Injury 53 (2022) 2725–2733

Contents lists available at ScienceDirect

Injury

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

Accuracy of prehospital triage systems for mass casualty incidents in trauma register studies - A systematic review and meta-analysis of diagnostic test accuracy studies

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ARTICLE INFO

Article history:
Accepted 7 May 2022

Keywords:
Triage
Prehospital
Mass casualty incidents
Accuracy
Meta-analysis
Systematic review
Register studies

ABSTRACT

Background: Prioritising patients in mass casualty incidents (MCI) can be extremely difficult. Therefore, triage systems are important in every emergency medical service. This study reviews the accuracy of primary triage systems for MCI in trauma register studies.

Methods: We registered a protocol at PROSPERO ID: CRD42018115438. We searched MEDLINE, EMBASE, Central, Web of Science, Scopus, Clinical Trials, Google Scholar, and reference lists for eligible studies. We included studies that both examined a primary triage system for MCI in trauma registers and provided sensitivity and specificity for critically injured vs non-critically injured as results. We excluded studies that used paediatric, chemical, biological, radiological or nuclear MCIs populations or triage systems. Finally, we calculated intra-study relative sensitivity, specificity and diagnostic odds ratio for each triage system.

Results: Triage Sieve (TS) significantly underperformed in relative diagnostic odds ratio (DOR) when compared to START and CareFlight (CF) (START vs TS: 19.85 vs 13.23 ($p<0.0001$) | CF vs TS: 23.72 vs 12.83 ($p<0.0001$)). There was no significant difference in DOR between TS and Military Sieve (MS) ($p<0.710$). Compared to START, MS and CF TS had significantly higher relative specificity (START vs TS: 93.6% vs 96.1% ($p=0.047$) | CF vs TS: 96% vs 95.3% ($p=0.0006$) | MS vs TS: 94% vs 88.3% ($p=0.0002$)) and lower relative sensitivity (START vs TS: 57.8% vs 34.8% ($p<0.0001$) | CF vs TS: 53.9% vs 34.7% ($p<0.0001$) | MS vs TS: 51.9% vs 35.2% $p<0.0001$)).

CF had significantly better relative DOR than START (CF vs START: 23.56 vs 27.79 ($p=0.043$)). MS had significantly better relative sensitivity than CF and START (MS vs CF: 49.5% vs 38.7% ($p<0.0001$) | MS vs START: 49.4% vs 43.9% ($p=0.01$)). In contrast, CF had significantly better relative specificity than MS (MS vs CF: 91.3% vs 93.3% ($p<0.0001$)). The remaining comparisons did not yield any significant differences.

Conclusion: As the included studies were at risk of bias and had heterogenic characteristics, our results should be interpreted with caution. Nonetheless, our results point towards inferior accuracy of Triage Sieve compared to START and CareFlight, and less firmly point towards superior accuracy of Military Sieve compared to START, CareFlight and Triage Sieve

Introduction

Making decisions between life and death is an uncomfortable, but not uncommon, part of the job for many health workers. In a mass casualty incident (MCI), decisions may become even more difficult. As resources no longer suffice for every patient, decisions affect more than the patient at hand. In MCIs situations may arise where one must choose to save one of two critically ill patients. Decisions in MCIs are not only difficult; they also need to be made swiftly, as delayed time to treatment may have fatal consequences [1–4]. Therefore, there is a need for tools supporting decision making in such situations.

Pre-hospital triage systems for MCIs are such tools. The purpose of a triage system is to predict, categorise and prioritise the patients' need for life-saving interventions (LSI) and evacuation with both speed and precision. Numerous triage systems exist, yet it is unknown which system is superior [5–7].

To determine which triage system is best at predicting the need for LSIs, we wished to develop high-quality prospective studies examining the accuracy of pre-hospital MCI triage systems. In order

Abbreviations: MCI, Mass Casualty Incident; LSI, Life Saving Intervention.

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https://doi.org/10.1016/j.injury.2022.05.006
0020-1383/

to do so, a status on what is currently known about triage systems was needed. Existing reviews are either not up to date [5,8,9], not systematic [7], use narrow search strategy [6], use narrow exclusion criteria [8] or do not include accuracy measures [7]. Furthermore, no review includes a systematic bias rating, specifically for the results of triage systems [5–9]. Thus, an up-to-date systematic review addressing these gaps is needed

Despite the fact that randomised controlled trials are ideal, they are both ethically and practically unfeasible in disaster-like settings. However, retrospective studies, simulation studies, computer and tabletop exercise studies have provided alternative assessment methods. Due to heterogeneity of study methods, we chose to conduct a series of systematic reviews in order to find comparable results. In a future review we plan to investigate the accuracy of pre-hospital triage systems in full scale live simulations. In this review, the main objective is to determine the comparative accuracy of pre-hospital triage systems for MCIs in registry studies.

Methods

A protocol was developed before starting this study and registered at PROSPERO, with registration ID: CRD42018115438 [10].

This review is reported according to the PRISMA-DTA guidelines [11].

Our inclusion and exclusion criteria were as follows:

Population: We included trials that examines triage systems in a trauma database/register (as we regard this type of patient as the closest approximation to MCI casualties). We excluded trials if the population was children, burn casualties or Chemical, Biological and Nuclear (CBRN) casualties.

Intervention: Trials examining one or more primary triage systems for MCIs were included. Primary triage systems were defined as triage systems designed to be applied by first responders at the incident site. If the examined triage system was designed for children, burn or CBRN casualties it was excluded.

