivity in identifying older adults with tICH (>90%) but with a significantly decreased specificity (<13%)(27, 28).

The recognition of patients with severe TBI is a challenging task in the prehospital setting, especially in the older population. This might be explained by the fact that the presenting GCS in older patients might not reflect the severity of TBI [39]. In two studies, false-negative severe TBI cases were reported in older patients who presented with low TBI severity and sustained a fall from standing. These findings are consistent with the current literature, which indicated the undertriage of elderly patients with TBI [14,40]. In fact, undertriage of older adults (>55 years) with major trauma from the scene has been acknowledged [41]. Several factors that could affect the prehospital triage accuracy within the elderly population have been proposed. These factors include major trauma resulting from low impact mechanisms (low-level falls) that could not be captured by the current triage tools, age-related physiological responses to injuries, frailty, anticoagulant and antiplatelet medications use and comorbidities [42,43]. Age-related cerebral atrophy is another factor that may also be proposed as a potential mechanism. Recently, there has been an increasing interest in developing geriatric-specific prehospital triage criteria to reduce under-triage of older adults with major trauma.

It should be noted that most of the articles reviewed did not include sufficient information on whether all patients were followed up throughout their initial inpatient admission to determine whether neurosurgical intervention took place, highlighting the need for further comprehensive studies. In addition, severe TBI patients were defined using AIS $\geq$ 3 as a reference standard in most of the included studies. However, it should also be pointed out that patients with minor TBI may have other significant trauma required immediate admission to a specialist trauma centre. Lastly, all studies included in this systematic review were conducted in high-income countries with mature trauma care systems, which highlights the need for further studies from different countries.

Future research

Given the low accuracy of the current prehospital triage tools for identifying TBI patients, future research should be conducted to obtain further insight into the accuracy of field triage tools and also to improve the identification of severely injured patients. Further high-quality studies are also needed to investigate the utility of clinical predictors and paramedics' judgement in triage decisions to optimise prehospital triage performance. More research is also required to develop triage criteria to optimise the identification severe TBI in order patients. We identified several ongoing trials that are currently evaluate the feasibility of using prehospital point-of-care measurement of brain biomarkers and the potential use of Near-infrared spectroscopy (NIRS) in patients with TBI [44–46]. Using these tools in combination with accurate prehospital triage tools could help to optimise the prehospital triage of patients with TBI.

Limitations

We have adhered to PRISMA guidelines in reporting this systematic review. However, we should acknowledge several potential limitations. Efforts have been made to ensure that all relevant citations are included in this review. However, despite our comprehensive selection process, it is still possible that some relevant studies may not have been identified. Nevertheless, an extensive hand searching of reference lists was performed to mitigate this effect. Additionally, we excluded non-English studies, which can introduce a gap in our accuracy estimation.

Another limitation that should be acknowledged is the degree of between-study heterogeneity in the definition of serious TBI. Collating the evidence in a narrative manner allowed us to take an inclusive approach, including all relevant studies despite variations in the definition of the primary outcome. A universally accepted definition of neurosurgically significant TBI would help to maximise the external validity of future research in this area.

Because of the degree of between-study heterogeneity, it was not possible to aggregate data by meta-analysis, which precluded the presentation of single pooled measures of diagnostic accuracy. Finally, it is important to state that most of the included studies were retrospective and suffered from incomplete or missing data. Future studies should consider the conceptual limitation of the current evidence.

Conclusion

Our current insight into the existing prehospital triage tools in identifying patients with suspected isolated TBI requiring specialist trauma care suggested that the accuracy of the current tools is low, indicating that a proportion of patients with TBI and intracranial injury might be transported to non-MTCs. Existing tools appear to systematically under-triage older patients. Recent attempts to improve triage tools resulted in a significant decrease in specificity. Therefore, future high-quality studies should focus on improving TBI identification in the prehospital setting. This can be achieved by developing accurate triage tools that must be sensitive enough for TBI recognition and determining the need for specialised trauma centre care. Consideration of additional predictors (e.g., biomarkers, paramedic judgement and NIRS) may be required to improve diagnostic accuracy.

Author contributions

NA: corresponding author, protocol, analysis of data, drafting article; RB: participated in the design of the study, methodological support, revising article; AA: data interpretation, methodological support, revising article; SB: revising article, overall support study; FL: overall support study, revising article.

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Conflicts of interest

All listed authors do not have conflicts of interest to disclose.