Outcomes: To be included, trials had to provide results as or convertible to sensitivity and specificity for critically ill/injured (Red/immediate/P1/T1) vs not critically ill/injured (Yellow green/Urgent-minor/P2-P3/T2-T3) (see Table 1).

Reasoning for inclusion and exclusion criteria are provided in the discussion.

We defined a MCI, as defined in the guideline from the WHO:

"For the purposes of these guidelines, a mass casualty incident is defined as an event which generates more patients at one time than locally available resources can manage using routine procedures. It requires exceptional emergency arrangements and additional or extraordinary assistance.

It can also be defined as any event resulting in a number of victims large enough to disrupt the normal course of emergency and health care services" [12].

A preliminary information retrieval was done to find relevant Medical Subject Headings (MeSH). Next, a search strategy was developed from the discovered terms, with assistance from an information specialist. We used EMBASE, MEDLINE, Central and Web of Science. For EMBASE and MEDLINE we used OVID as interface. No limitations to language, publishing year or publication status were applied. The last search was performed March 9th, 2022. Search strategies are provided in the online supplementary material. The included trials' reference lists were hand searched, and a citation search via Scopus was performed. We searched for unpublished literature through ClinicalTrials.gov and Google Scholar. Two authors independently (CEM and KBB) screened all retrieved records by title and abstract. In case of disagreement on which articles to screen full-text for inclusion, the two authors reached consensus by discussion. If consensus still could not be reached, a third author was consulted (AMM). Next the same two authors independently screened full text articles for inclusion. Again, consensus on which trials to include was reached by discussion and consulting a third author if necessary. Included studies were eligible for meta-analysis if they provided sufficient data for our calculations. A triage system was included in the meta-analysis if it was examined 5 times or more.

Independently, two authors (CEM and KBB) used a standardised and piloted extraction form to extract data. Disagreements were solved in the same manner as described for the screening process.

The characteristics extracted were: Study ID, triage method, origin of database, did the database consist of civilians, military personnel or a mix, target group of the database, period of extraction, validation of the database, age range, mean age, distribution of sex, median injury severity score, survival proportions, other measures of injury severity, database eligibility criteria, study eligibility criteria, number of patients in the database, number of patients included in the study, reference standard, total number of triage decisions, how was triage performed, categories of the triage algorithm evaluated, imputations, primary outcomes, secondary outcomes, conflict of interests, and funding sources.

Risk of bias was rated based on the Quadas-2 tool [13]. Bias were assessed by two authors (CEM and KBB), and disputes were solved by discussion or consulting a third author. The QUADAS-2 domains assessed were: patient selection, index test, reference standard, and flow and timing. Applicability was not assessed for index test (see discussion). The remaining domains recommended by Quadas-2 were assessed for applicability. Selection of the reported results were assessed according to ROBINS-I [14] as it is

Table 1
Nomenclature of Included Triage Systems.

Triage systems	Clinical state	SALT	START, MSTART, Naru Sieve, MTS	TS, MS, MMS, Careflight	RAMP	MPTT, MPTT-24	BCD Triage Sieve
Nomen-clature for triage categories	Immediate life-threatening condition	Immediate	Red	Immediate	Urgent	Priority 1 (P1)	T1
	Serious injuries, but no immediate needs	Delayed	Yellow	Urgent	Delayed	Priority 2 (P2)	T2
	Minor injuries such as abrasions and smaller lacerations	Minimal	Green	Delayed	NA	Priority 3 (P3)	T3
	The patient is unlikely to survive given the available resources	Expectant	NA	NA	NA	NA	NA
	Dead	Dead	Black/Dead	Dead/ Unsalvageable	Dead	Dead	Dead

SALT = Sort, Assess, Lifesaving interventions, Treatment/Transport, START = Simple Triage and Rapid Treatment, MSTART = Modified Simple Triage and Rapid Treatment, MPTT =Modified Physiological Triage Tool, MPTT-24 = Modified Physiological Triage Tool 24, MS = Military Sieve, MMS = Modified Military Sieve, TS = Triage Sieve, MTS = Manchester Triage Sieve, RAMP= Rapid Assessment of Mentation and Pulse, BCD = Battlefield Casualty Drills.

not included in QUADAS-2. Finally, we introduced a new category: "Bias due to deviation from the intended triage category".

Bias due to deviation from the intended triage category was assessed with the following signalling questions:

1. Was every patient triaged exactly as the triage system suggested?
2. Is it true that no parameters were imputed from another vital sign?
3. If imputations were made, is it fair to assume that imputations did not bias the results?

To determine whether 3 was high, low or unclear, we resorted to peer reviewed literature about each imputation and by discussion in the author group. If question 1 or both question 2 and 3 were answered with no, the domain would be rated with a high risk of bias. If question 1 or 3 were answered with unclear the domain would be rated unclear. If question 1 and 3 were answered with yes, the domain was rated with a low risk of bias.

Bias in patient selection included the question "did the study avoid inappropriate exclusions?", which we also used to assess bias due to missing data as missing data lead to exclusions of patients in all studies. We set a limit of $\leq$5% to get low risk of bias. If appropriate analyses to correct for missing data were made, the risk of bias was downgraded from high to unclear.

Furthermore, as we could not be certain that the assessment criteria used would identify every possible type of bias, we included additional observations under "other bias" if relevant. The studies were graded as proposed by QUADAS-2 as either having a low, unclear or high risk of bias. The rating of risk of bias for each domain was done on an outcome specific level.

The rating of risk of bias on an overall study level was done as suggested by QUADAS 2: If one or more domains were rated as unclear or high risk of the bias the study is rated as "at risk of bias".

Outcomes

The principal summary measure was sensitivity and specificity. Relevant studies that examined specificity and sensitivity looked at the triage system's ability to identify the critically ill and injured and classify them correctly. The studies used the triage systems' most urgent category (P1/immediate/red – from here on denoted as P1) as the indicator for critical illness and injury and all lower categories as the indicator for non-critical illness and injury. We used the same definitions when conducting meta-analysis.

Meta-analysis

We conducted our meta-analysis with a direct comparison model. We used the statistical software of RevMan 5.3 to create a 2 $\times$ 2 table for each triage system. Furthermore, we used SAS 9.2 to conduct meta-analysis using the SAS package provided on Cochrane's website [15,16].

We assessed heterogeneity between studies using a visual approach (forest plots) and a clinical approach. The clinical heterogeneity assessment was conducted in discussion amongst three authors (CEM, KBB and AMM) and a statistician. Higgins' I^2 statistic was left out as it is not recommended for diagnostic test accuracy reviews [17].

Using direct comparison we found the relative sensitivity, specificity and diagnostic odds ratio (DOR) for each triage system represented more than 5 times using a random effect model and hierarchical summary receiver operating characteristic (HSROC) [18]. The HSROC model allows for measuring of significance level and is usable in studies which may have a flawed reference standard [19]. Direct comparison [20] and the random effect model [21] reduces the impact of potential heterogeneity and bias.

There were several studies using data from the Trauma Audit and Research Network (TARN) database in identical or similar extraction periods. To ensure that the same data was only used once, data from some studies was excluded from our meta-analysis. Identical data for Military Sieve and MPTT from Vasallo 2017 1 and 3 was reused in Vasallo 2017 4, which lead to exclusion of Vasallo 2017 4. Similarly, data from Vasallo 2019 were identical to the data in Vasallo 2017 1, and results from Vasallo 2019 were excluded.

Finally, data from Malik 2021 were extracted from the TARN database from 2008 to 2017. Vasallo 2017 1 used data from the TARN database from 2006 to 2014. Additionally, the study from Malik and colleagues did not provide enough data for calculation of 2 $\times$ 2 tables which is the basis for our meta-analysis. Therefore, we chose to exclude data from Malik 2021.

The results of the above-mentioned studies are solely excluded from meta-analysis and are still represented in results of individual studies.

Results

Selected studies

7505 records matched our search criteria. After duplication removal 5222 records were screened, from which 352 records were full-text screened. 12 studies were eligible for inclusion (Fig. 1). No further studies were found through citation search or in the reference lists of the included studies. All included studies were retrospective register studies. Four triage systems were eligible for meta-analysis.

Nomenclature

The triage systems use widely different nomenclature to denote their categories. Table 1 shows a clarification of nomenclature amongst the triage systems' categories.

Study characteristics

A complete list of study characteristics is provided in the online supplementary material.

Methods

The studies were methodologically similar regarding application of the index test, reference standard, and choice of outcome measures (See online supplementary material). In other areas dissimilarities were observed:

For vital signs all studies that used triage systems which included palpable radial pulse (PRP) used systolic blood pressure (SBP) as imputation ranging from 80 to 110 mmHg. Unconsciousness was imputed from GCS <13 in all studies except one where it was imputed from GCS <8 [23]. All studies but one [24] assumed all patients to be non-ambulant. The time window in which the LSIs could occur varied from 1 to 12 hours. There were large demographic differences, namely in age and sex, and whether the register was military or civilian. Lastly, only two studies reported how triage was performed. Both studies specified, that the triage was conducted manually. However, the remaining 9 studies did not specify how triage was performed.

Triage Systems (Index Test)

Over the course of the 12 studies 15 different triage systems were examined. As seen in the online supplementary material we