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References

[1] Menon DK, Schwab K, Wright DW, Maas AI. Position statement: definition of traumatic brain injury. Arch Phys Med Rehabil 2010;91(11):1637–40.
[2] Dewan MC, Rattani A, Gupta S, Baticulon RE, Hung YC, Punchak M, et al. Estimating the global incidence of traumatic brain injury. J Neurosurg 2018:1–18.
[3] Kay A, Teasdale G. Head injury in the United Kingdom. World J Surg 2001;25(9):1210–20.
[4] National Clinical Guideline C National Institute for Health and Clinical Excellence: Guidance. Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Children, Young People and Adults. London: National Institute for Health and Care Excellence (UK) Copyright © National Clinical Guideline Centre; 2014. 2014.
[5] Lawrence T, Helmy A, Bouamra O, Woodford M, Lecky F, Hutchinson PJ. Traumatic brain injury in England and Wales: prospective audit of epidemiology, complications and standardised mortality. BMJ Open 2016;6(11):e012197.
[6] Organization WH. Prehospital trauma care systems: World Health Organization; 2005.
[7] MacKenzie EJ, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, et al. A national evaluation of the effect of trauma-center care on mortality. N Engl J Med 2006;354(4):366–78.
[8] Moran CG, Lecky F, Bouamra O, Lawrence T, Edwards A, Woodford M, et al. Changing the system-major trauma patients and their outcomes in the NHS (England) 2008–17. EClinicalMedicine 2018;2:13–21.
[9] Hodgkinson S, Pollit V, Sharpin C, Lecky F. Early management of head injury: summary of updated NICE guidance. BMJ: British Medical Journal 2014;348:g104.
[10] Rogers A, Rogers FB, Schwab CW, Bradburn E, Lee J, Wu D, et al. Increased mortality with undertriaged patients in a mature trauma center with an aggressive trauma team activation system. Eur J Trauma Emerg Surg 2013;39(6):599–603.
[11] Dehli T, Uleberg O, Wisborg T. Trauma team activation - common rules, common gain. Acta Anaesthesiol Scand 2018;62(2):144–6.
[12] Rotondo M, Cribari C, Smith R, ACoSCo Trauma. Resources for optimal care of the injured patient. Chicago: American College of Surgeons 2014;6.
[13] Vassar MJ, Holcroft JJ, Knudson MM, Kizer KW. Fractures in access to and assessment of trauma systems. J Am Coll Surg 2003;197(5):717–25.
[14] Xiang H, Wheeler KK, Groner JI, Shi J, Haley KJ. Undertriage of major trauma patients in the US emergency departments. Am J Emerg Med 2014;32(9):997–1004.
[15] Dehli T, Fredriksen K, Osbakk SA, Bartnes K. Evaluation of a university hospital trauma team activation protocol. Scand J Trauma Resusc Emerg Med 2011;19:18.
[16] Shanahan T, Marincowitz C, Fuller G, Sheldon T, Quilty F, Turton E. 11 External validation of the Dutch prediction model for prehospital triage of trauma patients in South West region of England, United Kingdom. Emergency Medicine Journal 2020;37(12):838.
[17] Ocak G, Sturms LM, Hoogeveen JM, Le Cessie S, Jukema GN. Prehospital identification of major trauma patients. Langenbecks Arch Surg 2009;394(2):285–92.
[18] Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 2009;339:b2700.
[19] Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Systematic Reviews 2016;5(1):210.
[20] van der Sluijs R, van Rein EAJ, Wijnand JGJ, Leenen LPH, van Heijl M. Accuracy of Pediatric Trauma Field Triage: A Systematic Review. JAMA Surg 2018;153(7):671–6.
[21] Brown JB, Gestring ML, Guyette FX, Rosengart MR, Stassen NA, Forsythe RM, et al. External validation of the Air Medical Prehospital Triage score for identifying trauma patients likely to benefit from scene helicopter transport. J Trauma Acute Care Surg 2017;82(2):270–9.
[22] Brown JB, Gestring ML, Guyette FX, Rosengart MR, Stassen NA, Forsythe RM, et al. Development and Validation of the Air Medical Prehospital Triage Score for Helicopter Transport of Trauma Patients. Ann Surg 2016;264(2):378–85.
[23] Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155(8):529–36.
[24] Fuller G, Lawrence T, Woodford M, Lecky F. The accuracy of alternative triage rules for identification of significant traumatic brain injury: a diagnostic cohort study. Emergency Medicine Journal 2014;31(11):914.
[25] Fuller G, McClelland G, Lawrence T, Russell W, Lecky F. The diagnostic accuracy of the HITSNS prehospital triage rule for identifying patients with significant traumatic brain injury: a cohort study. Eur J Emerg Med 2016;23(1):61–4.
[26] Nishijima DK, Gaona SD, Waechter T, Maloney R, Bair T, Blitz A, et al. Out--of-Hospital Triage of Older Adults With Head Injury: A Retrospective Study of the Effect of Adding "Anticoagulation or Antiplatelet Medication Use" as a Criterion. Ann Emerg Med 2017;70(2):127–38 .e6.
[27] Hon S, Gaona SD, Faul M, Holmes JF, Nishijima DK. How Well Do EMS Providers Predict Intracranial Hemorrhage in Head-Injured Older Adults? Prehosp Emerg Care 2020;24(1):8–14.
[28] Nishijima DK, Gaona SD, Waechter T, Maloney R, Blitz A, Elms AR, et al. The Incidence of Traumatic Intracranial Hemorrhage in Head-Injured Older Adults Transported by EMS with and without Anticoagulant or Antiplatelet Use. J Neurotrauma 2018;35(5):750–9.
[29] Newgard CD, Holmes JF, Haukoos JS, Bulger EM, Staudenmayer K, Wittwer L, et al. Improving early identification of the high-risk elderly trauma patient by emergency medical services. Injury 2016;47(1):19–25.
[30] Caterino JM, Raubenolt A. The prehospital simplified motor score is as accurate as the prehospital Glasgow coma scale: analysis of a statewide trauma registry. Emerg Med J 2012;29(6):492–6.
[31] van Rein EAJ, Jochems D, Lokerman RD, van der Sluijs R, Houwert RM, Lichtveld RA, et al. Diagnostic value of emergency medical services provider judgement in the identification of head injuries among trauma patients. Eur J Neurol 2019;26(2):274–80.
[32] Fuller G, Pandor A, Essat M, Sabir L, Buckley-Woods H, Chatha H, et al. Diagnostic accuracy of prehospital triage tools for identifying major trauma in elderly injured patients: a systematic review. J Trauma Acute Care Surg 2021;90(2):403–12.
[33] van Rein EAJ, Houwert RM, Gunning AC, Lichtveld RA, Leenen LPH, van Heijl M. Accuracy of prehospital triage protocols in selecting severely injured patients: a systematic review. J Trauma Acute Care Surg 2017;83(2):328–39.
[34] Mans S, Reinders Folmer E, de Jongh MA, Lansink KW. Direct transport versus inter hospital transfer of severely injured trauma patients. Injury 2016;47(1):26–31.
[35] Nakahara S, Matsuoka T, Ueno M, Mizushima Y, Ichikawa M, Yokota J, et al. Predictive factors for undertriage among severe blunt trauma patients: what enables them to slip through an established trauma triage protocol? J Trauma 2010;68(5):1044–51.
[36] Mulholland SA, Gabbe BJ, Cameron P. Is paramedic judgement useful in prehospital trauma triage? Injury 2005;36(11):1298–305.
[37] van Rein EAJ, van der Sluijs R, Raaijmaakers AMR, Leenen LPH, van Heijl M. Compliance to prehospital trauma triage protocols worldwide: a systematic review. Injury 2018;49(8):1373–80.
[38] Newgard CD, Hsia RY, Mann NC, Schmidt T, Sahni R, Bulger EM, et al. The trade-offs in field trauma triage: a multiregion assessment of accuracy metrics and volume shifts associated with different triage strategies. J Trauma Acute Care Surg 2013;74(5):1298–306 discussion 306.
[39] Kehoe A, Smith JE, Bouamra O, Edwards A, Yates D, Lecky F. Older patients with traumatic brain injury present with a higher GCS score than younger patients for a given severity of injury. Emergency Medicine Journal 2016;33(6):381.
[40] Hruska K, Ruge T. The Tragically Hip: Trauma in Elderly Patients. Emerg Med Clin North Am 2018;36(1):219–35.
[41] Garwe T, Stewart K, Stoner J, Newgard CD, Scott M, Zhang Y, et al. Out-of-hospital and Inter-hospital Under-triage to Designated Tertiary Trauma Centers among Injured Older Adults: A 10-year Statewide Geospatial-Adjusted Analysis. Prehosp Emerg Care 2017;21(6):734–43.