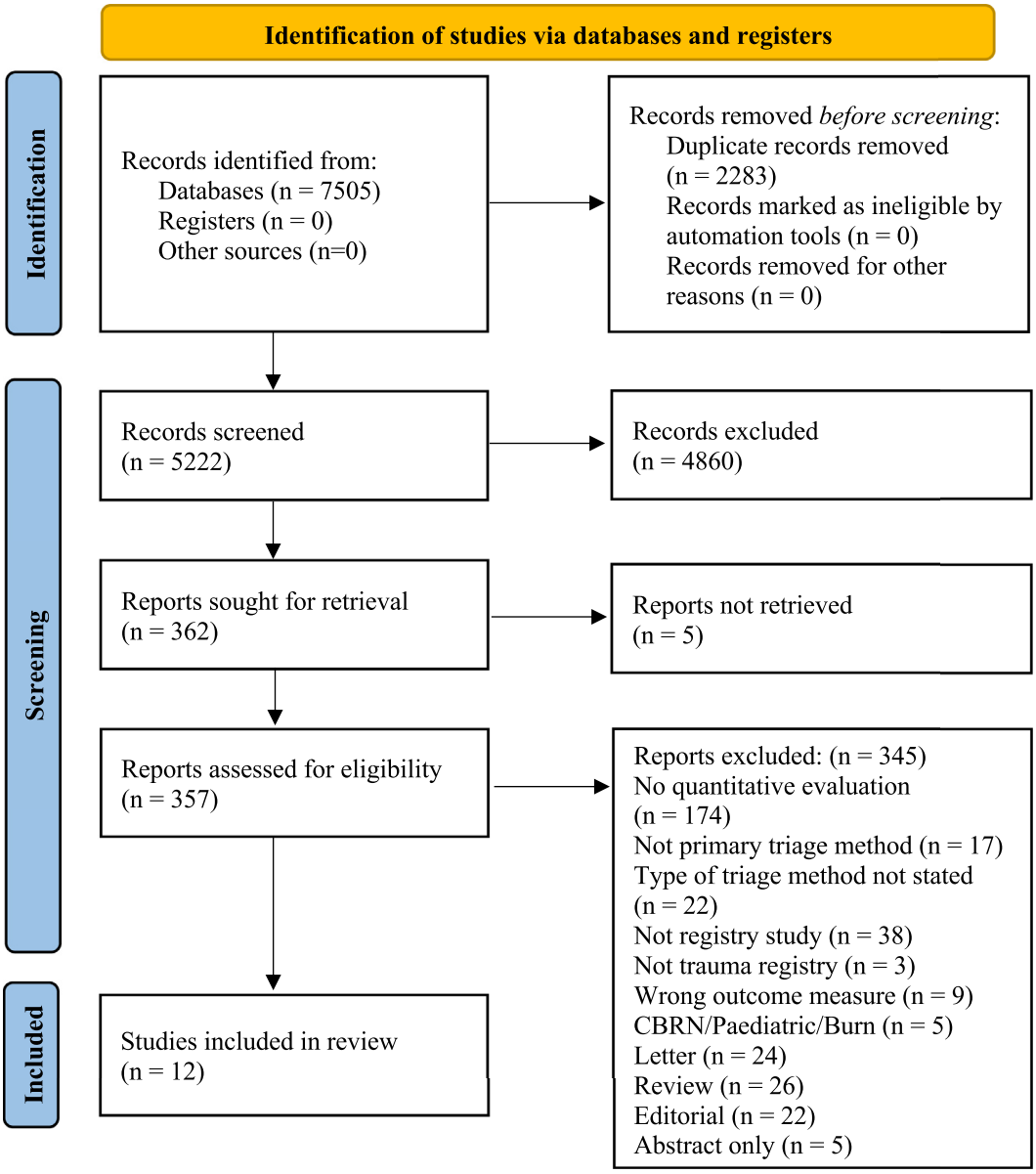

Fig. 1. PRISMA flowchart of study selection process [22].

included Simple Triage and Rapid Treatment (START) nine times, Triage Sieve (also referred to as MIMMS Triage sieve [25]) and CareFlight seven times, Military Sieve six times, Modified Physiological Triage Tool (MPTT) five times, Modified Military Sieve and Modified Physiological Triage-24 (MPTT-24) three times, Modified START (MSTART – See reference for exact version [26]), Naru Sieve two times. Lastly, Manchester Triage Sieve, Battlefield Combat Drill Triage Sieve (BCD Triage Sieve), Sort, Assess, Lifesaving interventions, Treatment/Transport (SALT) and Rapid Assessment of Mentation and Pulse (RAMP) were each included one time.

Databases

The data came primarily from official databases: the military database "JTTR" (Joint Theatre Trauma Registry) and the civil database "TARN" (UK Trauma Audit and Research Network). Additionally, data from relevant patient medical journals were used, e.g. victims from incidents such as the 7th July bombings of London, or journals from patients that have been transported by ambulance or admitted to an emergency room or ICU.

Reference Standard

All studies used similar reference standards, namely lists of LSIs. A patient receiving one or more LSIs inside a predefined time frame scored as a P1 and otherwise as non-P1. Garner and colleagues used a list of LSIs based on the work of Baxt and Upeniek [27]. Later studies by Horne and colleagues, Vasallo and colleagues, and Kahn and colleagues further modified the list by adding more items and changing the time window.

Outcomes

The primary outcome in all the 12 studies was a comparison of different accuracy measures in different triage systems. All studies compared the P1 group (the most urgent group) to the non-P1

Table 2
Risk of Bias Within Studies.

Study ID	Triage system	Patient selection	Index test	Reference standard	Flow and timing	Selection of reported results	Bias due to imputations	Other bias
Challen, 2013 [24]	START, MTS, CareFlight	High	Unclear	Unclear	Low	Unclear	Unclear	Low
Horne, 2013 [28]	MS, TS	High	Unclear	Unclear	Low	Unclear	High	Low
Vasallo, 2017 1 [29]	MPTT, START, CareFlight, MS, TS	High	Unclear	Unclear	Low	Unclear	High	Low
Bhalla, 2015 [30]	START, SALT	Unclear	Unclear	Unclear	Low	Unclear	Low	Low
Garner, 2001 [26]	TS, START, MSTART CareFlight	Low	Unclear	Unclear	Low	Unclear	High	Low
Vasallo, 2014 [23]	START, TS CareFlight, MS MMS	High	Unclear	Unclear	Low	Unclear	High	Low
Vasallo 2017, 2 [31]	START, CareFlight, TS, MS MMS, MPTT	High	Unclear	Unclear	Low	Unclear	High	Low
Vasallo 2017 3 [32]	MPTT, MMS, MS, TS, START, CareFlight	High	Unclear	Unclear	Low	Unclear	High	Low
Vasallo 2017, 4 [33]	MPTT, MPTT-24, MS	High	Unclear	Unclear	Low	Unclear	High	Low
Kahn, 2009 [34]	START	High	Low	Unclear	Low	Unclear	Low	Unclear
Vasallo, 2019 [35]	MPTT-24Naru Sieve	High	Unclear	Unclear	Low	Unclear	Unclear*	Low
Malik, 2021 [25]	BCD Triage Sieve, Care Flight, MIMMS Triage Sieve, MPTT, MPTT-24, MSTART, NARU Triage Sieve, RAMP, START	High	Unclear	Unclear	Low	Unclear	High	Low

SALT = Sort, Assess, Lifesaving interventions, Treatment/Transport, START = Simple Triage and Rapid Treatment, MSTART = Modified Simple Triage and Rapid Treatment, MPTT =Modified Physiological Triage Tool, MPTT-24 = Modified Physiological Triage Tool 24, MS = Military Sieve, MMS = Modified Military Sieve, TS = Triage Sieve, MTS = Manchester Triage Sieve, RAMP= Rapid Assessment of Mentation and Pulse, BCD = Battlefield Casualty Drills.
*No imputations were stated, but data was recorded from a trauma registry (TARN), where the same authors previously have used imputations (assumed to be non-ambulant and palpable radial pulse were equivalent to a systolic blood pressure over 90 mmHg), and exactly the same specificity and sensitivity were reached in both studies. Therefore, we must assume imputations were made, but not stated.

group. A few studies also compared the subgroups of the non-P1 group.

Conflicts of Interest and Funding

Although no authors declared conflicts of interest, the studies by Vasallo and colleagues included triage systems they created, which may cause conflict of interest. There was no reported funding that could have caused a conflict of interest.

Risk of bias

We assessed risk of bias using a combination of the Quadas 2 and Robins-I tools and by assessing the risk of bias due to imputations. A summary of our findings are shown in Table 2. At an overall level, all studies were at risk of bias. Most cases of unclear risk of bias were due to a lack of reporting, or imputations which were unclear whether they were based on fair assumptions or not.

Results of individual studies

Synthesis of results

Before conducting meta-analysis, we investigated the heterogeneity between studies to assess whether or not it was possible. We assessed the heterogeneity through Forest Plots and clinical appraisal. We created Forest Plots (See online supplementary material) for the studies included in the meta-analysis. We found some indication of heterogeneity as the studies sensitivity were scattered on both sides of 0.5. The results for specificity were all between 0.8 and 1.0. Regarding the clinical assessment of heterogeneity, we found that the index test and reference standard were conducted with sufficient similarity. In contrast, we found that the population had variation between studies, as some studies used a military population and others used a civil trauma population. Taking all this into consideration, we found that despite the demographic differences, the studies were conducted in a consistent manner and therefore were not too heterogeneous to do meta-analysis.

For each included triage system, we constructed a 2 × 2 table as seen in Table 4. It was not possible to calculate 2 × 2 tables from the systems included in Malik 2021, as the study did not provide sufficient data. The direct comparison shows that, based on relative sensitivity and diagnostic odds ratio (DOR), START and CareFlight significantly outperforms Triage Sieve. It also shows that Military Sieve has significantly better sensitivity than Triage Sieve, START and CareFlight, but no significant difference in DOR was found. In contrast, Triage Sieve had significantly better relative sensitivity than the other three systems. CareFlight had significantly better relative specificity than Military Sieve and significantly better relative DOR than START. No system performed significantly better in all aspects.

Table 5 shows a direct comparison between paired triage systems. The comparison only includes studies that used both paired systems. For each pairing an average relative sensitivity, specificity and DOR was calculated using HSROC. The significance threshold was set as a two-sided 0.05.

Discussion

Summary of evidence

In summary, we did not find sufficient evidence without risk of bias to conclude if one triage system had superior overall accuracy compared to the other systems. However, Military Sieve was superior compared to START, Careflight and Triage Sieve with regards to relative sensitivity. In contrast, Military Sieve did not show any significant differences at specificity or DOR.

We found that Triage Sieve significantly underperforms in sensitivity and DOR compared to START, CareFlight and MS (only sensitivity for MS). In contrast, Triage Sieve had significantly higher sensitivity compared to START, MS and CareFlight.

Finally, Careflight had significant higher specificity than Military Sieve and significantly higher DOR than START.

The studies examined P1 vs. non-P1 patients. Sensitivity is therefore an expression of the triage systems ability to find the most critically ill patients, and intuitively has high impact on critical mortality. Low specificity equals high levels of overtriage. Overtriage's effect on critical mortality is more complex and has been discussed back and forth in the literature arguing for both a small and large effect on critical mortality [36,37]. However, the difference in specificity between triage systems (1-5 percentage points)

Table 3
Results of individual studies: Sensitivity and Specificity.