[42] Morris JA Jr, MacKenzie EJ. Edelstein SL. The effect of preexisting conditions on mortality in trauma patients. JAMA 1990;263(14):1942–6.
[43] Spaniolas K, Cheng JD, Gestring ML, Sangosanya A, Stassen NA, Bankey PE. Ground level falls are associated with significant mortality in elderly patients. J Trauma 2010;69(4):821–5.
[44] Seidenfaden SC, Kjerulff JL, Juul N, Kirkegaard H, Møller MF, Münster AB, et al. Diagnostic accuracy of prehospital serum S100B and GFAP in patients with mild traumatic brain injury: a prospective observational multicenter cohort study - "the PreTBI I study". Scand J Trauma Resusc Emerg Med 2021;29(1):75.
[45] Kjerulff JL, Seidenfaden SC, Juul N, Møller MF, Munster AB, Bøtker MT. Influence of Simulated Pre-Hospital Transport, Time to Analysis, and Storage Temperature on S100 Calcium-Binding Protein B Values. J Neurotrauma 2020;37(17):1864–9.
[46] Peters J, Van Wageningen B, Hoogerwerf N, Tan E. Near-Infrared Spectroscopy: A Promising Prehospital Tool for Management of Traumatic Brain Injury. Prehosp Disaster Med 2017;32(4):414–18.