Study	Triage System	Triage decisions	Sensitivity % (95% CI)	Specificity % (95% CI)
Challen, 2013	START	124	100	75
	Manchester Triage Sieve	127	100	75
	Careflight	128	100	75
Horne, 2013	Military Triage Sieve	1213	58.5	89.2
	Triage Sieve	1213	53.2	87.8
Bhalla, 2015	START	100	13.8 (3.9-31.7)	93 (84.3-97.7)
	SALT	100	20.7 (8-39.7)	93 (84-97.7)
Garner, 2001	START	1144	85 (78-90)	86 (84-88)
	MSTART	1144	84 (76–89)	91 (89–93)
	Triage Sieve	1144	45 (37–54)	89 (87–91)
	CareFlight	1144	82 (75–88)	96 (94–97)
Vasallo, 2014	START	335	51.8 (44.8–58.7)	89.7 (84.6–94.8)
	Careflight	335	44.7 (37.8–51.6)	91.9 (87.3–96.5)
	Triage Sieve	335	50.3 (43.3–57.2)	89.0 (83.7–94.2)
	Military Sieve	335	63.3 (56.6–70.0)	82.4 (75.9–88.8)
	Modified Military Sieve	335	68.3 (61.9–74.8)	79.4 (72.6–86.2)
Kahn, 2009	START	148	100	86
Vasallo, 2017 1	MPTT	127233	57.6 (56.9–58.2)	71.5 (71.2–71.8)
	Military Sieve	127233	28.0 (27.5–28.6)	94.1 (93.9–94.2)
	Triage Sieve	127233	12.9 (12.5–13.4)	96.7 (96.5–96.8)
	START	127233	28.8 (28.2–29.4)	94.3 (94.2–94.4)
	CareFlight	127233	23.6 (23.1–24.1)	95.9 (95.7–96.0)
Vasallo, 2017 2	START	357	57.5 (50.6-64.2)	86.7 (80.0-91.8)
	CareFlight	357	56.1 (49.1-62.8)	88.8 (82.5-93.5)
	Triage Sieve	357	46.7 (39.9-53.7)	88.1 (81.6-92.9)
	Military Sieve	357	64.0 (57.2-70.4)	81.1 (73.7-87.2)
	Modified Military Sieve	357	68.7 (62.0- 74.8)	74.8 (66.9-81.7)
	MPTT	357	83.6 (78.0-88.3)	51.0 (42.6-59.5)
Vasallo 2017 3	START	3654	38.7 (36.5-41,1)	96.9 (96-97.6)
	CareFlight	3654	33.5 (31.3-35.8)	98.4 (97.7-98.9)
	Triage Sieve	3654	24.8 (22.8-26.9)	94.7 (93.6-95.7)
	Military Sieve	3654	43.8 (41.5-46.2)	93.6 (92.4-94.6)
	Modified Military Sieve	3654	50.9 (48.6-53.3)	87.5 (85.9-88.9)
	MPTT	3654	69.9 (67.7-72.0)	65.3 (63.2-67.5)
Vasallo, 2017 4,JTTRVasallo, 2017 4,TARN	MPTT-24	3654	66.7 (64.5–68.9)	69.9 (67.8–71.9)
	MPTT	3654	69.9 (67.7–72.0)	65.3 (63.2–67.4)
	Military Sieve	3654	43.2 (40.9–45.6)	93.7 (92.5–94.7)
Vasallo, 2017 4, TARN	MPTT-24	127233	53.5 (52.9–54.1)	74.8 (74.6–75.1)
	MPTT	127233	57.8 (56.9–58.2)	71.5 (71.3–71.8)
	Military Sieve	127233	28.0 (27.5–28.6)	94.1 (93.9–94.2)
Vasallo, 2019	MPTT-24	127233	53.5 (52.9-54.1)	74.8 (74.6-75.1)
	Naru Sieve	127233	29.5 (28.9-30.1)	93.6 (93.4-93.7)
Malik 2021	*16-64 years old*			
	BCD Triage Sieve	95306	70.4% (69.7-71.1)	65.6% (65.3-66.0)
	CareFlight	95306	43.3% (42.6-44.1)	92.8% (92.7-93.0)
	MIMMS Triage Sieve	95306	41.8% (41.0-42.5)	93.4% (93.3-93.6)
	MPTT	95306	49.9% (49.1-50.7)	59.1% (58.7-59.4)
	MPTT-24	95306	47.9% (47.1-48.7)	62.9% (62.6-63.2)
	MSTART	95306	57.2% (56.5-58.0)	89.0% (88.8-89.3)
	NARU Triage Sieve	95306	44.9% (44.1-45.7)	88.4% (88.2-88.6)
	RAMP	95306	39.4% (38.6-40.1)	93.3% (93.1-93.5)
	START	95306	53.7% (52.9-54.5)	90.9% (90.7-91.1)
	65 ± years old			
	BCD Triage Sieve	100403	56.7% (55.5-57.9)	72.7% (72.4-73)
	CareFlight	100403	33.5% (32.3-34.7)	93.4% (93.3-93.3)
	MIMMS Triage Sieve	100403	34.7% (33.5-35.9)	92.8% (92.7-93.0)
	MPTT	100403	45.4% (44.1-46.6)	66.4% (661.-66.7)
	MPTT-24	100403	43.1% (41.9-44.3)	69.9% (69.6-70.2)
	MSTART	100403	48.6% (47.4-49.9)	88.5% (88.3-88.7)
	NARU Triage Sieve	100403	33.2% (32.1-34.4)	89.6% (89.4-89.8)
	RAMP	100403	31.3% (30.1-32.4)	93.7% (93.5-93.9)
	START	100403	45.9% (44.7-47.2)	89.9% (89.7-90.1)

SALT = Sort, Assess, Lifesaving interventions, Treatment/Transport, START = Simple Triage and Rapid Treatment, MSTART = Modified Simple Triage and Rapid Treatment, MPTT =Modified Physiological Triage Tool, MPTT-24 = Modified Physiological Triage Tool 24, MS = Military Sieve, MMS = Modified Military Sieve, TS = Triage Sieve, MTS = Manchester Triage Sieve, RAMP= Rapid Assessment of Mentation and Pulse, BCD = Battlefield Casualty Drills.

compared to the difference in sensitivity (16-23 percentage points), makes specificity a less important factor when determining the most accurate system. DOR can be expressed as the risk of being triaged correctly relative to the risk of being triaged incorrectly, and thus combines specificity and sensitivity. Therefore, the fact that Triage Sieve is inferior with regard to both relative DOR and relative sensitivity suggests that Triage sieve has overall inferior accuracy compared to START and CareFlight. Interestingly, of the examined systems Triage Sieve is the only system that does not include an assessment of the patient's mental status. As Triage Sieve is one of the most commonly adopted triage systems around the world [38,39], these results may have an impact to the users of

Table 4
2 × 2 Tables.

	START N = 8		CareFlight N = 6		Military Sieve N = 5		Triage Sieve N = 7		MPTT N = 3		Modified Military Sieve N = 3	
	True	False	True	False	True	False	True	False	True	False	True	False
Positive	8411	6054	6992	4333	8445	6301	4413	3698	15.764	29.852	1242	283
Negative	99.565	19.065	101.073	20.453	19.332	98.714	102.224	23.728	74.510	11.118	1773	1048

	Naru Sieve N = 1		MPTT-24 N = 2		MSTART N = 1		SALT N = 1		Manchester Triage Sieve N = 1	
	True	False	True	False	True	False	True	False	True	False
Positive	7314	17.477	14.242	22.192	113	91	6	5	1	0
Negative	95.864	6578	82.166	12.107	919	21	66	23	123	3

N=number of times the triage system was presented in the studies with unique data.
Data from Vasallo 2017 4 for MPTT and Military Sieve as well as data from Vasallo 2019 for MPTT 24 was left out as the exact data had already been used Vasallo 2017 1.
Data from Malik 2021 has not been included as there were insufficient data to calculate 2 × 2 tables. Furthermore, there is a major overlap between data from Malik and Vasallo 2017 1.

Table 5
Statistic Significance of Calculated Relative Sensitivity, Specificity and Diagnostic Odds Ratio.

		Triage Sieve	Military Sieve	CareFlight
START	Relative sensitivity	START: 57.8% Triage Sieve: 34.8% P<0.0001	START: 43.9% Military Sieve: 49.4% P=0.01	START: 55.8% CareFlight: 51.5% P=0.067
	Relative specificity	START: 93.6% Triage Sieve: 96.1% P=0.047	START: 91.2% Military Sieve: 91.8% P = 0.52	START: 94.9% CareFlight: 96.3% P = 0.093
	Relative DOR	START: 19.85 Triage Sieve: 13.23 P <0.0001	START: 8.11 Military Sieve: 10.85 P = 0.128	START: 23.56 CareFlight: 27.79 P = 0.043
	Number of studies with both systems	Compared in 5 studies	Compared in 4 studies	Compared in 6 studies
Triage Sieve	Relative sensitivity		Triage Sieve: 35.2% Military Sieve: 51.9% P<0.0001	Triage Sieve: 34.7% CareFlight: 53.9% P<0.0001
	Relative specificity		Triage Sieve: 94% Military Sieve: 88.3% P = 0.0002	Triage Sieve: 96% CareFlight: 95.3% P = 0.0006
	Relative DOR		Triage Sieve: 8.55 Military Sieve: 8.11 P = 0.710	Triage Sieve: 12.83 CareFlight: 23.72 P < 0.0001
	Number of studies with both systems		Compared in 5 studies	Compared in 5 studies
Military Sieve	Relative sensitivity			Military Sieve: 49.5% CareFlight: 38.7% P < 0.0001
	Relative specificity			Military Sieve: 91.3% CareFlight: 93.3% P < 0.0001
	Relative DOR			Military Sieve: 10.31 CareFlight: 8.75 P = 0.342
	Number of studies with both systems			Compared in 4 studies

DOR = Diagnostic Odds Ratio, START = Simple Triage And Rapid Treatment.

Triage Sieve. As mentioned, Military Sieve had significantly better relative sensitivity, but as no significant differences were found in relative DOR and relative specificity we cannot make a firm statement that Military Sieve has overall superior accuracy. It is important to note that many of the studies had moderate to high risk of bias, and that there was heterogeneity among the study characteristics and individual results especially regarding sensitivity, limiting the strength of the evidence presented in this review.

Limitations of included studies

All studies had several issues both regarding validity and applicability.

To assess the validity and applicability, we modified the Quadas-2 bias rating tool, as it seemed like the best fit. We modified it by adding two extra elements and by removing some of the signalling questions. The following section will discuss our modifications of the bias tools and bias rating for each element rated.

One of the biggest issues in the studies was missing data, which affected patient selection. In all cases, missing data were due to incomplete patient records, which led to exclusion of the patient. In some studies, this meant that almost 50 % of the otherwise eligible patients were excluded. Such a large amount of missing data may also affect patient selection. The amount of missing data was equal for all index tests (triage systems) and though some studies included statistical corrections for the missing data, they had missing data close to 50 %, making statistical corrections impossible. This resulted in a high risk of bias in patient selection for almost all studies.

Regarding applicability for patient selection, a few studies [24,34] used patients from real MCIs and thus had low risk of bias. However, for many of the eligible studies males were predominantly included, especially studies examining military populations. It seems unlikely that these demographics are corresponding to that of a representative MCI. Furthermore, four of the studies [23,24,28,34] did not report patient characteristics, making it un-

clear if their populations were comparable to the other included populations.

As for risk of bias due to the index test, there was only one study [34] that was rated with a low risk of bias. They studied the primary triage decisions from a real MCI, which ensured that the people performing triage was blinded to the reference standard and only had access to the clinical information available in a normal situation. The remaining studies did not specify details of blinding or available clinical information.

The risk of bias due to the reference standard was rated as suggested by Quadas-2 without any modifications. No studies reported if the interpreters of the reference standard were blinded to results of the index test. Therefore, we rated the risk of bias as unclear. As for applicability, all studies used a list of LSIs as reference standard, though not identical. Every study but one [30] used criteria based on the list of LSI by Baxt and Upeniek [27]. Garner and colleagues were the first to modify these criteria, which were further modified by Horne and later Vasallo. The modifications consisted of adding new interventions or changing existing criteria. Some of the added interventions, e.g. haemorrhage control, increases the chances of finding more true positives. On the contrary, other added interventions such as correction of blood glucose are at best irrelevant for MCIs and may even increase the number of false positives. The lists of LSIs all contained a time frame within which the interventions had to be performed. The time frame helped excluding irrelevant interventions and improved the differentiating between P1 and P2. The time frames applied varied from 1 hour to 12 hours from admission to the hospital or emergency department. If the time frame is too short it may lead to undertriage of the P1s, whereas too long timeframes may cause overtriage. Consensus in a Delphi process has been achieved for both a time frame of 1 hour [40] and of 2 hours [28]; however, no studies have shown which time frame is the most accurate.

Using a list of LSIs as a reference standard may be flawed as the decision to perform a LSI conceivably is clinician-dependant or influenced by patient flow [28]. One alternative reference standard is the Injury Severity Score (ISS), however this too has been shown not to be completely accurate [27]. We chose LSI as reference standard as we regard it more closely related to patient outcome than the ISS.

We also included an assessment of risk of bias due to selection in the reported results, which were rated unclear in all studies as no studies reported of an accessible protocol.

Finally, we rated the risk of bias caused by imputations. It is unclear how the imputations affect the results. Several thresholds for systolic blood pressure were used as a surrogate for palpable pulse, indicating that there is no consensus on which value is most representative. Different values of systolic blood pressure has been shown to impact the diagnostic value of the triage system [41]. Furthermore, many of the studies assumed all patients to be non-ambulant. This may artificially increase the accuracy, as some of the triage systems start by categorising all ambulant patients as P3. An example of this is the patient with internal bleeding that still are able to walk around. This patient would have been misclassified in a real incident, as the vital signs that would have revealed the critical state were never examined.

Many of the studies used GCS < 13 to represent unconsciousness. It is debatable whether this is the best value to use as unconsciousness may be defined as GCS < 8 [42].

Another aspect that may decrease validity in these studies is that none of the registries were validated. Therefore, the quality of the databases and the registered vital signs is unclear, which obscures the true accuracy of the implicated triage systems. The fact that most of the studies suffered severely from incomplete data sets suggests that the quality of the databases is low.

Limitations of our review

There are some limitations to our review. We used sensitivity and specificity as the accuracy measures in this study. A limitation of these measures is that they cannot account for the triage systems' ability to save resources. Sensitivity and specificity for P1 vs. non-P1 does not differentiate between P2, P3 and P4 patients, and thus cannot reflect the level of appropriate triage of these categories. To exemplify, Kahn and colleagues reported overall accuracy for all categories to be 45%, whereas sensitivity and specificity (P1 vs. non-P1) were respectively 100% and 86%. Nonetheless, the advantage of using P1 vs non-P1 is that the outcome expresses the ability to differentiate between the most critically ill patients compared to non-critical.

In the present study, we examined registries for trauma patients to represent patients of MCIs. However, in smaller incidents where resources are unlimited, all patients are treated immediately and without restrictions. In contrast, at a MCI, patients deemed less urgent and expectant must wait until resources are available again. Nevertheless, patients from trauma registries are arguably the closest approximation, as we believe that the patients in MCI are more similar to trauma patients than internal medicine patients [43].

Furthermore, triage systems for a population of children, burn casualties or CBRN victims have not been examined in this study, as different pathophysiology applies for these types of patients [44,45]. Triage systems designed for children are very similar to those for adults, but have thresholds adapted to their physiology.

Finally, we chose to report according to PRISMA-DTA as this seemed to be the best fit, though there are some limitations as no current guidance is adapted to register studies.

The strengths of our review are a stringent methodology and a broad search strategy in order to include as many studies as possible. Furthermore, we are the first to make a systematic bias rating focused on the testing of triage systems. Finally, we are the first to conduct a meta-analysis of the accuracy of triage systems.

Conclusion and future directions

We set out to find which triage system for MCIs has the highest accuracy in register studies. Of the systems eligible for meta-analysis, no systems significantly outperformed all other systems in every aspect. The included studies were at risk of bias and had to some extend heterogenous study characteristics and results, making definitive conclusions impossible. Nonetheless, our results point towards inferior accuracy of Triage Sieve compared to START and CareFlight, and less firmly point towards superior accuracy of Military Sieve compared to START, CareFlight and Triage Sieve.

Interestingly, of the examined systems Triage Sieve is the only system that does not include an assessment of the patient's mental status.

Consequently, our study indicates that emergency medical services should reconsider their choice of Triage Sieve to be their standard prehospital triage system, while also keeping in mind the risk of bias and heterogeneity in the included studies. The evidence presented here is not strong enough to conclude which triage system has the highest accuracy.

Declaration of Competing Interest

None.

Acknowledgments

We thank Liva Christensen, MD, Department of Anaesthesia, Zealand University Hospital Koege for assisting the initial article screening. We would also like to thank Janne Vendt, Information

Specialist, Department of Anaesthesiology, Copenhagen University Hospital, Herlev and Gentofte for helping us with the creation of our search strategy. We would also like to thank C. Christensen, T. Quay and E. Jarnholt for language corrections and grammatical assistance. Lastly, we thank Tobias Wirenfeldt Klausen for impeccable support regarding all statistical analysis.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.05.006.

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